Nominee for IEA Fellow: Kazuo Aoki, Past President, Japan Ergonomics Society
Person submitting nomination: Kentaro Kotani, International Cooperation Committee Chair, Japan Ergonomics Society
The Nomination: IEA Fellow Award

1. Eligibility.

Full Name and Title:	Kazuo Aoki, Ph.D., CPE, Professor, College of Science and Technology, Nihon University
Address:	College of Science and Technology, Nihon University, 1-8-14, Kanda-Surugadai, Chiyoda-ku, Tokyo, 101-8308, JAPAN
E-mail:	aoki.kazuo@nihon-u.ac.jp
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Full Member of Japan Ergonomics Society (JES): Kazuo Aoki has been a Full Member of JES for the preceding 43 years, from 1974 up to the present.

Dr. Kazuo Aoki has been following international activities in the ergonomics community such as scientific committee members, scientific journal editors, etc.:

Activities concerned with IEA:

- The organizing committee member of the 8th Congress of IEA held at Tokyo, Japan in 1984
- The council member of IEA from 1992 to 1997 as a representative of JES
- Associate Editor of International Directory of Educational Programs in Ergonomics/Human Factors, A Publication of the IEA, 3rd Edition, August 1994
- IEA Technical Committee member of Slips, Trips and Falls
- In addition, it is particularly worth noting that Prof. Kazuo Aoki has shown his strong leadership in supporting the IEA while he was JES president (2012-2016), where JES has strongly supported IEA through the development of the information infrastructure via the website.

Dr. Kazuo Aoki served as the scientific board member and expert of ergonomics in the following Conferences, Committee and Project:

- Invited keynote speech at 1st Again Conference of Ergonomics Design in Jeju, 2013
- Chair of Japanese mirror committee for ISO/TC159 (Ergonomics) from 2001 to 2007
- Expert of ISO/TC159/SC1/WG1, WG2 and WG5

2. Distinction

Dr. Kazuo Aoki started his contribution to IEA as the organizing member for the 8th Congress of IEA held at Tokyo, Japan in 1984, where he devoted to convene the congress as a successful event. He was appointed as the council member of IEA for 1992-1997 as well as starting to show his excellence in research for joining the IEA technical committee member of Slips Trips, and Falls for acting as a key person to develop the discipline of the research. It is also highly significant to note his contribution to the IEA information infrastructure. During his JES presidency through 2012-2016, he showed his leadership to support IEA to contribute to develop the information infrastructure via the IEA website. These facts apparently prove the distinction for Dr. Kazuo Aoki.

Followings are the selected research publications in the field of Ergonomics of Dr. Kazuo Aoki with his colleagues including Original Papers, Books and Proceedings (excluded in Japanese):

Original Papers:

Murayama R, Tsuda M, Haruna M, Matsuzaki M, Sanada H, Aoki K. Relationship between perceived sleep posture and subjective sleep quality: Changes related to progression of pregnancy. Journal of Society of Nursing Practice, 25, 49-57, 2013

Murayama R, Kubota T, Kogure T, Aoki K. The effects of instruction regarding sleep posture on the postural changes and quality among middle-aged and elderly men: A preliminary study, BioScience Trends, 5, 111-119, 2011

Ozaki H, Aoki K. Kinematic and electromyographic analysis of infront curve soccer kick Football Science, 5, 26-36, 2008

Yamada KC and Aoki K. Usability of insulin self-injection devices in young and older adults, Ergonomia, 29, 61-70, 2007

Yokoi Y, Aoki K. Relationship between blood pressure and heart-rate variability during graded head-up tilt. Acta Physiologica Scandinavica, 165, 155-162, 1999

Lee JS, Aoki K, Kawakubo K, Gunji A. A study on indices of body fat distribution for screening for obesity, Journal of Occupational Health, 37, 9-18, 1995

Umemura Y, Ishiko T, Aoki K, Gunji A. Effects of voluntary exercise on bone growth and calcium metabolism in spontaneous hypertensive rats. International Journal of Sports Medicine, 13, 476-480, 1992

Aoki K, Suzuki Y, Noji A, Yanagibori R, Gunji A. Analysis of relationship between physical fitness level and risk factors of cardio-vascular disease on workers. Fitness for the aged, disabled, and industrial worker (Kaneko M. ed.), 239-244, Human Kinetics Books, Illinoi, U.S.A., 1990

Aoki K, Yamanoi N, Aoki M, Horie Y. A study on the change of visual function in CRT display task, Human-Computer Interaction (Salvendy G. ed.), 465-468, Elsevier Science Publishers, Amsterdam, Holland, 1984

Proceedings of international conferences:

Aoki K. Keynote Speech, History and activities of Japan Ergonomics Society during 50 years. The 1st Asian Conference on Ergonomics and Design, Jesu, 2014

Tanaka Y, Tanaka M, Miyasaka T, Aoki K, Horiuchi K, Ymanaka T. Effects of toes flexion strength to postural sway and ranges/area of weight shifts, 16th International WCPT (World Confederation for Physical Therapy) Congress, Amsterdam, 2011

Hagiwara CT, Gotaishi M, Aoki K. Network-centric healthcare algorithm development for the behavior change in non-intrusive way, 13th International Command and Control Research and Technology Symposium, Bellevue, 2008

Yamada KC, Aoki K. Effects of task difficulty and order on cardiovascular reactivity. Special Issue of Nihon University CST 2006 Annual Conference, 21-24, 2007

Mikami K, Yoshida JA, Aoki K and Hachisu H. A survey on the daily needs and actual behavior of quadriplegic persons in stressful thermal environments. The 3rd international conference on human-environment system, Abstracts, S-901, 71, Full paper-ICHES'05 CD-ROM, 2005

Horiuchi K, Aoki K. Measurement of force loaded on handgrip of rollator by Aged Person. The 15th Triennial Congress of the International Ergonomics Association, Seoul, 2003

Yanmada K, Aoki K. Study on evaluation of usability of insulin self-injection devices, The 15th Triennial Congress of the International Ergonomics Association, Seoul, 2003

Suzuki,Y, Kashihara H, Katagiri A, Yanagibori R, Aoki K, Kawakubo K, Gunji A, Effects of moderate physical training after 10 days horizontal bed-rest on peak VO2 and cardio-respiratory functions during submaximal supine and sitting exercise in young subjects, Proceedings of the 13th Annual Meeting of the IUPS Commission on Gravitational Physiology, San Antonio, 1992

Yanagibori R, Suzuki Y, Katagiri A, Kashihara H, Kawakubo K, Aoki K, Gunji A. Changes of serum lipids and lipoproteins after 10-days of bedrest and 4 weeks exercise training, The 8th International Biochemistry of Exercise Conference, Nogoya, 1991

Ishii K, Kagawa Y, Aoki, K, Suzuki Y, Gunji A. Effects of saturated-fatty-acid load and exercise training on serum lipoprotein in adult women. The 14th International Congress of Nutrition, Seoul, 1989

Aoki K, Suzuki Y, Noji A, Yanagibori R, Gunji A. Analysis of relationship between physical fitness level and risk factors of cardiovascular disease on workers, International Council for Physical Fitness Research Symposium, 1988

Noji A, Yanagibori R, Aoki K, Suzuki Y, Gunji A. Effect of habitual exercise on blood pressure response in middle-aged women. International Council for Physical Fitness Research Symposium, Osaka, 1988

Aoki K, Yamanoi N, Aoki M, Horie Y. A study on the change of visual function in CRT display task, Proceedings of the First U.S.A.-Japan Conference on Human-Computer Interaction, Honolulu, 1984

Aoki K. A study on walking up and down stairs in elderly people, The 8th Congress of the International Ergonomics Association, Tokyo, 1982

Furukawa T, Yamanoi N, Tanaka H, Yajima K, Aoki T, Aoki K, Kinoshita S, Hirayanagi K. Two dimensional fourier analysis of human torso surface, The 8th Congress of the International Ergonomics Association, Tokyo, 1982

Yamanoi N, Yajima K, Aoki T, Aoki K, Kinoshita S, Tanaka H, Furukawa T. Link analysis of electrocardiograph manipulation and application for design of electrocardiograph, The 8th Congress of the International Ergonomics Association, Tokyo, 1982

Aoki T, Yajima K, Aoki K, Tanaka H, Kinoshita S, Yamanoi N, Furukawa T. Analysis of precognitive dynamics in two Axis pursuit tracking task. The 8th Congress of the International Ergonomics Association, Tokyo, 1982

Ohashi M, Aoki K. A study on visual function of VDU operators. The 8th Congress of the International Ergonomics Association, Tokyo, 1982

Yajima K, Aoki K, Aoki T, Yamanoi N, Tanaka H, Kinoshita S, Furukawa T. Effects of fatigue and drugs on driving performance, The 8th Congress of the International Ergonomics Association, Tokyo, 1982

Kinoshita S, Yajima K, Aoki K, Tanaka H, Aoki T, Yamanoi N, Furukawa T. Autoregressive analysis of highway driving performance by a simulator. The 8th Congress of the International Ergonomics Association, Tokyo, 1982

3. Additional Information:

Dr. Kazuo Aoki received his Ph.D. degree in 1985 in Health Sciences from The University of Tokyo after graduation from The University of Tokyo in 1979. His doctoral dissertation is entitled “A study on the employment rate pattern of nurses and their forming factors”.

Work Experiences and Social Activities:

2016-present Chairperson, Award Committee, Japan Ergonomics Society

2014-present Committee member for the ICT (Information and Communication Technology) Use in Schools, Japan Ergonomics Society

2013 Committee member for the 50th anniversary of the founding of JES, Japan Ergonomics Society

2013-present Chairperson, Committee for Ergonomic Experiment, National Institute of Advanced Industrial Science and Technology, Japan

2013 President, Japanese Society for Safety Education

2012 President, Japan Ergonomics Society

2010 Technical Committee member, New Energy and Industrial Technology Department Organization, Japan

2010 Technical Committee member of Supporting Aged and Disabled, Japanese Industrial Standard Committee, Ministry of Economy, Trade and Industry
2007 Chairperson, Committee on Certification of Professional Ergonomists, Japan Ergonomics Society
2007 Vice President, Japan Ergonomics Society
2006 Committee member of Industrial Health, Saitama Medical Association, Japan
2005 Committee member of Aged and Disabled, National Institute of Technology and Evaluation, Japan
2004 Expert advisor, Pharmaceuticals and Medical Devices Agency, Japan
2003 Committee member of Human and Engineering, Science Council of Japan
2001 Chairperson, Japanese National Committee of ISO/TC159
1996 Professor, Department of Medical and Welfare Engineering, College of Science and Technology, Nihon University
1992 Chairperson, Japanese National Committee of ISO/TC159/SC1
1992 Expert of ISO/TC159/SC1/WG2
1992 Council member, International Ergonomics Association
1992 Associate Professor, Department of Medical and Welfare Engineering, College of Science and Technology, Nihon University
1990 Expert of ISO/TC159/SC1/WG1
1985 Executive Council member, Japan Society of Health Sciences
1983 Council member, Japan Ergonomics Society
1979 Assistant Professor, Department of Health Administration, Faculty of Medicine, Tokyo University

ENDORSEMENT

To: IEA fellow Award Committee, 2017
Re: Endorsement of the nomination of Dr. Kazuo Aoki
Date: May 1, 2017

It is my honor to endorse Dr. Kazuo Aoki for the 2017 IEA fellow award. Dr. Aoki has been a leading researcher at international level and active member of Japan Ergonomics Society for over 40 years and was the immediate past President of Japan Ergonomics Society.

I trust that Dr. Aoki's academic career highlights two of his highly significant accomplishments as a researcher: an extensive publication record of international papers associated with ergonomics and safety research has guided us a development of Japanese industry as well as many contributions to the international levels of Ergonomics. I would also like to highlight international contributions to International societies. He has been an Expert member of ISO/TC159 for many years and became the Chairperson of Japanese National Committee of ISO/TC159 in 2001. Still fresh in our memories is the fact that he made a significant effort for renovating IEA infrastructure when he was the President of JES.

IEA fellow Award is given to recognize extraordinary or sustained, superior accomplishments of an individual. On behalf of all the members of Japan Ergonomics Society, I give my full enthusiastic endorsement of Dr. Kazuo Aoki's nomination for the IEA fellow Award. This is a well-deserved award to recognize his 43 years' active membership in Japan Ergonomics Society.

Signature 堀江良典 May, 1, 2017

Name of Endorser: Yoshinori Horie
Position held: President of Japan Ergonomics Society

April 23, 2017

Selection Committee
IEA Fellows
International Ergonomics Association

Dear Committee:

I am writing in support of the nomination of Professor Kazuo Aoki for Fellow of the IEA. Professor Aoki graduated Tokyo University in 1974, and went to a graduate school for studying ergonomics. His first work of ergonomics was a study on human posture and movement during walking on stairs. He still have an interest in human posture and movement which can be found in some recent papers about sleep posture or an analysis of a motion for curve kick in soccer game. Professor Aoki has also interested in health science. He graduated medical school and studied health promotion and prevention of disease and injuries. His interest was prevention of cardiovascular disease by exercise and stress control. So he has tried to measure mental stress or mental fatigue by heart rate variability. Furthermore he studied a safety in medical care system especially medical devices which causes human errors and threatens patient safety. Professor Aoki received his doctoral degree in health sciences in 1985 from Tokyo University. He has been a leading international researcher on health and safety from the perspective of ergonomics. His interest is very wide and he is considering deeply on the subjects of his studies.

Professor Aoki has been an excellent leader in ergonomics standardization. He has been a member of the ISO/TC159, a standard committee on ergonomics and work for basic standards on ergonomics as an expert of Working Groups in Subcommittee 1(Ergonomic Principles). He has been involved in the development of the standards include ISO 6385 (Ergonomic principle of the design of work systems), ISO 10075s (Ergonomic principles related to mental work-load), ISO 26800 (Ergonomics – General approach, principles and concepts), ISO 27500 (The human-centred organization – Rationale and general principles) and so on. Professor Aoki was chair of Japanese National Committee of ISO/TC 159. He is a recognized international expert and a leader of the ergonomics standardization in Japan.

Professor Aoki has been very active as a member of several organizations in Japan related to ergonomics and health sciences. These have included Japan Ergonomics Society, Japan Society of Health Sciences, Science Council of Japan, Pharmaceuticals and Medical Devices Agency, National Institute of Technology and Evaluation, Saitama Medical Association, New Energy and Industrial Technology Development Organization, Japan Society for Safety Education, National Institute of Advanced Industrial Science and Technology.

Since 2012 Professor Aoki has been the President of the Japan Ergonomics Society. He had a leading role in the development and implementation of a certification program for professional ergonomists through the Japanese Ergonomics Society and endorsed by the International Ergonomics Association with me. He is a recognized international expert and very deserving of this honor.

Sincerely,

Susumu Saito

Susumu Saito, Ph.D., CPE
Research Advisor and Board Member of the Ohara Memorial Institute for Science of Labour, Japan

Original Article

DOI: 10.5582/bst.2011.v5.3.111

The effects of instruction regarding sleep posture on the postural changes and sleep quality among middle-aged and elderly men: A preliminary study

Ryoko Murayama[1,*], Tomio Kubota[2], Takamasa Kogure[3], Kazuo Aoki[4]

[1] *Graduate School of Medicine, The University of Tokyo, Tokyo, Japan;*
[2] *School of Health and Social Services, Saitama Prefectural University, Koshigaya, Saitama, Japan;*
[3] *Paramount Bed Co., Ltd. Tokyo, Japan;*
[4] *Graduate School of Science and Technology, Nihon University, Tokyo, Japan.*

Summary **The purpose of this study was to examine whether instruction to sleep in a lateral posture prior to falling asleep could increase the frequency of instructed posture and sleep quality, as evaluated by sleep parameters and a questionnaire for subjective assessment of sleep. The participants were comprised of 8 middle-aged and elderly men who had an awareness of their habitual snoring during sleep. Data were gathered from observations of sleep posture, sleep polysomnography and a subjective sleep quality questionnaire. As a result of the instruction, the frequency of the instructed posture was significantly increased, and there were no significant effects on sleep parameters or the frequency of postural changes. The subjective sleep quality during the instructed sleep showed worse scores than free postural-sleep for all factors. Our findings suggest that the instructed sleep posture could be increased during sleep without substantially worsening the sleep parameters and the frequency of postural changes. Future studies will therefore be required to clarify the mechanism and the long-term effects of such instruction on sleep posture, including the influence on subjective sleep quality.**

Keywords: Instruction of sleep posture, postural change, sleep parameters, subjective sleep quality

1. Introduction

Body movements during sleeping are classified as minor movements and major movements based on the amplitude using the static charge method (*1*). Change in sleep posture, or rolling over, is included in the major movements, which are accompanied by a transfer of the center of gravity. It is reported that the type and frequency of major movements differ significantly from individual to individual (*1*).

Rolling over is defined as a Postural Change during Sleeping (PCS). PCS is considered to have a physiological function, such as enhancing blood circulation and avoiding or decreasing the pressure on certain areas of the body. It is thought to be possible to regulate body temperature and moisture in bed by the physiological function of anti-side diaphoresis and PCS (*2*). Furthermore, PCS converges just before Rapid Eye Movement (REM) and the latter part of the REM phase (*3*). PCS is considered to be an important factor for REM; PCS enhances the transition from the waking stage to the sleeping stage, and is related to the procession and sustaining mechanism of the sleep cycle (*4,5*). As a result, there have been numerous reports regarding the physiological effects and roles of PCS.

When PCS is accompanied by large movements of the trunk, head and pelvis, it sometimes causes an awakening reaction on the electroencephalogram (EEG), thus indicating the presence of an alpha wave and light sleep; however, the short term awareness between a few and ten seconds during sleep are not remembered. PCS is generally accomplished

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unconsciously, and the trunk direction is unconsciously decided. Therefore, fixing the body in a compulsory manner seems to be a reliable method when a client's PCS should be controlled for the treatment of certain diseases.

It is reported that the apnea-hypopnea-index among patients who have sleep apnea syndrome, especially obstructive sleep apnea, shows improvement in the lateral posture rather than the supine posture (*6,7*). Therefore, an increase in the rate of lateral sleep posture would help prevent an apnea event, and some studies have reported interventions for controlling sleep posture using physical methods (*8-10*). These studies reported that the parameters of a sleep polysomnograph between intervention nights and controlled nights showed no differences. However, the compulsory intervention in sleep posture could have an effect on the frequency of PCS and subjective sleep quality.

A previous study examined the time that participants sustained the instructed posture during sleep when the sleep posture was instructed prior to sleep (*11*). It was suggested that the instruction could influence sleep posture, and that the instruction would be the easiest way to control sleep posture for the participants who had a general ability to understand and communicate without the need for physical restraint or other compulsory methods. Furthermore, sleep posture could be improved without interfering with the various natural roles of PCS. However, the previous study was not able to clarify the effects of instruction of sleep posture on sleep quality. Therefore, the purposes of the present study were *i*) to clarify the instruction of sleep posture prior to sleep which could increase the rate of the instructed posture during sleep and *ii*) to clarify the effect of instructed posture toward sleep quality, including such factors as sleep parameters and subjective sleep quality.

2. Materials and Methods

2.1. *Participants*

The participants were recruited in a Silver Human Resources Center or by a snowball sampling method. The participants were 8 males aged 51 to 72 (mean ± S.D.: 63.1 ± 6.9, median: 64.5). They had awareness of snoring during sleep, had no treatment history for sleep disorders, and were not using medication that affected the central nervous system. The average body mass index (BMI) was 25.2 ± 4.1 kg/m^2. Four out of 8 participants were smokers (Table 1). We targeted middle-aged and elderly men because their sleep structures were more susceptible due to aging and sex (*12*), because it has been shown that aging is a risk factor for Sleep Disordered Breathing (SDB), and an increase in incident prevalence until 60 years of age was also reported (*13*). Sleep disorders among women were most likely accompanied by menopause (*14*) and the ratio of insomnia per capita among women who were aged 50-70 and older surpasses that of their male counterparts (*15*).

Table 1. Demographics and characteristics of participants

	Mean ± S.D. [range] or *n* (%) (*n* = 8)
Age (years)	63.1 ± 6.9 [51-72]
Height (m)	1.68 ± 0.09 [1.57-1.84]
Weight (kg)	71.0 ± 13.4 [54-95]
BMI (kg/m^2)*	25.2 ± 4.1 [21.1-34.1]
Current smoker	4 (50)
Drinking (days/week)	4 or more:5 (62.5), 0:3 (37.5)
Awareness of snoring	Often:7 (87.5), sometimes:1 (12.5)

* BMI: body mass index.

A full explanation of all procedures and possible outcomes was given to the participants, and written informed consent was obtained from each participant. This research was reviewed by the Research Ethics Committee of Saitama Prefectural University.

2.2. *Schedule and environment of the experiments*

Participants were evaluated during a consecutive 3 night experimental session. The authors developed a schedule that sustained the participants' habits, such as time for awakening, going to bed, meals and bathing. Participants arrived at the laboratory 3.5 h earlier than their usual schedule for going to bed, and polysomnography electrodes were attached after having dinner (3 h before going to bed). Participants were prohibited from consuming alcoholic and caffeinated beverages after they entered the laboratory. They answered the questionnaire about sleep quality after waking up at the scheduled time, and wore a wrist actigraph device (Micro-Mini Actigraph: Ambulatory Monitoring Inc., Ardsley, NY, USA). They were allowed to do anything they wanted except for taking naps and engaging in intense exercise during the daytime.

During the sleep period, an environmental control chamber (Tabai Espec, Tokyo, Japan) was used to maintain the level of temperature and humidity at levels based on the guidelines from the Healthcare Engineering Association of Japan (26.0°C, 50% RH) (*16*). Normal bedclothes were used, a mattress was put on the floor in the experimental room, and a cotton blanket was used for cover.

2.3. *Measurement items and procedures*

2.3.1. *Sleep posture*

Sleep posture was recorded with an infrared video camera (TK-N1100; Victor, Kanagawa, Japan) between going to bed at night and rising the next morning. The first night was the acclimation night, and participants were informed to roll over freely. For the second and third nights, the subjects were randomly provided instructions for sleep posture using a cross-over method: some patients received instructions the second night, others received them the third night. During the instructed sleep (Instruction-S), the patients were asked to: 'Please sleep in a lateral position as much as possible, it doesn't matter which side' and 'Please keep in a lateral position as much as possible while sleeping'. Meanwhile, free postural-sleep (Free-S) was defined as when the participants slept in their preferred posture.

2.3.2. *Sleep polysomnography*

EEGs were read using a mono-polar C3, C4, and Fpz parts based on the Ten Twenty Electrode System of the International Federation (*17*) and recorded with a Digital Multiuse Electroencephalograph (SYNAFIT5000; NEC Digital Systems, Tokyo, Japan). Electrooculography (EOG) was performed for both eyes, electromyography (EMG) was monitored for the mentalis muscle (both sides) and electrocardiography (ECG) (led between the right shoulder and left subclavicular) was also recorded at the same time. Data were gathered from the time when the subject went to bed until arising the next morning.

2.3.3. *Subjective sleep quality and sleep habit*

The subjective assessment of sleep states was measured with the Oguri-Shirakawa-Azumi sleep survey sheet- Middle Age and Aged edition (OSA-MA edition) (*18*), and a sleep onset questionnaire (*19*). The OSA-MA edition was a short form, targeting middle-aged and elderly people, revised by Yamamoto *et al.*, and based on the OSA sleep survey sheet, second edition (*20*) to estimate the subjective sleep profile that was developed by Oguri *et al.* The OSA-MA edition was scored using 5 factors with 16 items and 4 scales. Those five factors were *1*) sleepiness on rising (4 items), *2*) initiation and maintenance of sleep (5 items), *3*) frequent dreaming (2 items), *4*) feeling refreshed (3 items) and *5*) sleep length (2 items). A sleep onset questionnaire, revised by Yamamoto *et al.*, was a sociological estimation of sleep onset from going to bed and remaining asleep. In this experiment, the 9 items that estimate a sleep onset profile in the questionnaire were used because instructions just before sleep onset could possibly affect the sleep onset profile.

Participants confirmed that they had not traveled anywhere with a time difference of more than 5 h and had not engaged in night shift work within one month prior to the study. Their usual sleep and wake patterns were recorded using the wrist actigraph while they had worn the device on their non-dominant hand beginning one week before the experiment and throughout the experimental period. Participants responded to a Sleep Health Risk Index (SHRI) (*21*) and a questionnaire about habitual sleep posture that was originally developed by the authors. The SHRI, developed by Shirakawa *et al.*, aimed at clarifying sleep health risk by categorizing the degrees of risk for sleep health into 5 factors and scoring them (*21*). Another questionnaire about the awareness of posture during sleep was originally developed by the authors. It asked them about their awareness of their usual sleep postures of sleep onset and during sleep, then asked them why they slept in that posture.

The participants' awake states during the experimental night were measured using the wrist actigraph. Participants were asked about their awareness of posture during sleeping, such as sleep posture at sleep onset on each experimental night, and about the sleep posture that they were aware of most frequently during sleep.

2.4. *Analysis*

2.4.1. *Sleep posture and PCS*

Sleep postures recorded on video-tape were categorized visually in the following 4 directions based on the scapulas' direction: if participants slept on their back, it was defined as *i*) supine when the angle between the acromions and the mattress was between 0 to 45 degrees, *ii*) lateral sleep posture when the angle was between 45 to 90 degrees, if participants slept on stomachs, it was defined as *iii*) a lateral sleep posture when the angle was between 45 to 90 degree, and *iv*) prone when and the angle was between 0 to 45 degree (Figure 1). The categorization was done by one of the authors. The obtained data were analyzed every second and the duration of sustained posture was accumulated. The frequency of PCS was counted when a certain posture was sustained for more than 10 sec. Sleeping posture was analyzed for the whole night and it was divided into first half and second half sleep phases and the phases were compared.

2.4.2. *Sleep polysomnography*

Data were analyzed every 30 sec based on the International Classification of Sleep Process (Stage 1, 2, 3, 4, REM, Wake stage) (*22*). The first nights' data were excluded from the whole 24 nights' data of sleep polysomnography because of first night effects. Data from three participants was excluded from the analysis, because the data detection was incomplete or impossible to analyze. Therefore, data from a total of 10 nights were analyzed.

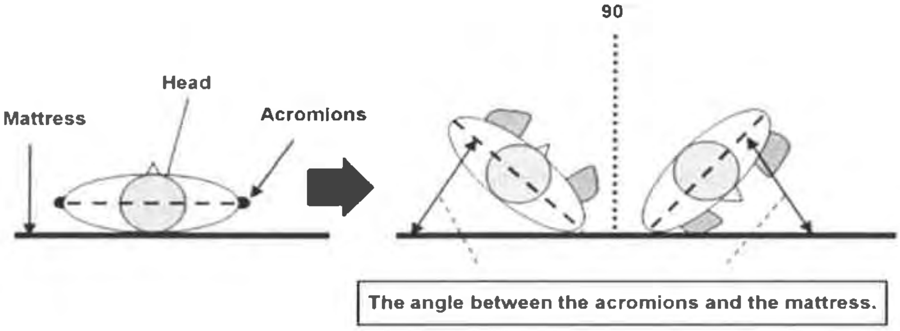

Figure 1. The categorization of sleep posture. The scapulas' direction: the angle between the acromions and the mattress. 0-45 degree. supine or prone: 45-90 degree. right or left lateral.

2.4.3. *Subjective sleep quality and sleep habit*

The OSA-MA edition was plotted in an MS-Excel sheet for converting sleep profile scores, and the results were analyzed based on the scores for 5 factors. In this process, high scores were judged as good sleep quality. Standard rating scales to estimate sleep onset were utilized as a sleep onset questionnaire and high scores were judged as good sleep onset quality.

Data that was consecutively recorded as activity level every 1 min with the wrist acitgraph were analyzed using a statistical software program with a specific interface, and the results were divided into sleep and awake phases based on the method reported by Cole *et al.* (*23*).

2.4.4. *Statistical analysis*

The SPSS 11.0J for Windows software package (SPSS Japan Inc., Tokyo, Japan) was used as a statistical tool. After excluding the first night data, Instruction-S and Free-S were compared. The paired *t*-test was used for comparisons of the sleep parameters. The Wilcoxon signed-rank sum test was used for the comparison of position rates, frequencies of PCS and subjective sleep quality data. Spearman's rank correlation coefficients were calculated to analyze the relationship of various parameters with the frequencies of PCS. The level of significance was set at $p < 0.05$.

3. Results

3.1. *Instructions and sleep postures*

The duration of each posture was calculated each night (mean ± S.D.). As a result, the supine position was used 64.9 ± 21.4% of the time, and the lateral posture accounted for 35.1 ± 21.4% of the first night, and for Free-S, the supine position was used 56.0 ± 18.2% and the lateral posture was used 43.7 ± 18.2% of the time. For Instruction-S, the supine position was used 14.2 ± 9.0% and lateral posture was used 85.8 ± 9.0% of the time. The prone posture was only used for 11 min in one participant's Free-S. The duration of the lateral posture thus increased during Instruction-S compared to Free-S among all 8 participants. The increase was 42.1 ± 12.5% (mean ± S.D.), which was a significant difference ($p = 0.012$). Figure 2 shows the rate of lateral posture after receiving instructions. The filled circle and the solid line represents the rate of lateral posture in 5 men whose polysomnographs were analyzed, and the open circle and the dotted line represents 3 men who were excluded.

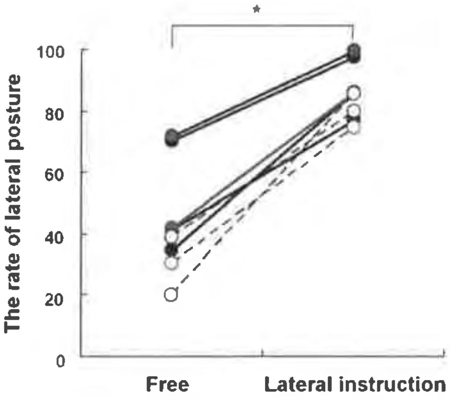

Figure 2. The rate of lateral posture [%] according to the presence of instructions; the change in each subject. The filled circle and the solid line represented the rate of lateral posture in 5 men whose polysomnographs were analyzed. and the open circle and the dotted line represented 3 men who were excluded. Wilcoxon signed-rank sum test: * $p < 0.05$.

Supine and lateral postures were compared based on sleep phases and whether instructions were given to the subjects. The duration (mean ± S.D.) of sleep postures between the first and second halves of sleep phases were compared. As a result, the supine position was used during the first half 61.0 ± 14.9% of the time, while it was used 51.2 ± 28.1% in the second half. The lateral posture during the first half was used 38.4 ± 14.8% of the time. and was used 48.8 ± 28.1% of the time when no instructions were given. Meanwhile, the supine position was used 12.4 ± 8.2% of the time and

16.5 ± 15.2% of the time in the first and second halves, while the lateral posture was used 87.6 ± 8.2% and 83.5 ± 15.2% of the time when subjects were instructed to sleep in a lateral position. The rates between the halves were not significantly different, regardless of whether or not instructions had been given.

3.2. *Instructions for sleep posture and the frequency of PCS*

The frequency of PCS (mean ± S.D.) per hour was analyzed separately when the instructions were given and not given. We observed that the frequency of PCS for Free-S was 2.2 ± 2.0 times/h while the frequency of PCS with Instruction-S was 2.2 ± 1.6 times/h. There were no statistically significant differences between the frequency of PCS with and without instructions. However, there were wide variations among participants during the first night, with a PCS frequency ranging from 0.4 times/h to 6.1 times/h, and there was a significant correlation between the frequency of PCS with and without instructions ($r = 0.862$, $p = 0.006$).

The frequency of PCS was also compared between the first and the second halves of sleep phases (mean ± S.D.). The frequency of Free-S for the first half was 1.9 ± 2.0 times/h, the frequency of Free-S for the second half was 2.4 ± 2.2 times/h, the frequency with Instruction-S for the first half was 1.8 ± 1.3 times/h and the frequency with Instruction-S for the second half was 2.7 ± 2.3 times/h. There were no statistically significant differences between the frequency of PCS during the first and second halves of sleep, regardless of whether instructions were given.

3.3. *Sleep postures and sleep parameters*

The rate of lateral posture during sleep in 5 men whose polysomnographs were analyzed and 3 men who were excluded were compared. No statistically significant difference was observed between the groups in terms of Instruction-S ($p = 0.13$) and Free-S ($p = 0.06$).

Table 2 shows each sleep parameter compared with and without instructions. There were no statistically significant differences between the parameters among the participants who slept with and without instructions. Figure 3 shows an example of sleep stages and postural changes that were extracted from a participant's final nights of Free-S (Figure 3a) and Instruction-S (Figure 3b). The participant went to bed with the instructed posture, and moved on to the third and fourth stages still sustaining the instructed posture.

The rate of sleep stages such as the first, second, third and fourth (Slow Wave Sleep: SWS), and REM sleep were analyzed with the exclusion of the times for not being in bed and being awake. The rates of each sleep stage were not significantly different between the Instruction-S and Free-S sleep. The rates of each sleep stage were compared for supine and lateral postures on each experimental night. There were no statistically significant differences between the rates of sleep stages with supine and lateral postures of Free-S, while the rates of SWS for the lateral posture significantly increased compared to the supine position ($p = 0.04$) when subjects were part of the Instruction-S group (Table 3).

3.4. *Subjective sleep quality and sleep habits*

Activities and rest in the daytime within the experimental terms were also recorded by the wrist actigraph. The length of activities in the daytime for sleep without instruction (mean ± S.D.) was 214.5 ± 25.3 min, and was 215.5 ± 27.0 min for Instruction-S, and the length of rest in the daytime for Free-S was 21.4 ± 35.9 min, while that for Instruction-S was 19.0 ± 24.9 min.

Scores of the OSA-MA edition were calculated separately for five factors. A higher score indicates a better quality of sleep. These scores were compared between sleep with and without instructions. The average scores for Instruction-S were lower than that for Free-S for all factors. The data of 5 men whose

Table 2. Comparison of various nocturnal sleep parameters in the presence of instructions

Parameter	Free[a]	Instruction[a]	p-value[†]
Time In Bed (min)	492.8 (14.5)	492.4 (13.9)	0.74
Total Sleep Time (min)	406.1 (46.0)	412.5 (25.9)	0.67
Waking After Sleep Onset (min)	74.2 (49.1)	61.1 (30.8)	0.41
Sleep Latency (min)	11.4 (7.3)	17.9 (14.7)	0.25
Sleep Latency to Stage 2 (min)	1.0 (2.0)	1.4 (2.0)	0.10
Sleep Latency to REM (min)	74.1 (41.9)	69.3 (34.9)	0.81
Sleep Period Time	480.3 (14.0)	473.6 (12.2)	0.29
Sleep Efficiency (%)	82.5 (10.6)	3.9 (7.3)	0.66
% Awake	15.4 (10.1)	12.8 (6.4)	0.43
% of Stage 1	7.7 (4.3)	7.7 (4.7)	0.99
% of Stage 2	45.8 (15.0)	44.8 (13.3)	0.70
% of SWS	13.2 (12.4)	17.1 (10.4)	0.29
% of REM	17.9 (5.3)	17.6 (7.6)	0.91

All values are the means (S.D.). [a] $n = 5$ for each group; [†] paired t-test. SWS, slow wave sleep (stage 3 and 4); REM, rapid eye movement

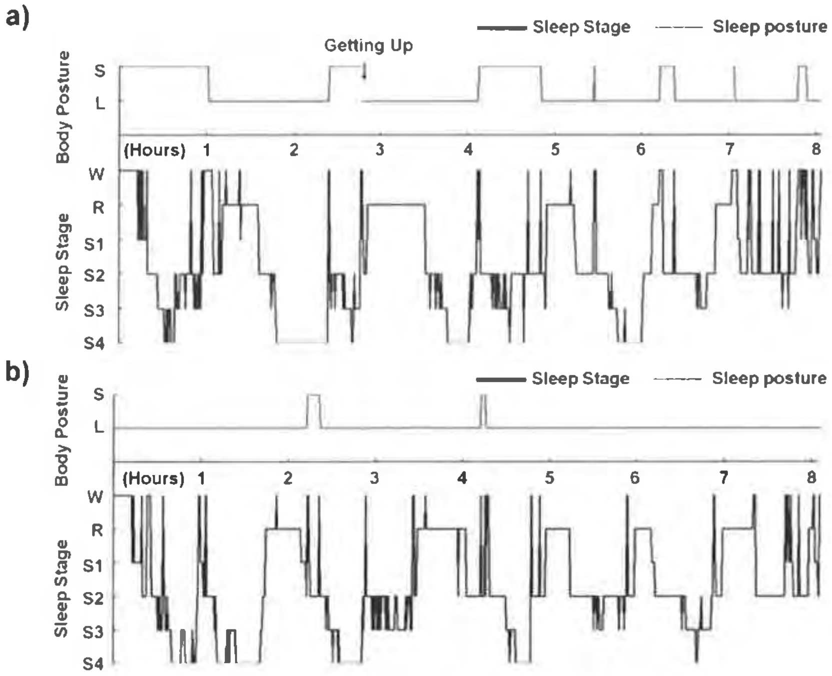

Figure 3. Nocturnal sleep stages and body posture in Free-S and Instruction-S. (a) Free-S: The free postural sleep: the participants slept in their preferred posture. **(b)** Instruction-S: The instructed sleep: the participants were asked to sleep in a lateral position as much as possible. Abbreviations: S. supine: L. lateral: W. awake: R. rapid eye movement: S1-4. stages 1-4. respectively.

Table 3. The rate of sleep stages according to a position in the presence of instructions

Sleep stage[b]	Free[a]			Instruction[a]		
	Supine	Lateral	*p*-value[†]	Supine	Lateral	*p*-value[†]
% Awake	16.5 (9.7)	14.3 (9.4)	0.14	29.2 (19.5)	10.7 (5.9)	0.15
% of Stage 1	7.7 (4.4)	7.8 (4.3)	0.91	10.6 (6.5)	6.8 (5.2)	0.48
% of Stage 2	52.9 (18.7)	46.4 (14.6)	0.17	30.6 (24.3)	46.9 (13.9)	0.36
% of SWS	14.2 (12.8)	13.3 (12.5)	0.18	1.6 (3.7)	19.2 (11.2)	0.03*
% of REM	8.6 (12.1)	18.2 (5.4)	0.08	28.1 (21.0)	16.5 (7.0)	0.36

All values are the means (S.D.). [a] $n = 5$ for each group; [b] Sleep stages except for awake time; [†] paired *t*-test; $^{*}p < 0.05$. SWS, slow wave sleep (stage 3 and 4); REM, rapid eye movement.

Table 4. Evaluation of subjective sleep quality in the presence of instructions

Factor[a]	Free[b]	Instruction[b]	*p*-value[†]
I Sleepiness on rising	19.5 (3.5)	17.3 (4.9)	0.36
II Initiation and maintenance of sleep	21.8 (3.5)	17.0 (5.1)	0.06
III Frequent dreaming	25.5 (5.9)	19.8 (8.4)	0.04
IV Feeling of refreshment	18.3 (4.1)	16.8 (3.1)	0.22
V Sleep length	21.1 (4.9)	20.6 (6.0)	1.00

All values are the mean (S.D.). [a] The Oguri-Shirakawa-Azumi sleep survey sheet (MA edition) are classified under 5 factors (I-V). A higher score indicates a better quality of sleep; [b] $n = 8$ for each group; [†] Wilcoxon signed-rank sum test.

polysomnography results were analyzed also showed the same tendency. The factor of frequent dreaming for Instruction-S was significantly lower than for Free-S (Table 4). In terms of scores in the sleep onset questionnaire, sleep in the Free-S group was 23.5 ± 7.6, while that for Instruction-S was 19.7 ± 5.7, and there were no statistically significant differences between these scores.

The postures for habitual sleep onset and the postures that participants were aware of most frequently during sleep were analyzed according to participants' awareness of postures during sleeping. In total, 4 participants out of 8 reported using the supine position, 3 the lateral posture, and one the supine or lateral posture, in terms of their postures for habitual sleep onset. Meanwhile, 7 participants reported the supine and one reported the lateral posture in terms of their awareness of the most frequent posture while sleeping on the experimental nights when the instructions were not given. One out of 8 participants' awareness differed from the recorded data. In contrast, 7 participants reported the lateral posture and one reported the supine position during the experimental nights when Instruction-S was evaluated. The participants whose awareness differed from recorded data were again one out of 8, and it was the same subject who had differed from the experimental nights when the instructions were not given.

The participants' feedback about what affected their habitual postures during sleeping was analyzed based on voluntary written reasons on the questionnaire. As a result, five out of 8 participants wrote that it was habit and one wrote that it was for the prevention of snoring.

4. Discussion

The major contribution of this study was to clarify that providing instruction on sleep postures could truly affect actual sleep postures, even though the participants were not trained. Moreover, the instructions increased the length of the instructed posture compared to the length of sustained lateral sleep posture without instructions. Furthermore, the instructions did not substantially affect the sleep parameters and the frequency of PCS. Recently, positional therapy, which is designed to minimize supine sleep, has become an important method in the successful management of stroke patients (*24,25*). This result suggested that such instructions represent a simple intervention method for improving sleep posture.

Miki *et al.* disciplined seven male OSA patients' sleep postures prior to their experiments, and gave an instruction about sleep posture on experimental nights (*26*). If patients changed position from the instructed sleep posture, the examiners corrected the sleep posture to the instructed posture without arousal. As a result, they concluded that the lateral position improved the apnea symptoms without inducing any significant difference in sleep parameters (*26*). However, they did not refer to the degree of increase in terms of the instructed posture or the influence on PCS and subjective sleep quality. We were apprehensive about possibly influencing sleep quality by such an intervention. The present study was therefore an intervention that only provides instructions about sleep postures given prior to going to bed, without intervention during sleep. However, the rate of the instructed posture during the experimental night's sleep was significantly increased. The participants' sleep parameters of Free-S in this study were similar to those of healthy men reported in a previous meta-analysis study (*12*). There were no significant differences between Instruction-S and Free-S in terms of the sleep latency, awakening after sleep onset, sleep efficiency, or the rate of the different stages. Furthermore, the rates of SWS for the lateral posture significantly increased compared to the supine position using Instruction-S. Therefore, when the participants were instructed to sleep in the lateral posture, they were still able to move on to deep sleep.

The frequency of PCS in our study correlated within individuals, but there were no statistically significant differences between the frequency of PCS during Instruction-S and Free-S. The rates of SWS in the second half of the total sleep time have been reported to decrease compared to the first half, while the frequency of PCS has been reported to increase with the repetition of a sleep cycle (*3*). Therefore, the postural changes were compared in the first and second halves of the sleep phases. The average frequency of PCS increased in the second half compared to the first half, regardless of whether participants received instructions; however, there were no statistically significant differences. For example, there is the tennis ball technique (TBT), which is a method to put a tennis ball under one's back during sleep, and this helps the patients to maintain a lateral posture (*27*). However, long-term patient compliance with TBT has been suggested to be poor (*28*). As a result, one potential disadvantage of TBT may be related to the fact that PCS is disturbed.

On the other hand, the participants were able to sleep in both lateral sleep postures when instructions were clearly provided in this study, and no disturbance in the participants' postural change was observed. Accordingly, because no difference in the frequency of PCS was observed, the physiological functions of PCS were therefore not suggested to be strongly influenced by the instruction provided in this study.

The subjective sleep quality with Instruction-S showed lower average scores than Free-S in all factors. The factor of 'Frequent dreaming' showed a statistically significant difference. The subjective sleep quality may have been worse in the Instruction-S group. This may have been because the subjects might have been aware of their sleep posture, and underwent a psychological load due to instruction of a posture that they did not like, although this was not proven. Of note, many participants responded that their habits influenced their sleep postures. This may have been related to the reason why 7 out of 8 participants were able to recognize their actual sleep postures, no matter whether instructions were given or not. However, so far, no studies have shown any concrete evidence regarding the mechanism of awareness of humans' sleep posture. In our previous study, correlations were observed between the body positions that participants chose when they fell asleep and in the actual head positions that were observed during sleep, even though there were some individual differentiations (*29*). It suggested that participants would be aware of sleep postures. Although this study could not address the mechanism of the increase in instructed posture, this indicates that the instructions given to participants who sleep in unusual postures affected their subjective sleep quality. We should also be aware of the possibility that a worsening of the subjective sleep quality may occur after participants are given instruction on sleep posture, in particular after the first instruction.

This study has several limitations. First, we only investigated a small number of participants comprising middle-aged and elderly men. Therefore, this study was not able to clarify any effects regarding gender and age differences. This study also did not clarify the mechanism or the long-term effect of instructions on sleep posture, because the experimental term was only 2 nights. In addition, although the participants in this study had an awareness of their habitual snoring during sleep, this study was not able to elucidate any relationship between respiratory function of the participants and sleep quality. However, the results of this study suggest that giving instructions regarding sleep posture could provide a simple, noninvasive, and effective method for improving sleep posture.

Further studies are therefore required to recognize these limitations, and to clarify the mechanism and long-term effectiveness of such instruction on sleep posture, including influence on subjective sleep quality. Furthermore, it is necessary for the instruction of sleep posture to be evaluated in regard to whether it can actually improve respiratory function in obstructive sleep apnea patients.

Acknowledgements

We'd like to express our deep appreciation for all of the participants. This research was funded by Saitama Prefectural University and Paramount Bed Co., Ltd.

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NOMINATION FORM FOR IEA FELLOW AWARD 2017

For use by IEA Member Societies to nominate an individual for the IEA Fellow Award

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Please complete this form electronically and e-mail as an attachment (together with other attachments such as CV, letters of support, etc.) to: **PastPres@iea.cc and vpsg@iea.cc**

Deadline: April 30, 2017

Nominee for IEA Fellow: Nancy Cooke, PhD
Person submitting nomination: David Rempel, MD
The Nomination: IEA Fellow

NOMINEE:
Full Name (and title): Professor Nancy J. Cooke, PhD
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PERSON SUBMITTING NOMINATION:
Name: Professor David Rempel, MD
Address: Department of Bioengineering; College of Engineering; University of California at Berkeley; 1301 S. 46th Street, Building 163; Richmond, CA 94804; USA
E-mail: david.rempel@ucsf.edu
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1. Eligibility

Professor Cooke received her Ph.D. degree in Cognitive Psychology in 1987 from New Mexico State University and is currently Professor of Human Systems Engineering at the Ira A. Fulton School of Engineering at Arizona State University. She has been a full member of HFES for more than 10 years and has served HFES, IEA and the profession in many ways - she is currently the President of HFES. Other service to the profession includes membership on the US National Academy of Sciences (NAS) Board on Human Systems Integration from 2007 to present with service as Board Chair from 2012 to 2016. Other service to the NAS includes membership on the following committees: Safety and Security of Spent Nuclear Fuel Storage; Engineering, and Medicine new Intelligence Science and Technology Experts Group; Connector Reliability for Offshore Oil and Natural Gas Operations; and Social and Behavioral Sciences for National Security. Based on her contributions she was designated a National Associate of the NAS in 2016. She has done extensive research and consulting with the Office of Naval Research and Air Force Research Laboratory. Other service to HFES includes program chair on the Cognitive Engineering and Decision Making TG in 2001 and member of the Fellow Selection Committee 2006-2009.

Professor Cooke has published 94 book chapters and articles in peer reviewed international journals including articles in Applied Ergonomics, Ergonomics, Cognitive Systems Research, Human Factors, Journal of Experimental Psychology, International Journal of Cognitive

Ergonomics, Human-Computer Interaction, International Journal of Human-Computer Studies, and International Journal of Man-Machine Studies. She serves on the editorial boards of the Erlbaum Series: Expertise-Research and Applications and Advances in Human Performance and Cognitive Engineering Research.

2. Distinction.

Professor Cooke was elected a Fellow of the American Psychological Association in 2009 and a Fellow of HFES in 2000. She is internationally recognized for her research on team training, interaction and function and her work has been extensively published in international scientific journals as outlines above. This is exemplified in her critical work on measuring team cognition and performance and factors that influence team performance. In 2006 she was the recipient of the HFES Oliver Keith Hansen Outreach Award for individuals who engage in significant activities that broaden awareness of the existence of human factors/ergonomics profession and the benefits it brings to mankind. In 2010 she was the recipient of the HFES Jerome H. Ely Award for the most outstanding article in the *Human Factors* journal: Gorman, Cooke, & Amazeen, "Training Adaptive Teams". In 2014 she was the recipient of the HFES Arnold M. Small President's Distinguished Service Award for individuals whose career-long contributions have brought honor to the profession and HFES.

Additional Information:
Curriculum Vitae Attached

Endorsement by a Federated Society
Human Factors and Ergonomics Society

Endorsers:

Name of endorser: Thomas Sheridan, PhD
Position held: IEA Fellow, HFES Fellow, Past President HFES
Name of Federated Society: HFES

Name of endorser: Eduardo Salas, PhD
Position held: IEA Fellow, HFES Fellow, Past President HFES
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Name of endorser: William Marras, PhD
Position held: IEA Fellow, HFES Fellow, Past President HFES
Name of Federated Society: HFES

Name of endorser: Andrew Imada, PhD
Position held: IEA Fellow, HFES Fellow, Past President HFES, PastPresident IEA
Name of Federated Society: HFES

Name of endorser: Waldemar Karwowski, PhD
Position held: IEA Fellow, HFES Fellow, Past President HFES
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Name of endorser: Debbie Boehm-Davis, PhD
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April 19, 2017

IEA Fellow Selection Committee
International Ergonomics Association

RE: Nancy J. Cooke, Ph.D.

Dear IEA Fellows Selection Committee:

I am pleased to provide a letter of support for Dr. Nancy J. Cooke's nomination as an IEA Fellow. I have known Professor Cooke for the past 15 years and feel that I know her well and thus, can speak to her accomplishments. Nancy is well known for two reasons. First, she has established herself as one of the preeminent researchers in the field of team science and team cognition. And, second, she has proven herself as a true leader in the human factors and ergonomics movement within the United States.

Dr. Cooke has had a long history of scholarship relative to team science research. She has published extensively on team cognition and her work has been used extensively by the military. Recently she chaired a National Academies of Science, Engineering and Medicine report on team science that has been very well received. According to the *Web of Science* she has 56 publications that have been cited nearly 1300 times. Her h-index ranges from 16 via the conservative *Web of Science* to 36 according to Google Scholar. These are very strong indicators of her productivity and stature within the field. Another indication of her research accomplishments is suggested by her research funding support. Her research has been continuously supported particularly by military sources throughout her career. Professor Cooke has also served as an advisor to many of the U.S. military efforts where much of her team science work has been translated to practice and used under many military operational conditions.

Perhaps the area where Professor Cooke excels the most is in her leadership endeavors. She has served in many capacities within the Human Factors and Ergonomics Society within the U.S. including editor of *Human Factors*, Executive Council member, and (currently) President of the Society. She has also served on numerous National Research Council committees (which serves the prestigious National Academies of Science, Engineering and Medicine) and was the past chair of the Board on Human Systems Integration within this organization. These are just a sampling of the activities she has been involved with through the most prominent Human Factors and Ergonomics organizations within the United States.

Dr. Cooke is also responsible for bringing an awareness and educational exposure of human factors and ergonomics to the College of Engineering at Arizona State University where she has managed to place human factors in a prominent course position within the College of Engineering.

Professor Cooke is a strong supporter of women's roles within the profession. She has been instrumental in promoting the role of women within human factors and ergonomics efforts within both the National Research Council and the Human Factors and Ergonomics Society. She has significantly changed the mix of women and men in these efforts and has been able promote the contributions of women within both of these organizations.

On a personal note, I have also found Nancy to represent the voice of reason in professional interactions. She is thinks through the issues at hand and always presents a balanced perspective on the issues. She is a strong advocate of the profession and can draw people in to her research very easily through her passion for the profession.

In summary, I hope that the above comments are useful in your decision to award Nancy with Fellow status. Dr. Cooke is an accomplished researcher and has taken on a strong leadership role within our profession. I think she is well deserving of the distinction of an IEA Fellow.

Sincerely,

William S. Marras, Ph.D. CPE
Honda Chair Professor, Integrated Systems Engineering
Executive Director and Scientific Director
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CURRICULUM VITAE

NANCY J. COOKE

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Ph.D., Cognitive Psychology, 1987, New Mexico State University, Las Cruces, NM
M.A., Experimental Psychology, 1983, New Mexico State University, Las Cruces, NM
B.A., Psychology, 1981, George Mason University, Fairfax, VA

PRIMARY PROFESSIONAL POSITIONS

2003-present	Professor, Human Systems Engineering, The Polytechnic School, Ira A. Fulton Schools of Engineering, Arizona State University
2014-2016	Program Chair, Human Systems Engineering, The Polytechnic School, Ira A. Fulton Schools of Engineering, Arizona State University
2003-present	Science Director and board member, Cognitive Engineering Research Institute, Mesa, AZ
1992-2002	Assistant/Associate ('94)/Full Professor ('99), Department of Psychology, New Mexico State University, Las Cruces, NM.
1987-1992	Assistant Professor, Department of Psychology, Rice University, Houston, TX.
1981-1987	Graduate Research Assistant, Department of Psychology and Computing Research Laboratory, New Mexico State University, Las Cruces, NM. (Roger Schvaneveldt, advisor)

OTHER PROFESSIONAL POSITIONS

2017-present	Member, Decadal Survey of Social and Behavioral Sciences and Applications to National Security Study Committee, National Academies of Science, Engineering, and Medicine
2017-present	Member, Subsea Bolts Performance and Critical Drill-Through Equipment Fasteners Study Committee, National Academies of Science, Engineering, and Medicine
2016-present	Co-director, Advanced Distributed Learning Partnership Lab within the Institute for the Science of Teaching and Learning
2015-present	President, Human Factors and Ergonomics Society (Elect in 2015)
2015-present	Participant, National Academies, Intelligence Science and Technology Experts Group
2014-present	Associate Editor, *Human Factors*
2014-present	Chair, William C. Howell Young Investigator Award for HFES
2013-2015	Chair, National Academies Committee on the Science of Team Science
2013-2015	Member, Human Factors and Ergonomics Society Blue Ribbon Task Force

2010-2014	Member, National Research Council, Panel on Human Factors Science at the ARL
2010-2013	Cognitive Track Editor, *Human Factors*
2011-2015	*Human Factors* Prize Board of Referees (chair 2011-2013)
2008-present	Affiliate Professor, Biomedical Informatics Arizona State University
2007-2016	Member (Chair since 2012), National Academies of Sciences National Research Council Board on Human Systems Integration (prior to 2010, Committee on Human Systems Integration)
2007-2013	Human Factors and Ergonomics Society, Executive Council Member-at-Large (Accreditation Taskforce chair and Federal Spending Taskforce chair)
2008-2012	Member, US Air Force Scientific Advisory Board
2011-2012	Advisory Board, Center for the Evaluation of Human Factors in Reprocessing Safety (CEHFRS), VISN 18 Patient Safety Center of Inquiry (PSCI), Phoenix VA Healthcare System
2005-2009	Editor, *Human Factors*
2003-2004	National Research Council Research Associateship, AFRL, Mesa, AZ
1992	Summer Faculty, Armstrong Lab, Brooks AFB, San Antonio, TX.
1987-1992	Research Consultant, Lockheed Engineering and Sciences Corp. and NASA Johnson Space Center, Houston, TX.

PROFESSIONAL ACTIVITIES

Member of

American Psychological Association (Fellow since 2009)
Association for Psychological Science
Cognitive Science Society
Human Factors and Ergonomics Society (Fellow since 2000)
  Fellow Selection Committee (2006 – 2009)
  HFES Cognitive Engineering and Decision Making Technical group (program chair 2001-02)

Editorial Boards

Erlbaum Series - *Expertise: Research and Applications*
JAI Press Series - *Advances in Human Performance and Cognitive Engineering Research*

Recent Consulting

Charles River Analytics, SA Technologies, Knowledge Based Systems, Inc., Embry Riddle University, MIT, Aptima

Honors and Awards

Appointed to the National Academies of Sciences Panel on Human Factors Science at the ARL (2010)
Elected Fellow of the American Psychological Association (2009)
Appointed to National Academies of Sciences National Research Council Committee on Human Systems Integration (now Board on Human Systems Integration, January 2007 – present)
Appointed Chair National Academies of Sciences National Research Council Board on Human Systems Integration (January 2012 - present)
Recipient of the 2006 Human Factors and Ergonomics Society's O. Keith Hansen Outreach Award.
Appointed to National Academies of Sciences National Research Council Committee on Human-System Design Support for Changing Technology (May 2005 – March 2007)
Appointed to National Academies of Sciences National Research Council Committee on the Safety and Security of Spent Nuclear Fuel Storage (March 2004 – January 2005)
Elected Fellow of the Human Factors and Ergonomics Society in 2000
On short list for AFRL Chief Technologist position (2011)
Recipient of Jerome H. Ely Award for the most outstanding article in the *Human Factors* journal in 2010. Gorman, Cooke, & Amazeen, "Training Adaptive Teams."
Medal for exemplary service to the Department of the Air Force for Scientific Advisory Board work (2008-12)
Received the George Mason University, Psychology Department's Distinguished Alumna Award for 2012.
Recipient of the Human Factors and Ergonomics Society's Arnold M. Small President's

Distinguished Service Award that recognizes individuals whose career-long contributions have brought honor to the profession and the Society (2014).

ASU SUN Award for participation in OKED's Funding Success Skills Series (fs3).

Selected "Star" by NMSU Psychology Department for "A Starry Night" program on February 7, 2015.

Salute to Service Award, Arizona State University, October 29, 2015.

Appointed to The National Academies of Sciences, Engineering, and Medicine new Intelligence Science and Technology Experts Group (ISTEG), 2015-

FAI Air Sport Medal for efforts on the Two Eagles flight, February 5, 2016.

Designated a National Associate of the National Research Council of the National Academies of Sciences, Engineering, and Medicine, June 2016.

Ira A. Fulton School of Engineering Exemplar Faculty, August 2016-2018

Appointed to The National Academies of Sciences, Engineering, and Medicine new Intelligence Science and Technology Experts Group (ISTEG), 2015-

Appointed to The National Academies of Sciences, Engineering, and Medicine study committee on Connector Reliability for Offshore Oil and natural gas Operations, 2017-

Appointed to The National Academies of Sciences, Engineering, and Medicine study committee on Social and Behavioral Sciences for National Security: A Decadal Survey, 2017-

Review Panels

National Science Foundation, Information Technology Research (ITR) Program review panel (June 2005).

Ad Hoc reviewer for Air Force Office of Scientific Research

Invited by University of North Dakota President, Robert O. Kelley to participate in a program review Unmanned Aerial System research at the University of North Dakota (1/18/12-1/19/12).

PhD Program Reviewer, Wright State University, Human factors and Industrial/ Organizational Psychology (3/14/13)

USAF Scientific Advisory Board Consultant for Review of AFRL-RH November, 2013

Board of Referees, *Human Factors* Prize (2014)

National Academies of Sciences, Engineering, and Medicine, Reviewer for Review of Army Research Lab report (2016)

Arizona State University Committees

Aviation Human Factors Search Committee Chair- 2016-2017

HSE Search Committee 2015-16

Deans Faculty Advisory Committee – 2015-16

IAFSE Dean's Search Committee – 2015-16

Personnel Committee, The Polytechnic School, Ira A. Fulton Schools of Engineering, 2014-present

Fulton Associate Dean of Research Search Committee, 2014

Fulton School 6 Director Search Committee, 2014

University Librarian Search Committee, 2014

College P&T Committee, 2014-present

University Research and Creative Activities Committee member, 2013-2015

Data Archiving Taskforce of University RCA, 2013 – 2014

Advisor, Student Chapter of the Human Factors and Ergonomics Society, 2012-present

Graduate Council Representative, CTI Executive Committee, Fall 2010-2012

Chair, Executive Committee, PhD in Simulation, Modeling , and Applied Cognitive Science, Fall 2010 – present

University Graduate Council - Fall 2007 – 2012

Chair, Cognitive Science and Engineering Search Committee, Fall 2012

Member, TEIM Chair Search Committee, Fall 2010

Chair, Cognitive Science and Engineering Search Committee, Fall 2010

Program Director, Cognitive Science and Engineering Program, Fall 2010

University Promotion and Tenure Committee – Fall 2008 – Spring 2011

Applied Arts and Sciences Personnel Committee Fall 2005 – Spring 2009

Applied Arts and Sciences Dean Search Committee Fall 2007 – Spring 2008

Applied Psychology Program Review Committee – Fall 2007-Spring 2008

EXPERTISE

Courses Taught: capstone course in applied psychology, cognitive psychology, experimental methods, memory, thinking, engineering psychology, human-computer interaction, expertise and expert systems, expertise and skill acquisition, introduction to psychology (honors level), industrial-organizational psychology, cognitive engineering and advanced technologies, team cognition, ASU 101.

ASU Graduate Faculty: Psychology, Computer Science and Engineering, Simulation, Modeling and Applied Cognitive Science

Research Areas: **cognitive engineering, knowledge elicitation, cognitive task analysis, team cognition, team situation awareness, team training, mental models, expertise, human-computer interaction, command-and-control of unmanned aerial vehicles, emergency response systems, healthcare, cyber security**

GRANTS & CONTRACTS

Computing Research Laboratory, NMSU: *The User Interface in Computer Systems, 7*/1/83-6/30/85, $127,463, with R.W. Schvaneveldt.

Sperry Corporation, Albuquerque, NM: *The Acquisition and Representation of Knowledge for Expert Systems, 9*/85-8/86, $24,000, with J. McDonald, D. Partridge, & P. Lopez.

Rice University Faculty Research Grant: *Chess Expertise and Chess Knowledge*, 9/87-9/88, $945.00.

Rice University Faculty Research Grant: *Expert Conceptual Representations,* 9/88-9/89, $1000.00.

Rice University Faculty Research Grant: *The Development of Expertise,* 9/89-9/90, $1000.00.

New Mexico State University Minigrant, *A Comparative Evaluation of Knowledge Elicitation Techniques,* 5/93-12/93, $1709.00.

AFOSR Research Initiation Proposal, *An Approach to On-line Assessment and Diagnosis of Student Troubleshooting Knowledge*, 1/93-12/93, $20,000.00.

XSOFT contract, *Tabworks Usability Project,* 4/94-5/94, $7521, with D. Gillan.

INTEL gift in support of research, 9/95-11/95, $6500.

Microsoft Corporation, Making *Usability Data More Usable*, 1/96-7/96, $24,323, with D. Gillan.

AFOSR, *Assessing Structural Knowledge: An Analysis of Knowledge Referents,* 1/97-10/97, $23,073.

DOD DURIP (Defense University Research Instrumentation Program) grant, CERTT*: Facility for Cognitive Engineering Research on Team Tasks,* 4/97-12/97, $296,104.

AFOSR, *Shared Knowledge and Team Performance: A Cognitive Engineering Approach to Measurement* 2/98-12/00, $447,000.

AFOSR, *CERTT Laboratory System Improvements,* 6/00-12/00, $67,621.

ONR, *Methods for the Analysis of Team Communication*, 6/00-3/03, $470,430 with P. Foltz.

AFOSR*, Team Cognition in Distributed Mission Environments*, 2/01-12/02, $408,644. (Year 3 at ASU)

ARI, *Understanding Aspects of Individual and Collaborative Skill Acquisition in Face-to-Face and Distance Training Situations*, 9/01-8/04, $418,341 co-pi with A. Lee and D. Gillan. (at NMSU)

ONR, *Toward a Universal Metric of Human Performance,* 11/01-1204, $310,797, with A. Lee (PI) (At NMSU).

NASA. *Toward a Model of Organizational Risk: Critical Factors at the Team Level* 6/02-8/02, $39,709.

ONR, *Using Team Communication to Understand Team Cognition in Distributed vs. Co-located Mission Environments*, 3/24/03-9/30/05, $437,351. [grant to ASU]

AFOSR, *The Role of Individual and Team Cognition in Uninhabited Air Vehicle Command-and-Control,* 2/15/03-12/31/03, $250,127. [grant to ASU]

AFOSR, *Acquisition and Retention of Coordination in Command-and-Control,* 3/15/04-12/31/06, $449,640. [grant to CERI]

AFRL, *Acquisition and Retention of Coordination in Command-and-Control,* 3/11/04-12/31/06, $224,990. [grant to CERI and subcontract to ASU]

AFRL, AFOSR, NASA: *Human Factors of UAVs Workshop: Manning the Unmanned*, 5/24-25, 2004 CERI workshop, $27,000. [funds to CERI]

AFRL, AFOSR, FAA, Microanalysis and Design: *Second Annual Human Factors of UAVs Workshop*: *Manning the Unmanned*, 5/25-26, 2005 CERI workshop, $28,000. [funds to CERI]

ONR, *Automatic Tagging of Macrocognitive Collaborative Processes through Communication Analysis,* 6/1/05-9/30/08, $564,546, co-pi with P. Kiekel, CERI. [grant to ASU and subcontract to CERI]

ONR, *IMAGES: Instrument for Measuring and Advancing Group Environmental Situation Awareness,* $49,799, 9/1/05 – 3/1/07. [Aptima subcontract to CERI on Phase II STTR].

Northrop Grumman/AFRL, *Team-Based Assessment of Socio-Technical Logistics (TASL),* $58,861 6/1/2005 – 11/30/2005 [awarded to CERI]

AFRL, AFOSR, FAA, Research Integrations: *Third Annual Human Factors of UAVs Workshop*: *Manning the Unmanned*, 5/24-26, 2006 CERI workshop, $21,000. [funds to CERI]

ARI SBIR, *Shared Understanding Across Levels of Command*: $129,605, 1/3/06-12/21/07. [Aptima subcontract to ASU on Phase II SBIR]

CA Space Grant Foundation, *UAV Alliance, Research, and Development Curriculum Project*, $54,899, 11/21/05-8/30/06. [grant to ASU]

ONR MURI, (grant to ASU, UCF Prime) *Cognition and Collaboration in Network Centric Operations: Understanding & Measuring Macrocognition in Teams* , $1,155,182.00, 5/1/06-9/30/11.

AFRL SBIR, *Intelligent Decluttering of UAV Displays, $19,503,* 5/1/06-1/30/07. [Kutta Consulting subcontract to CERI on SBIR Phase I]

AFOSR STTR, *Communication Analysis for Enhanced Team Performance in the AOC*, $41,451, 8/1/06-4/30/07. [Aptima subcontract to CERI on STTR Phase I]

AFOSR, AFRL *Cognitive Coordination on the Network Centric Battlefield,* $545,105, FA9550-07-1-0081, 1/1/07-11/30/09 [grant to CERI].

ONR STTR*, MIMIC: Human-Directed Learning for Unmanned Air Vehicle Systems in Expeditionary Operations*, $30,117, 8/1/07-5/31/08. [Aptima subcontract to CERI on STTR Phase I]

ONR STTR, *Dynamical Modeling of Discourse for Team Performance Analysis and Enhancement,* $44,480, 8/1/07-5/31/08. [Sandia Research subcontract to ASU Phase I]

AFOSR STTR, *CIFTS: Communications and Information Flow Tracking System*, $230,000, 8/1/07 – 7/31/09. [Aptima subcontract to CERI on STTR Phase II]

Leonard Wood Institute, *Harnessing Human IED Emplacement Detection Expertise,* $224,176, 9/30/2008-10/1/2009. [Subcontracted to ASU by Carnegie Mellon/Batelle]

ONR STTR*, MIMIC (Mixed Initiative Machine for Instructed Computing)Operations*, $149,980, 10/1/2008 – 12/31/2009, [Aptima subcontract to CERI on STTR Phase II].

ONR, *Developing a Synthetic Teammate,* $179,740, 12/1/2008-11/30/2009. [co-pi with Christopher Myers]

Army Research Office MURI, *Computer-aided Human Centric Cyber Situation Awareness,* $593,592, 6/01/09-5/31/14. [Subcontracted to ASU by Penn State University]

Veterans Health Administration Systems Redesign Veterans Engineering Resource Centers, Mid-West Mountain VERC, 2010-2011, consortium [funds Cooke IPA and multiple task orders totaling $159,110].

ONR STTR, *CRA PUMA*, $241,205, 11/18/2009-11/30/2010, [Charles River Analytics subcontract to CERI on STTR Phase II].

ONR DURIP, *Next Generation CERTT Laboratory*, $702,794, 6/2010-6/ 2011.

Science Foundation AZ, Aerospace Defense Initiative: *Human Systems Integration of Remotely Piloted Aircraft (RPA)*. $130,000, 10/1/2010-9/30/2011.

Office of Naval Research, *Synthetic Teammates as Team Players: Coordination of Human and Synthetic Teammates* (CERI $714, 264, 3.5 years), 2011-2016.

Air Force Research Laboratory, Unmanned Aerial Systems (UAS) Phase I Training Analysis (to CERI through L3, $100K for 1 year)

ONR SBIR, *Smart Interaction Device for VTOL UAS.* $66, 738, 9/6/12-1/31/14. [SoarTech contract to CERI]

ONR, *Planning for Peer-to-Peer Human Robot Teaming in Open Worlds, 6/2013-6/2016, $450,000.*[PI: Subbarao Kambhampati, ASU]

ARO SBIR Phase I *Cyber Warfare Simulation Environment*, $30,035, *5/1/13-10/31/13 [*Subcontract to ASU from Sandia Research).]

ARO SBIR Phase II *Effective Cyber Situation Awareness (CSA) Assessment and Training*, $359,782.75, *10/15/14-06/30/15 [*Subcontract to ASU from Sandia Research).]

AFRL SBIR Phase II *ADAPTER II*, $58,870, *8/26/14-8/25/15 [*Subcontract to ASU from Charles River Analytics).]

AFRL SBIR Phase II *Monitoring Extracting and Decoding Indicators of Cognitive Load (MEDIC II) (Co-PI)*, $103,455.00, 6/12/2015 – 12/11/*2016 [Subcontract* to ASU from Charles River Analytics).]

NGA Foresight Initiative, $20M [Nadia Bliss PI; Cooke one of 11 Co-Is; 2014-15]

Center for the Science of Healthcare Delivery – Mayo Clinic, *A Human Factors Approach to Building High-Performance Multi-Professional Cardiac Arrest Teams: Innovative Simulations to Real Life and Back,* $20,000, 2/13/15-2/12/16 [PI: Ayan Sen, MD]

DOE NEUP Project 15-8121 *Automatic Imagery Data Analysis for Proactive Computer-Based Workflow Management during Nuclear Power Plant Outages*, $778,531, 10/1/2015-9/30/2018 [PI: Pingbo Tang]

ONR, *Planning Challenges in Human-Robot Teaming: An Integrated Exploration of Representations, Algorithms and Human Factors*, $774,376, 6/1/16-5/31/19 .[PI: Subbarao Kambhampati, ASU]

AFRL SBIR FA8650-16-M-6754, *Coordination and Performance Metrics for the JTAGSS Training System,* $27,000, 8/1/2016 – 4/30/2017, to CERI [PI: Sandia Research Corporation]

ONR, *Human-Autonomy Teaming in Remotely Piloted Aircraft Systems Operations Under-Degraded Conditions,* $920,652.00, [PI Cooke, award pending to CERI]

PUBLICATIONS

Journal Articles (refereed)

1) Schvaneveldt, R. W., Durso, F. T., Goldsmith, T. E., Breen, T. J., Cooke, N. M., Tucker, R. G., & DeMaio, J. C. (1985). Measuring the structure of expertise. *International Journal of Man-Machine Studies, 23*, 699-728.
2) Cooke, N.M., & McDonald, J.E. (1986). A formal methodology for acquiring and representing expert knowledge. *Proceedings of the IEEE: Special Issue on Knowledge Representation*, *74,* 1422-1430. (Reprinted in *Expert Systems: A Software Methodology for Models and Applications,* (1990) P. Raeth (Ed.). Los Alamos, CA: IEEE Computer Society Press.)
3) Cooke, N.M, Durso, F.T., & Schvaneveldt, R.W. (1986). Recall and measures of memory organization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12 (4)*, 538-549.
4) Durso, F.T., Cooke, N.M., Breen, T.J., & Schvaneveldt, R.W. (1987). Is consistent mapping necessary for high-speed search? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13* (2), 223-229.
5) Cooke, N.M., & McDonald, J. E. (1987). The application of psychological scaling techniques to knowledge elicitation for knowledge-based systems. *International Journal of Man-Machine Studies, 26,* 533-550.
6) Cooke, N. J. & Schvaneveldt, R. W. (1988). Effects of computer programming experience on network representations of abstract programming concepts*. International Journal of Man-Machine Studies, 29,* 407-427.
7) Cooke, N. J. (1990). Practice makes perfect -- or does it? (Review of *The Nature of Expertise* by Chi, Glaser, and Farr) *Journal of Contemporary Psychology, 35*, 251-253.
8) Gillan, D. J., Breedin, S. D., & Cooke, N. J. (1992). Network and multidimensional representations of the declarative knowledge of human-computer interface design experts. *International Journal of Man-Machine Studies, 36,* 587-615.
9) Cooke, N. J. (1992). Predicting judgment time from measures of psychological proximity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 640-653.
10) Cooke, N. J., & Bartha, M. C. (1992). An empirical study of psychological metaphor. *Journal of Metaphor and Symbolic Activity: Special Issue, 7,* 215-235.
11) Cooke, N. J. (1992). Eliciting semantic relations for empirically derived networks. *International Journal of Man-Machine Studies, 37,* 721-750.
12) Halgren, S. L. and Cooke, N. J. (1993). Towards ecological validity in menu research. *International Journal of Man-Machine Studies, 39,* 51-70.
13) Cooke, N. J., Atlas, R.S., Lane, D. M., & Berger, R. C. (1993). The role of high-level knowledge in memory for chess positions. *The American Journal of Psychology, 106,* 321-351.
14) Cooke, N. J., & Breedin, S. D. (1994). Constructing naive theories of motion on-the-fly. *Memory and Cognition, 22,* 474-493.
15) Cooke, N. J. & Breedin, S. D. (1994). Naive misconceptions of Cooke and Breedin's research: Response to Ranney. *Memory and Cognition, 22,* 503 - 507.
16) Cooke, N. J., Durso, F. T., & Schvaneveldt, R. W. (1994). Retention of skilled search after nine years. *Human Factors, 36,* 597-605.
17) Cooke, N. J. (1994). Varieties of knowledge elicitation techniques. *International Journal of Human-Computer Studies, 41,* 801-849.
18) Rowe, A. L., & Cooke, N. J. (1995). Measuring mental models: Choosing the right tools for the job. *Human Resource Development Quarterly, 6,* 243-255.
19) Cooke, N. J., & Neville, K. J., & Rowe, A. L. (1996) Procedural network representations of sequential data. *Human-Computer Interaction, 11,* 29-68.

20) Rowe, A. L., Cooke, N. J., Hall, E. P., & Halgren, T. L. (1996). Toward an on-line knowledge assessment methodology: Building on the relationship between knowing and doing. *Journal of Experimental Psychology: Applied, 2,* 31-47.
21) Cooke, N. J., & Rowe, A. L. (1997). Measures of mental models: A synthesis of evaluative data. *Training Research Journal, 3,* 185-207.
22) Cooke, N. J., Salas, E., Cannon-Bowers, J. A., & Stout, R. (2000). Measuring team knowledge. *Human Factors, 42*, 151-173.
23) Cooke, N. J., Kiekel, P. A., & Helm E. (2001). Measuring team knowledge during skill acquisition of a complex task. *International Journal of Cognitive Ergonomics: Special Section on Knowledge Acquisition, 5,* 297-315.
24) Cooke, N. J., Kiekel, P.A., Salas, E., Stout, R.J., Bowers, C., Cannon-Bowers, J. (2003). Measuring Team Knowledge: A Window to the Cognitive Underpinnings of Team Performance. *Group Dynamics: Theory, Research and Practice, 7*, 179-199.
25) Gorman, J.C., Cooke, N. J., & Winner, J.L. (2006). Measuring team situation awareness in decentralized command and control systems. *Ergonomics, 49,* 1312-1325.
26) Pedersen, H. K, & Cooke, N. J. (2006). From Battle Plans to Football Plays: Extending Military Team Cognition to Football. *International Journal of Sport and Exercise Psychology, 4,* 422-446.
27) Cooke, N. J., Gorman, J. C., Duran, J. L., & Taylor, A. R. (2007). Team Cognition in Experienced Command-and-Control Teams. *Journal of Experimental Psychology: Applied*, *Special Issue on Capturing Expertise across Domains, 13,* 146-157.
28) Salas, E., Cooke, N. J., Rosen, M.A. (2008). On Teams, Teamwork and Team Performance: Discoveries and Developments. *Human Factors: Golden Anniversary Special Issue, 50,* 540-547.
29) Cooke, N. J. (2008). Preface to the Special 50th Anniversary Issue of *Human Factors. Human Factors: Golden Anniversary Special Issue, 50,* 347-350.
30) Cooke, N. J. & Gorman, J. C. (2009). Interaction-Based Measures of Cognitive Systems. *Journal of Cognitive Engineering and Decision Making: Special Section on: Integrating Cognitive Engineering in the Systems Engineering Process: Opportunities, Challenges and Emerging Approaches 3, 27-46.*
31) Gorman, J. C., Amazeen, P. G., & Cooke, N. J. (2010). Team Coordination Dynamics. *Nonlinear Dynamics Psychology and Life Sciences, 14,* 265-289.
32) Gorman, J. C., Cooke, N. J., & Amazeen, P. G. (2010). Training adaptive teams. *Human Factors, 52,* 295-307. [Winner of HFES 2010 Jerome Ely Award]
33) Ball, J. Myers, C., Heiberg, A. Cooke, N. J., Matessa, M., Freiman, M., & Rodgers, S. (2010). The synthetic teammate project. *Computational and Mathematical Organization Theory*, *16,* 271-299. DOI 10.1007/s10588-010-9065-3
34) Gorman, J. S., & Cooke, N. J. (2010). Preface to the Special Issue on Collaboration, Coordination, and Adaptation in Complex Sociotechnical Systems, *Human Factors, 52*, 143-146.
35) Gorman, J. C., & Cooke, N. J. (2011). Changes in team cognition after a retention interval: The benefits of mixing it up. *Journal of Experimental Psychology: Applied, 17*, 303-319.
36) McNeese, M. D., Cooke, N. J., & Champion, M. (2011). Situating Cyber Situation Awareness. *Cognitive Technology, 16,* 5-9.
37) Gorman, J.C., Cooke, N. J., Amazeen, P. G., & Fouse, S. (2012). Measuring patterns in team interaction sequences using a discrete recurrence approach. *Human Factors, 54,* 503-517.
38) Cooke, N. J., Duchon, A., Gorman, J. C., Keyton, J., & Miller, A. (2012). Preface to the special section on Methods for the Analysis of Communication. *Human Factors, 54*, 485-488.
39) Cooke, N. J., Gorman, J. C., Myers, C. W., & Duran, J.L. (2013). Interactive Team Cognition, *Cognitive Science, 37, 255-285,* DOI: 10.1111/cogs.12009.
40) Gorman, J. C., Hessler, E. E., Amazeen, P. G., Cooke, N. J., & Shope, S. M. (2012). Dynamical analysis in real time: Detecting perturbations to team communication. *Ergonomics, 55,* 825-839. http://dx.doi.org/10.1080/00140139.2012.679317
41) Cooke, N. J., Champion, M., Rajivan, P., & Jariwala, S. (2013). Cyber Situation Awareness and Teamwork. *EAI Endorsed Transactions on Security and Safety*. Special Section on: The Cognitive Science of Cyber Defense, 13.
42) Cooke, N. J. & McNeese, M. (2013). Preface to special issue on the cognitive science of cyber defense analysis. *EAI Endorsed Transactions on Security and Safety*. Special Section on: The Cognitive Science of Cyber Defense, 13.
43) Keel, P., Cooke, N. J., & Sither, M. (2013) Improving Cognitive Interaction through Computational Collaboration Agents, *Theoretical Issues in Ergonomic Science, 1-17,* DOI:10.1080/1463922X. 2012.751636

44) Waterson, P., Robertson, M. M., Cooke, N. J., Militello, L., Roth, E. & Stanton, N. A. (2015). Defining the methodological challenges and opportunities for an effective science of sociotechnical systems and safety. *Ergonomics, 58,* 565-599. http://dx.doi.org/10.1080/00140139.2015.1015622
45) Cooke, N. J. (2015). Team cognition as interaction. *Current Directions in Psychological Science, 34,* 415-419.
46) McNeese, N. J., Khera, N., Wordingham, S. E., Arring, N., Nyquist, S. Gentry, A., Tomlinson, B. Cooke, N. J., & Sen, A. (2016). Teams in cancer care delivery. *Journal of Oncology Practice.*
47) McNeese, N., Cooke, N., Branaghan, R., Knobloch, A., & Taylor, A. (2017). Identification of the emplacement of Improvised Explosive Devices by experienced mission payload operators *Applied Ergonomics, 43-51.*
48) Demir, M., McNeese, N., & Cooke, N. (in press). Team Situational Awareness within the Context of Human-Autonomy Teaming. *Cognitive Systems Research.*

Books and Book Chapters (refereed)

44) Schvaneveldt, R.W., Cooke, N.M., Durso, F. T., Onorato, L. A., & Bailey, G. (1984). A taxonomy of human-computer interactions: Toward a modular user interface. In G. Salvendy (Ed.), *Human-Computer Interaction*. Amsterdam: Elsevier, 121-124.
45) Cooke, N.M. (1989). The elicitation of domain-related ideas: Stage one of the knowledge acquisition process. In C. Ellis (Ed.), *Expert Knowledge and Explanation:* England: Ellis Horwood Limited, 58-75.
46) Howell, W. C., & Cooke, N. J. (1989). Training the human information processor: A look at cognitive models. In I. L. Goldstein and Associates (Eds.), *Training and development in organizations* (pp. 121-182). New York: Jossey Bass.
47) Cooke, N. J. (1990). Using Pathfinder as a knowledge elicitation tool: Link interpretation. In R. Schvaneveldt (Ed.), *Pathfinder Associative Networks: Studies in Knowledge Organization.* Norwood, NJ: Ablex, 227-239.
48) Cooke, N. J. (1990). Empirically-defined semantic relatedness and category judgment time. In R. Schvaneveldt (Ed.), Pathfinder *Associative Networks: Studies in Knowledge Organization.* Norwood, NJ: Ablex, 101-110.
49) Cooke, N. J. (1992). Modeling human expertise in expert systems. In R. Hoffman (Ed.), *The Psychology of Expertise: Cognitive Research and Empirical AI.* New York: Springer-Verlag, 29-60.
50) Paap, K. R. & Cooke, N. J. (1997). Design of menus. In M. Helander, T. Landauer, & P. Prabhu (Eds.), *Handbook of Human-Computer Interaction,* pp. 533-572 Amsterdam: North-Holland.
51) Cooke, N. J. (1999). Knowledge elicitation. In. F.T. Durso, (Ed.), *Handbook of Applied Cognition,* pp. 479-509. UK: Wiley.
52) Cooke, N. J. & Gillan, D. J. (1999). Representing user behavior in human-computer interaction. In A. Kent and J. G. Williams (Eds.), *Encyclopedia of Computer Science and Technology,* pp. 283-308. New York: Marcel Dekker, Inc. Also to be reprinted in the *Encyclopedia of Library and Information Science.*
53) Stout, R. J., Cooke, N. J., Salas, E. & Cannon-Bowers, J. A. (2000). Cognitive engineering in team performance measurement. In M. M. Beyerlein, D. A. Johnson, & S.T. Beyerlein (Eds.), *Advances in Interdisciplinary Studies of Work Teams, 6*, 27-53.
54) Gillan, D.J., and Cooke, N. J. (2001). Using Pathfinder networks to analyze procedural knowledge in interactions with advanced technology. In E. Salas, C. Bowers, N. Cooke, J. Driskell, & D. Stone (Eds.), *Advances in Human Performance and Cognitive Engineering Research.* Greenwich, CT: JAI Press Inc., Vol. 1.
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4) USAF SAB. *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare.* (2010). Report of the USAF Scientific Advisory Board.
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9) Cooke, N. J. (1992). The implications of cognitive task analyses for the revision of the Dictionary of Occupational Titles. Report for APA-sponsored symposium for the Department of Labor.
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Halgren, S. L. (1991). Information displays: The effect of organization and category distinctiveness on user performance. Master's Thesis, Rice University.

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Rowe, A. L. (1994). Mental models of physical systems: Examining the relationship between knowing and doing. Ph.D. Thesis, Rice University. Winner of the 1994 Bullock Dissertation Award in Human Resource Development.

Flowers, K. A. (1995). On-line Catalog Interfaces: Knowledge Structure and Subject Access. Master's Thesis, Rice University.

Kozak, K. A. (1994). Effects of implicit instruction on complex system performance. Master's Thesis, New Mexico State University.

Melton, J. S., (1995). Empirically-derived associative networks and subclinical depression: Implications for theory, research, and assessment. Master's Thesis, New Mexico State University.

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La Salle, S. M. (1999). The effects of expanded realism of interface metaphor on performance and understanding of the system. Master's Thesis, New Mexico State University.

Kiekel, P.A. (2000). Communication of emotion in remote collaborative writing with rich versus lean groupware environments. Master's Thesis, New Mexico State University.

Lassiter, Honore' (2002). Interpersonal trust in small work groups. Master's Thesis, New Mexico State University

Gorman, Jamie C. (2003). A Latent Semantic Analysis-based metric of team communications efficiency. Master's Thesis, New Mexico State University.

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Kiekel, P.A. (2004). Developing automatic measures of team cognition using communication data. Ph.D. Thesis, New Mexico State University.

DeJoode, J. A. (2004). Understanding failure to attach. M.A. Thesis, New Mexico State University.

Connor, O. O. (2005). Assessing clinical expertise in anesthesiology. M.A. Thesis, New Mexico State University.

Gorman, J. C. (2006). Team coordination dynamics in cognitively demanding environments. Ph.D. Thesis, New Mexico State University.

Rowe, L. (2007). Effects of Distributed Mission Operations (DMO) on Knowledge Acquisition of Fighter Pilots Utilizing the Air Superiority Knowledge Assessment System, M.S. Thesis, Arizona State University.

Winner, J. (2007). Measuring the Shared Interpretation of Commander's Intent, M.S. Thesis, Arizona State University.

Duran, J. (2010). Are Teams Equal to the Sum of Their Members? An Empirical Test. M.S. Thesis, Arizona State University.

Covas- Smith, C. M. (2011). The development of robust intuitive decision making in simulated real-world environments, PhD thesis, Psychology, Arizona State University.

Rajivan, P. (2011). CyberCog: A Synthetic Task Environment for Measuring Cyber Situation Awareness. M.S. Thesis, Arizona State University.

Fouse, S. (2012). Understanding Team Cognition through Communication Analysis: Measuring Team Interaction Patterns Using Recurrence Plots. M.S. Thesis, Arizona State University.

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Rajivan, P. (2014). Information pooling bias in collaborative cyber forensics. PhD thesis, Simulation, Modeling, and Applied Cognitive Science, Arizona State University.

Bartlett, C. (2015). Communication between teammates in urban search and rescue. M.S. Thesis, Arizona State University.

Buchanan, V. (2016). The Role of Teamwork in Predicting Movie Earnings . M.S. Thesis, Arizona State University.

Bradbury, A. (2016). Network Defense and Team Cognition: A Team-Based Cybersecurity Simulation, M.S. Thesis, Arizona State University.

Fedele, M. (2016). Synchrony: Biometric Indication of Team Cognition. Synchrony: Biometric Indication of Team Cognition.

Driggs, Jade (2017). Towards Predicting Completion for United States Air Force (USAF)

Remotely Piloted Aircraft (RPA) Training

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Mumtaz, Muhammad Khan. (2009) Implicit Coordination Behaviors: Team Process for Effective Management. M.Phil./Ph.D. Dissertation, National College of Business Administration and Economics, Pakistan

Taber, Michael, J. (2010). Human Systems Integration and Situation Awareness in Microworlds: An Examination of Emergency Response Within the Offshore Command and Control Training System. PhD Dissertation, Dalhousie University.

.Steiner, Lisa (2013). Reducing Underground Coal Roof Bolting Injury Risks Through Equipment Design. PhD Dissertation, The University of Queensland.

PHD RESEARCH PRACTICUM ADVISOR

Dube, Genevieve (2012). Université Laval, Québec

CURRENT PHD COMMITTEES

Mustafa Demir, 2012, chair, Simulation, Modeling, and Applied Cognitive Science, ASU
Sandra Hinski, 2013, chair, Simulation, Modeling, and Applied Cognitive Science, ASU
Saliha Akca-Hobbins, 2015, chair, Simulation, Modeling, and Applied Cognitive Science, ASU
Aaron Bradbury, 2016, chair, Simulation, Modeling, and Applied Cognitive Science, ASU
Verica Buchanan, 2016, chair, Simulation, Modeling, and Applied Cognitive Science, ASU
Jamil Alomari, 2015, member, Simulation, Modeling, and Applied Cognitive Science, ASU
Sung Hun Sim, 2013, member, Simulation, Modeling, and Applied Cognitive Science, ASU
Loretta Cheeks, member, School of Computing, Informatics, and Decision Systems Engineering, ASU
Tracy Chesney, member, School of Nursing, Duquesne University
Virginia Counts, member, School of Sustainable Engineering and the Built Environment, ASU
Yafeng Lu, member, School of Computing, Informatics, and Decision Systems Engineering, ASU
Eric Nunes, member, School of Computing, Informatics, and Decision Systems Engineering, ASU
Erin Peavey, member, Nursing, ASU
Cheng Zhang, member, School of Computing, Informatics, and Decision Systems Engineering, ASU

PAPERS PRESENTED

1) Cooke, N.M., & Smith, R. (1984). Evidence for networks from recall. In K. Paap (chair), Link-weighted Networks. Paper presented at the meetings of the Rocky Mountain Psychological Association, Las Vegas, NV.

2) Schvaneveldt, R. W., Cooke, N.M., Durso, F. T., Onorato, L., & Bailey, G. (1984). A Taxonomy of Human-Computer Interactions: Toward a Modular User Interface. Paper presented at the First USA-Japan Conference on Human-Computer Interaction, Honolulu, HI.
3) Cooke, N.M. (1985). Computer programming expertise: Variations in cognitive structures. In F. Durso (chair), Human Expertise: Papers in Honor of William Chase. Paper presented at the meetings of the Southwestern Psychological Association, Austin, TX.
4) Durso, F.T., Cooke, N.M., Breen, T.B., & Schvaneveldt, R.W. (1985). Practice Effects Without Consistent Mapping. Paper presented at the meetings of the Southwestern Psychological Association, Austin, TX.
5) Cooke, N.M. & Schvaneveldt, R.W. (1986). The Evolution of Cognitive Networks with Computer Programming Experience. Paper presented at the workshop on Empirical Studies of Programmers, June 5-6, 1986, Washington, D.C.
6) Cooke, N.M. & McDonald, J. E. (1986). The Application of Psychological Scaling Techniques to Knowledge Elicitation for Knowledge-based Systems. Paper presented at the Knowledge Acquisition for Knowledge-based Systems workshop, November 2-7, 1986, Banff, Alberta, Canada.
7) Cooke, N.M., & Schvaneveldt, R.W. (1987). The application of empirically derived semantic networks to knowledge engineering. In F. Durso (chair), Knowledge structures: What are they good for? Paper presented at the meetings of the Southwestern Psychological Association, April 16-18, New Orleans, LA.
8) Cooke, N. J. (1988). A methodology for capturing the elusive mental model. Paper presented at User System Interface Conference, February 1988, Austin, TX
9) Cooke, N. J. (1988). Spatial vs. network scaling and category judgment time. Paper presented at Southwestern Psychological Association, April 13, 1988, Houston, TX.
10) Gillan, D. & Cooke, N. J. (1989). Cognitive modeling in human-computer interaction. Paper presented at Human Factors Symposium, NASA/JSC, September 19, 1989.
11) Halgren, S.L. & Cooke, N. J. (1990). Information displays: The effect of organization and category distinctiveness on user performance. Poster presented at the CHI' 90 - Human factors in computing systems conference, April 1-5, 1990, Seattle, WA.
12) Breedin, S. D., Cooke, N. J., Rudisill, M., & Gillan, D. (1990) Effects of knowledge elicitation techniques on naive models of physics. Paper presented Southwestern Psychological Association, April 12-14, 1990, Dallas, TX.
13) Cooke, N. J., Berger, R. C., & Lane, D. L. (1990). Conceptual chunking in chess: Beyond perception. Paper presented Southwestern Psychological Association, April 12-14, 1990, Dallas, TX.
14) Cooke, N. J., & Breedin, S. D. (1990). Implicit knowledge about object motion. Paper presented at the Texas Cognition Conference, May 25-26, San Antonio, TX.
15) Jones, S. F., & Cooke, N. J. (1990). The effects of training on statistical reasoning. Paper presented at the 34th annual meeting of the Human Factors Society, October 8-12, Orlando, FL.
16) Cooke, N. J., & Breedin, S. D. Implicit knowledge about motion. Poster presented at the 31st annual meeting of the Psychonomic Society, November 16-18, New Orleans, LA.
17) Atlas, R. S., & Cooke, N. J. (1991). Chess expertise and capacity for immediate recall of visually presented positions. Paper presented Southwestern Psychological Association, April 11-13, 1991, New Orleans, LA.
18) Halgren, S. L. & Cooke, N. J. (1991). Toward ecological validity in menu research. Poster presented at the CHI' 91 - Human factors in computing systems conference, April 29-May 2, 1991, New Orleans, LA.
19) Halgren, S. L., Flowers, K. A., & Cooke, N. J. (1991). The effect of explanation type on human-expert system interactions. Poster presented at the 35th annual meeting of the Human Factors Society, September 2-6, San Francisco, CA.
20) procedural knowledge development during skill acquisition. Paper presented at the South Texas Symposium on Human Factors and Ergonomics, November 15, San Antonio, TX.
21) Rowe-Hallbert, A. L., Neville, K. J., & Cooke, N. J. (1991). Measuring the elusive mental model. Paper presented at the South Texas Symposium on Human Factors and Ergonomics, November 15, San Antonio, TX.
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23) Neville, K. J., & Cooke, N. J. (1992). A methodology for assessing procedural knowledge. Paper presented at the Southwestern Psychological Association Meeting, April 16-18, 1992.

24) Cooke, N. J. (1992). Structural modeling techniques and sequential analysis. Paper presented at CHI '92 - Human factors in computing systems conference, Workshop on Exploratory Sequential Data Analysis, May 3 -May 7, 1992, Monterey, CA.

25) Flowers, K. A., & Cooke, N. J. (1992). Knowledge structures and subject access. Poster presented at CHI '92 - Human factors in computing systems conference, May 3-May 7, 1992, Monterey, CA.

26) Rowe, A. L., Cooke, N. J., Neville, K. J., Schacherer, C. W. (1992). Mental models of metal models: A comparison of mental model measurement techniques. Paper presented at the 36th annual meeting of the Human Factors Society, October 12-16, Atlanta, GA.

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29) Bauhs, J. A., & Cooke, N. J. (1994). Is knowing more really better? Effects of system development information in human-expert system interactions. Poster presented at CHI '94 - Human factors in computing systems conference, April 24-April 28, 1994, Boston, MA.

30) Rivera, K., Cooke, N. J., Rowe, A. L., & Bauhs, J. A. (1994). Conveying emotion in remote computer-mediated communication. Poster presented at CHI '94 - Human factors in computing systems conference, April 24-April 28, 1994, Boston, MA.

31) Rowe, A. L., Lowry, T., Halgren, S. L., & Cooke, N. J. (1994). A comparison of usability evaluations conducted by different teams. Poster presented at CHI '94 - Human factors in computing systems conference, April 24-April 28, 1994, Boston, MA.

32) Cooke, N. J., & Rowe, A. L. (1994). Mapping avionics troubleshooting actions onto mental models. Paper presented at the Practical Aspects of Memory Conference, July 31-August 5, College Park, MD.

33) Cooke, N. J., & Rowe, A. L. (1994). Evaluating mental model elicitation methods. Paper presented at the 38th annual meeting of the Human Factors and Ergonomics Society, October 24-28, Nashville, TN.

34) Cooke, N. J. (1995). Pathfinder network scaling: Potential Applications for modeling instructional developers. Evaluating mental model elicitation methods. Paper presented at 39th annual meeting of the Human Factors and Ergonomics Society, October 9-13, San Diego, CA.

35) Rivera, K, Cooke, N. J., & Bauhs, J. A. (1996). Effects of emotional icons on remote communication. Poster presented at CHI '96 - Human factors in computing systems conference, April 13-April 18, Vancouver, British Columbia, Canada.

36) Cooke, N. J., & Rowe, A. L. (1996). Evaluating measures of mental models. Paper presented the 104th Convention of the American Psychological Association, August 9-13, Toronto, Canada.

37) Cooke, N. J., Stout, R. J., & Salas, E. (1996). Methods for eliciting and assessing the shared cognitions underlying team situation awareness. Paper presented in the Colloquium on Multi-Operator Performance in Complex Military Systems, Human Factors and Ergonomics Society Conference, September 2-6, Philadelphia, PA.

38) Cooke, N. J., Stout, R., & Salas, E. (1997) Expanding the measurement of situation awareness through cognitive engineering methods. Paper presented at the 41st annual meeting of the Human Factors and Ergonomics Society, September 22-26, Albuquerque, NM.

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43) Cooke, N. J. (1999). Knowledge metrics for teams. Paper presented at Meeting of the Southwestern Psychological Association, April 1-3, Albuquerque, NM.

44) Cooke, N. J., Rivera, K., Shope, S.M., & Caukwell, S. (1999). A synthetic task environment for team cognition research. Paper presented at the 43rd annual meeting of the Human Factors and Ergonomics Society, September 27-October 1, Houston, TX.
45) Cooke, N. J. (1999). CERTT Lab. Poster presented at the technical group meeting of the Cognitive Engineering and Decision Making technical group at the 43rd annual meeting of the Human Factors and Ergonomics Society, September 27-October 1, Houston, TX.
46) Cooke, N. J., Cannon-Bowers, J. A., Kiekel, P. A., Rivera, K., Stout, R., and Salas, E. (2000). Improving team's interpositional knowledge through cross training. Paper presented at 44th annual meeting of the Human Factors and Ergonomics Society and International Ergonomics Association, July 30-August 4, San Diego, CA.
47) Cooke, N. J., Shope, S.M., & Rivera, K. (2000). Control of an uninhabited air vehicle: A synthetic task environment for teams. Demonstration presented at the 44th annual meeting of the Human Factors and Ergonomics Society and International Ergonomics Association, July 30-August 4, San Diego, CA.
48) Kiekel, P. A., & Cooke, N. J. (2001). A clustering approach to determining discrete pattern shifts in sequential data. Talk and abstract presented at the meeting of the Psychometric Society, June 25, King of Prussia, PA.
49) Foltz, P. W., Cooke, N. J., Kiekel, P. & Shope, S. M. (2001) Automating the measurement of team cognition through an analysis of team communication. Talk presented at the Society for Text and Discourse, July, Santa Barbara, CA.
50) Cooke, N. J., Kiekel, P. A., & Helm E. (2001). Comparing and validating measures of team knowledge. Paper presented at 45th annual meeting of the Human Factors and Ergonomics Society, October 8-12, Minneapolis, MN.
51) Hottman, S.B., Jackson, J., Sortland, K., Witt, G., and Cooke, N.J. (2001). UAVs and air traffic controllers: Interface considerations. Paper presented at the AUVSI 2001 Annual Symposium of the Association for Unmanned Vehicle Systems International, July 31-August 2, Arlington, VA.
52) Kiekel, P. A., Cooke, N. J., Foltz, P. W., & Shope, S. M. (2001). Automating measurement of team cognition through analysis of communication data. Paper presented at Human Computer Interaction International, August 8, New Orleans, LA.
53) Cooke, N. J., & Bell, B. (2001) The CERTT Lab: Cognitive Engineering Research on Team Tasks. Poster presented at the first annual NMSU Research and Creative Activities Fair, September 27, Las Cruces, NM.
54) Cooke, N. J., & Shope, S. M. (2002). The CERTT-UAV Task: A Synthetic Task Environment to Facilitate Team Research. Paper presented at the Advanced Simulations Technologies Conference, April 14-18, San Diego, CA.
55) Cooke, N. J., Kiekel, P. A., & Bell, B., & Salas, E. (2002). Addressing limitations of the measurement of team cognition. Paper presented at 46th annual meeting of the Human Factors and Ergonomics Society, September 30-October 4, Baltimore, MD.
56) Cooke, N. J. (2002). Team communication analysis: Exploiting the wealth. Symposium overview presented at 46th annual meeting of the Human Factors and Ergonomics Society, September 30-October 4, Baltimore, MD.
57) Kiekel, P. A., Cooke, N.J., Foltz, P.W., Gorman, J. C., & Martin, M.J. (2002). Some promising results of communication-based automatic measures of team cognition. Paper presented at 46th annual meeting of the Human Factors and Ergonomics Society, September 30-October 4, Baltimore, MD.
58) Cooke, N. K., DeJoode, J. D., Gorman, J., Keith, Rebecca, Lee, S., & Pedersen, H. (2002). Team cognition and homeland defense. Poster presented at 46th annual meeting of the Human Factors and Ergonomics Society, Special poster session on Cognitive Engineering and Decision Making Applied to Homeland Defense, September 30-October 4, Baltimore, MD.
59) Foltz, P.W., Martin, M., Kiekel, P. A., Gorman, J., & Cooke, N.J. (2003). Automated Team communication analysis with latent semantic analysis. Paper presented at CTA Symposium, April 29-May 1, College Park, MD.
60) DeJoode, J., Cooke, N. J., & Shope, S.M. (2003). Naturalistic observations of an airport mass casualty exercise. Poster presented at 47th annual meeting of the Human Factors and Ergonomics Society, October 13-17, Denver, CO.
61) Bell, B. G., & Cooke, N. J. (2003). Cognitive ability correlates of performance on a team task. Poster presented at 47th annual meeting of the Human Factors and Ergonomics Society, October 13-17, Denver, CO.
62) Gorman, J.C., Foltz, P.W., Kiekel, P.A., Martin, M. J., & Cooke, N. J. (2003). Evaluation of

Latent-Semantic Analysis-based measures of team communications. Paper presented at 47th annual meeting of the Human Factors and Ergonomics Society, October 13-17, Denver, CO.

63) Cooke, N. J. (2003) Knowledge modeling and design for the aging. Panel paper presented at 47th annual meeting of the Human Factors and Ergonomics Society, October 13-17, Denver, CO.
64) Connor, O., Cooke, N. J., Slagle, J., and Weinger, M. (2004). Pilot Study of the Measurement of Context-Dependent Concept Relatedness to Assess Anesthesiology Expertise. Paper presented at annual meeting of the Society for Technology in Anesthesia, January 15, Albuquerque, NM.
65) DeJoode, J. A., Cooke, N.J., & Shope, S. M. (2004). Naturalistic observation of airport incident command. Poster presented at Human Performance, Situation Awareness and Automation Technology Conference, March 22 – 25, Daytona Beach, FL.
66) Cooke, N. J. (2004). Team Cognition: Why, What, and How? Paper presented at the annual convention of the American Psychological Association, July 29, Honolulu, Hi.
67) Cooke, N. J., Kiekel, P. A., & Gorman, J. C. (2005). Team Communication as a Team Cognition Barometer. Paper presented at the Society of Industrial Organizational Psychologists, April 16, Los Angeles, CA.
68) Pedersen, H. K., & Cooke, N. J. (2005). Team Coordination in UAV Operations. Paper presented at the International Symposium on Aviation Psychology, April 18-21, Oklahoma City, OK.
69) Cooke, N. J., Connor, Cooke, N. J. (2005). Augmented Team Cognition. Paper presented and session chaired at Augmented Cognition International, HCII, July 22-27, Las Vegas, NV
70) Gorman, J. C., Cooke, N. J., Pedersen, H. K., Connor, O.O., & DeJoode, J. A. (2005). Coordinated awareness of situation by teams (CAST): Measuring team situation awareness of a communication glitch. Paper presented at 49th annual meeting of the Human Factors and Ergonomics Society, September 26-30, Orlando, FL.
71) Gorman, J. C., Cooke, N. J., Pedersen, H. K., Winner, J. L., Andrews, D., Amazeen, P. G. (2006). Changes in Team Composition After a break: Building adaptive command-and-control teams. Paper presented at 50th annual meeting of the Human Factors and Ergonomics Society, October 16-20, San Francisco, CA.
72) Cooke, N. J. (2006). Human Factors of Remotely Operated Vehicles. Panel chaired at 50th annual meeting of the Human Factors and Ergonomics Society, October 16-20, San Francisco, CA.
73) Cooke, N. J. (2006). Cross Cultural Interactions: Methods and Motivations for Study. In C. A. Miller, panel position paper presented at 50th annual meeting of the Human Factors and Ergonomics Society, October 16-20, San Francisco, CA.
74) Gorman, J.C., Amazeen, P.G., & Cooke, N.J. (2007). Team coordination dynamics. Poster presented at Coordination Dynamics 2007. February 22-25. Boca Raton, FL.
75) Cooke, N. J., Gorman, J. C., Pedersen, H. K., Myers, C. W., Duran, J., and Andrews, D. (2007). Retention of team coordination skill. Presentation at the Distributed Mission Operations Workshop, September 3, Mesa, AZ.
76) Myers, C. W., Cooke, N. J., Robinson, F. E., Heiberg, A., Ball, J., & Gluck, K. (2007). Collaborating with synthetic teammates. Presentation at the Distributed Mission Operations Workshop, September 6, Mesa, AZ.
77) Cooke, N., Amazeen, N., Andrews, D., Duran, J., Gorman, J., Pedersen, H., Rowe, L., Taylor, A., & Winner, J. (2007). Acquisition and retention of team UAV Coordination Skill. Paper presented at the Fourth Annual Human Factors of UAVs Workshop, May 21-23, Chandler, AZ.
78) Gorman, J. C., Cooke, N. J., Warner, N., Wroblewski, E. (2007). Tagging Macrocognitive Processes Using Communication Flow Patterns, paper presented at the Annual Meeting of the Human Factors and Ergonomics Society, October 2007, Baltimore, MD.
79) Cooke, N. J. (2007). Panel presentation on Multiple Perspectives on the Macro-Cognition Construct. Paper position presented at Naturalistic Decision Making VIII, June 5, Monterey, CA.
80) Cooke, N. J. (2007). Communication-Based Metrics of Macrocognition. In E. Salas & S. Fiore, Panel position presented at the 51st annual meeting of the Human Factors and Ergonomics Society, October 1-5, Baltimore, MD.
81) Cooke, N. J. (2007). Design Specs for a Cognitive Engineering Textbook. In A. Kirlik, Panel position presented at the 51st annual meeting of the Human Factors and Ergonomics Society, October 1-5, Baltimore, MD.
82) Cooke, N. J., & Durso, F. T. (2007). Modern technology failures, Cognitive engineering successes, panel chaired at the Annual Meeting of the Human Factors and Ergonomics Society, October 2007, Baltimore, MD.
83) Duran, J. L., Robinson, F. E., Cooke, N. J., & Gorman J. C. (2008) A synthetic task environment

for the study of macrocognition in teams. Poster presented at the Annual meeting of the Interdisciplinary Network for Group Research, July 2008, Kansas City, MO.

84) Winner, J. L., Cooke, N. J., Freeman, J., Sager, L., & Goodwin, G. F. (2008). Rank Order Procedure: Measuring the Shared Interpretation of Commander's Intent. American Psychological Association, August 16, 2008, Boston, MA.
85) Cooke, N. J. (2008). The Real Deal: Essential Lessons Learned from Human Factors Leaders. In C. Nemeth, Panel position presented at the 52nd annual meeting of the Human Factors and Ergonomics Society, September 22-26, New York, NY.
86) Gorman, J. C., Hessler, E. E., Cooke, N. J., & Amazeen, P.G. (2009). Dynamics of Team Coordination and Adaptive Performance. Paper presented at the International Conference on Perception and Action 15, July 13, 2009, Minneapolis, MN.
87) Durso, F. T., & Cooke, N. J. (2009). Modern Technology Failures and Cognitive Engineering Successes. Panel at the 2009 American Psychological Association Annual Convention, August 8, 2009, Toronto, Ontario, CA.
88) Ball, J, Myers, C., Hieberg, A., Cooke, N., Matessa, M. & Freiman, M. (2009). The Synthetic Teammate Project. Paper presented at the *Behavior Representation in Modeling and Simulation Conference*.
89) Cooke, N. J. (2009). Synthetic Agents as Team Players. Panel position at the 53rd annual meeting of the Human Factors and Ergonomics Society, October 22, San Antonio, TX.
90) Duran, J. L., Goolsbee, Z., Cooke, N. J., & Gorman, J. C. (2009). Embedded collaboration metrics in the MacroCog synthetic task environment. Poster presented at the 53rd annual meeting of the Human Factors and Ergonomics Society, October 21, San Antonio, TX.
91) Gorman, J. C., Cooke, N. J., Duran, J. L., McGrane, K., & Rima, N. (2009). Representing Workflow within the Air Operations Center: The Lifecycle of a Dynamic Target. Poster presented at the 53rd annual meeting of the Human Factors and Ergonomics Society, October 21, San Antonio, TX.
92) Cooke, N. J., Hosch, C., Banas, S., Hunn, B. P., Staszewski, J., & Fensterer, J. (2010). Expert detection of Improvised Explosive Device behavior. Poster presented at the 54th Annual Conference of the Human Factors and Ergonomics Society. Santa Monica, CA: Human Factors and Ergonomics Society.
93) Cooke, N. J. (2011). Synthetic Task Environments. Presentation at A Cyber Situation Awareness Workshop, February 10, 2011, Gilbert, AZ.
94) Cooke, N. J., Rajivan, P., Champion, M., & Shankaranarayanan V.(2011). CyberCog: A Synthetic Task Environment for Studies of Cyber Situation Awareness. Poster presented at ASU's Fourth Annual Workshop on Information Assurance Research and Education, May 4, 2011, Tempe, AZ.
95) Cooke, N. J., Rajivan, P., Champion, M., & Shankaranarayanan V.(2011). CyberCog: A Synthetic Task Environment for Studies of Cyber Situation Awareness. Poster presented at ASU's Innovation Showcase, May 4, 2011, Mesa, AZ.
96) Cooke, N. J., Hosch, C., Banas, S., Hunn, B. P., Staszewski, J., & Fensterer, J. (2011). Expert detection of Improvised Explosive Device behavior. Poster presented at ASU's Innovation Showcase, May 4, 2011, Mesa, AZ.
97) Fouse, S., Cooke, N. J., Gorman, J. C., Murray, I., Uribe, M., & Bradbury, A. (2011). Effects of Role and Location Switching on Team Performance in a Collaborative Planning Environment. Poster presented at the 55th annual meeting of the Human Factors and Ergonomics Society, September 21, Las Vegas, NV.
98) Bruni, S., Schurr, N., Cooke, N., Riordan, B., & Freeman, J. (2011). Designing a Mixed-Initiative Decision-Support System for Multi-UAS Mission Planning, Paper presented at the 55th annual meeting of the Human Factors and Ergonomics Society, September 20, Las Vegas, NV.
99) Champion, M., Rajivan, P., Cooke, N. J., & Jariwala, S. (2012). Team-Based Cyber Defense Analysis. *2012 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support.* March 6-8. New Orleans, LA.
100) Cooke, N. J., Jariwala, S. (2012). CyberCog: A Synthetic Task Environment for Studies of Cyber Situation Awareness. Poster presented at ASU's Fifth Annual Workshop on Information Assurance, April 25, 2012, Tempe, AZ.

101) Champion, M., Rajivan, R., Jariwala, S., Cooke, N. J., & Buchanan, V. Understanding the cyber security task. Poster presented at ASU's Sixth Annual Workshop on Information Assurance, May 1, 2013, Tempe, AZ.

102) Cooke, N.J. & Myers, C. W. (2013). Issues relevant for synthetic teammate-human teammate

interactions in operations of a synthetic unmanned aerial system. Paper presented at the 17th International Symposium on Aviation Psychology. May 6-9, Dayton, OH: Wright State University.

103) Cooke, N. J. (2013). Synthetic Task Environments: Challenges and Opportunities. Paper presented at the 17th International Symposium on Aviation Psychology. May 6-9, 2013, Dayton, OH: Wright State University.

104) Cooke, N., Shope, S., Bradbury, A., and Champion, M. (2014). DEXTAR: A Cyber Security Testbed. Poster presented at the Symposium on Information Assurance Research and Education. October 16, 2014, Arizona State University.

105) Ben-Asher, N., Rajivan, P., Cooke, N., & Gonzalez, C. (2014). Studying the dynamics of cyber-war through instance-base learning and multi-agent modeling. Paper presented at the fourth annual Midwestern cognitive science conference, May 30-31, 2014.

106) Cooke, N. J., Champion, M, Bradbury, A..& Shope, S. M. (2014). DEXTAR: A Cyber Security Testbed. ASU's Symposium on Information Assurance Research and Education, October 16, 2014, Tempe, AZ

107) McNeese, N.J., Fedele, M., Buchanan, V., & Cooke, N. J. (2015). Human Factors Guidance for Intelligence Analysis. Poster presented at the Foresight Partner Meeting, February 19, 2015.

108) Buchanan, V., Lu, Y., Wang, F., Cooke, N. J., Maciejewski, R., & McNeese, N. J. (2015). An Empirical Testbed for Human-in-the-Loop Studies of Collaboration with Visualization, Poster presented at the Foresight Partner Meeting, February 19, 2015.

109) Buchanan, V., Cooke, N. J., & McNeese, N. J. (2015). The Cognitive Science of Intelligence Analysis, Poster presented at the Foresight Partner Meeting, February 19, 2015.

110) Salas, E., Stevens, R., Gorman, J., Cooke, N. J., Guastello, S., & von Davier, A. (2015). What Will Quantitative Measures of Teamwork Look Like in 10 Years? Panel talk presented at the *59th Annual Conference of the Human Factors and Ergonomics Society,* Santa Monica, CA: Human Factors and Ergonomics Society (pp. 235-239).

111) Hinski, S., Cooke, N. J., McNeese, N., Sen, A., & Patel, B. (2016). A Human Factors Approach to Building High-Performance Multi-Professional Cardiac Arrest Teams: Developing a Code Blue Team Performance Metric. Poster presented at the 2016 HFES Health Care Symposium, April 15.

112) Demir, M., McNeese, N. J., & Cooke, N. J. (2016). Team Communication Behaviors of the Human Automation Teaming. Paper presented at the 2016 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support, March 2016.

113) Cooke, N. J., Sen, A., McNeese, N. J., Khera, N., Wordingham, S. E., Arring, N., Nyquist, S. Gentry, A., Tomlinson, B. (2016), Improving Cancer Care Coordination through Team Science. Paper presented at the 2016 Science of Team Science (SciTS) Conference, May 2016.

114) Bradbury, A., Cooke, N. J., Shope, S. M., & Blythe, J. (2016). DEXTAR: Cyber Defense EXercises for Team Awareness Research. Poster presented at the 2016 ASU information Assurance Symposium.

115) Hobbins, S., Cooke, N. J., & Tang, P. (2016). Analyzing Licensee Event Reports for Improved Teamwork and Nuclear Power Plant Safety During Outages. Presentation at the 22nd Semana De Salud Ocupacional, Medellin, Columbia.

INVITED TALKS AND WORKSHOPS

1) Cooke, N. J. (1992). Do people know what they're doing? Investigating the relationship between knowledge and performance. Colloquium given as Henry Jones Invited Speaker, North Carolina State University, November, Raleigh, NC.

2) Cooke, N. J. (1994). Cognitive task analysis and its role in job analysis. Workshop given to the Peace Officer Standards and Training Commission, State of California, July 14 and 15, Sacramento, CA.

3) Gillan, D. J., & Cooke, N. J. (1994). Methods of perceptual and cognitive research applied to interface design and testing. Tutorial presented at CHI '94 - Human factors in computing systems conference, April 24-April 28, 1994, Boston, MA.

4) Cooke, N. J., & Gillan, D. J. (1994). Cognitive methods applied to human factors. Workshop presented at the 38th annual meeting of the Human Factors and Ergonomics Society, October 24-28, Nashville, TN.

5) Cooke, N. J., & Gillan, D. J. (1995). Psychological scaling methods. Workshop given to

Microsoft's Usability Group, January 27, Redmond, WA.

6) Gillan, D. J., & Cooke, N. J. (1995). Methods of cognitive analysis for HCI. Tutorial presented at CHI '95 - Human Factors in Computing Systems Conference, May 7-11, 1995, Denver, CO.
7) Cooke, N. J. (1996). Knowledge elicitation and assessment methods. Workshop presented to Naval Air Warfare Center, Training Systems Division, March 6, Orlando, FL.
8) Cooke, N. J. (1998). KNOT: A tool for representing conceptual structure. Invited talk presented at Sun Break '98: Conference on Organizations, February 6-8, 1998, Department of Management, New Mexico State University, Las Cruces, NM.
9) Schoenfeld, V. S., Shapiro, R. G., Brown, M. L., Jahns, D. W., Andre, A. D., Lund, A. M., Eggemeier, F. T., & Cooke, N. J. (1998). To Ph.D. or not to Ph.D.? That is the question. Panel presentation at the 42nd annual meeting of the Human Factors and Ergonomics Society, October 5-9, Chicago, IL.
10) Cooke, N. J. & Shope, S. M. (1999). CERTT-UAV Task. Invited talk and demonstration presented at the Scaled Worlds Symposium, June 24-27, Athens, GA.
11) Cooke, N. J. (1999). Lessons learned from the trenches: A panel on the application of knowledge methods to training evaluation. Panel presentation with Sward, D., Foltz, P., Gillan, D., Goldsmith, T., & Schvaneveldt, R. at Schvanfest '99, Festschrift in Honor of Roger W. Schvaneveldt, September 10-12, Las Cruces, NM.
12) Cooke, N. J., & Shope, S. M. (2001). The CERTT-UAV Synthetic Task: Validity, Flexibility, Availability. Paper presented at the Air Force Office of Scientific Research Workshop on Team Performance, October 16-17, Fairfax, VA.
13) Cooke, N. J. Eliciting the Knowledge of Individuals and Teams. Invited talk San Diego Center for Patient Safety, Visiting Professor Series, December 12, 2001.
14) Cooke, N. J. (2001). Team Cognition: What Have We Learned? Paper presented at the Air Force Office of Scientific Research Workshop on Team Performance, October 16-17, Fairfax, VA.
15) Cooke, N. J., Gorman, J., & Pedersen, H. (2002). Toward a Model of Organizational Risk. Paper presented at NASA HORM Workshop, June 13-14, Moffett Field, CA.
16) Cooke, N. J. (2002). Cognitive Task Analysis for Teams. On-line CTA Resource Seminar sponsored by Aptima and Office of Naval Research, October 11, US Positioning, Las Cruces, NM.
17) Cooke, N. J. (2002). Diagnosing Team Performance Through Team Cognition, Paper presented at ONR-NMSU Workshop on New Directions in Cognitive Science, October 25-26, New Mexico State University, Las Cruces, NM.
18) Cooke, N. J., Gorman, J., & Pedersen, H. (2002). My Favorite Ways to Measure Team Stuff. Paper presented at NASA HORM Workshop, November 13-14, Moffett Field, CA.
19) Cooke, N.J. (2003). Measuring Collaborative Cognition. ONR Workshop on Collaborative Knowledge Management, January 14-16, College Park, MD.
20) Cooke, N.J. (2003). Assessing Team Cognition. Invited Talk, Los Alamos National Laboratory, June 2, Los Alamos.
21) Cooke, N.J., & Kiekel. P. A. (2003). Team Cognition. AFRL-Rome sponsored seminar on Cognitive Systems Engineering. August 5-7, Hamilton, NY.
22) Cooke, N.J. (2003). Assessing Team Cognition. Invited talk to the Air Force Research Lab. August 28, Mesa, AZ.
23) Cooke, N.J. (2003). Assessing Team Cognition. Invited talks to Arizona State University's Cognition and Behavior Seminar. September 22, 2003.
24) Cooke, N. J. (2003). Types of academic institutions and why you might want to work in one. Paper presented at the APA sponsored workshop on Entering the Academic Marketplace: Advice from Experts at 47th annual meeting of the Human Factors and Ergonomics Society, October 13, Denver, CO.
25) Cooke, N. J. (2003). Playing well with others: Emotional intelligence meets team performance. Paper presented at ETS Workshop: Emotional Intelligence: Knowns and Unknowns, November 15, Princeton, NJ.
26) Cooke, N.J. (2003). Command-and-Control Teams: The Outcome of Cognitive Engineering. Journeys of the Mind Series, November 18, Arizona State University East, Mesa, AZ.
27) Cooke, N.J., & Gorman, J. (2004). Team Communication and Cognition. Invited talk to ONR's Collaboration and Knowledge Management Workshop, January 13-15, San Diego, CA.
28) Cooke, N. J. (2004). Team cognition in distributed command-and-control. Paper presented at AFOSR Cognitive Decision Making Program Review Workshop, March 9-10, Chandler, AZ.
29) Cooke, N. J. (2004). Command-and-Control Coordination: Cognitive Processing at the Team Level.

Paper presented at Human-Technology Integration Colloquium Series, Air Force Research Laboratory, Human Effectiveness Directorate, May 19, WPAFB, Ohio.

30) Cooke, N. J. (2004). Opening Session Overview. Human Factors of UAVs: Manning the Unmanned Workshop, May 24-25, Chandler, AZ.
31) Cooke, N. J. (2004). Team Coordination and UAV Operations. Human Factors of UAVs: Manning the Unmanned Workshop, May 24-25, Chandler, AZ.
32) Cooke, N. J. (2004). Team Cognition, Coordination, and Communication: Effects of Distributed Versus Co-located Environments. Invited Symposium. American Psychological Society 16th Annual Convention, May 28, Chicago, IL.
33) Cooke, N. J. (2004) Design for Coordination and Control. National Academies of Science workshop on Scalable Interfaces for Air and Ground Military Robots, November 11-12, Washington, DC.
34) Cooke, N. J. (2004). Where's the Sharing in Shared Mental Models? Invited talk presented at ARI/ UCF team workshop, December 16, Orlando, FL.
35) Cooke, N.J. (2005). Communication in Team Cognition. Invited talk to ONR's Collaboration and Knowledge Management Workshop, January 13-15, San Diego, CA.
36) Cooke, N.J. (2005). Emergent Team Cognition or What Was Wrong With The US Olympic Basketball Team? Colloquium presented at Texas Tech University, February 7, Lubbock, TX.
37) Cooke, N.J. (2005). Emergent Team Cognition or What Was Wrong With The US Olympic Basketball Team? Colloquium presented at Georgia Tech University, March 30, Atlanta, GA.
38) Cooke, N. J. (2005). Acquisition and Retention of Team Coordination in Command-and-Control: Data, Metrics, and Models. Paper presented at AFOSR Cognitive Decision Making Program Review Workshop, April 18-19, St. Augustine, FL.
39) Cooke, N.J. (2005). Emergent Team Cognition or What Was Wrong With The US Olympic Basketball Team? Colloquium presented at North Dakota State University, April 22, Fargo, ND.
40) Cooke, N. J., Connor, O., & Pedersen, H. (2005). Acquisition and Retention of Team UAV Skills. Paper presented at the Second Annual Human Factors of UAVs Workshop, May 25-26, Mesa, AZ.
41) Cooke, N. J. (2005). Lessons Learned from My Career. Presented at Student Professional Development Day at the 49th annual meeting of the Human Factors and Ergonomics Society, September 26-30, Orlando, FL.
42) Cooke, N.J. (2005). Human Factors of Homeland Security. Overview talk given at the Homeland Security Science Forum sponsored by Human Factors and Ergonomics Society and the Federation of Behavioral, Psychological, and Cognitive Sciences. November 17, Washington, DC.
43) Cooke, N. J. (2006). Cognitive Engineering Research. Invited Talk to ASU Discovery Tours, January 18, 2006.
44) Cooke, N. J. (2006). Automatic Tagging of Macrocognitive Processes Through Communication Analysis. Invited talk to ONR's Collaboration and Knowledge Management Workshop, January 24-26, Cambridge, MA.
45) Cooke, N. J. (2006). Designing for Collaboration. Invited talk at MIT's Humans and Technology Symposium, January 27, Cambridge, MA.
46) Cooke, N. J. (2006). When mixed up teams are good teams: The Development of Coordination in Command and Control Teams. Paper presented at AFOSR Cognitive Decision Making Program Review Workshop, April 21-22, Dayton,OH.
47) Cooke, N. J. (2006). Designing for Collaboration. Invited talk at Ohio State University, Department of Industrial, Welding and Systems Engineering, June 6, Columbus, OH.
48) Cooke, N. J. (2006). Talk to Preparing Future Faculty group at Arizona State University at the Polytechnic Campus, October 7, Mesa, AZ.
49) Cooke, N. J. (2007). Panel Participant for Barbara Ainsworth's Physical Activity, Nutrition, and Wellness doctoral program seminar.
50) Cooke, N. J. & Gorman, J. C. (2007). Automatic Tagging of Macrocognitive Collaborative Processes through Communication Analysis. Invited talk to ONR's Collaboration and Knowledge Management Workshop, January 23, Orlando, FL.
51) Cooke, N. J. (2007). Measuring Team Cognition. Invited talk to the National Research Council Committee on Human Factors, February, 26, Irvine, CA.
52) Cooke, N. J. & Gorman, J. C. (2007). Measuring and Modeling Team Coordination Dynamics. Paper presented at AFOSR Cognitive Decision Making Program Review Workshop, March 22-23, Dayton, OH.
53) Cooke, N. J. (2007). Invited participant of the Macrocognitive Metrics Conference, June 14, Columbus, OH.

54) Cooke, N. J. (2007). Team Cognition. Invited Colloquium, Biomedical Informatics, ASU, November 8, Phoenix, AZ.
55) Cooke, N. J. (2007). Technology for Collaboration: Solution or Problem? Keynote Speaker, World Usability Day Phoenix, November 8, Mesa, AZ.
56) Cooke, N. J. (2007). UAV Podcast hosted by Texas Tech Psychology Department, November 12.
57) Cooke, N. J. (2007). Teams and Coordination. ASU Polytechnic Faculty Brown Bag Series, November 28.
58) Cooke, N. J. & Gorman, J. C. (2008). Automatic Tagging of Macrocognitive Collaborative Processes through Communication Analysis. Invited talk to ONR's Collaboration and Knowledge Management Workshop, January 15, Orlando, FL.
59) Cooke, N. J. & Shope, S. M. (2008). Systems for Understanding & Measuring Macrocognition in Teams: Task Environment Development (SUMMIT-TED). Invited talk to ONR's Collaboration and Knowledge Management Workshop, January 16, Orlando, FL.
60) Cooke, N. J. (2008). Unmanned Aircraft Systems: Human Factors Issues. NTSB Forum on the Safety of Unmanned Aircraft Systems, April 30, 2008, Washington, DC.
61) Cooke, N. J. (2008). Team Cognition. Invited lecture for ASU's Biomedical Informatics Foundation class, April 1 & 3, 2008, Phoenix, AZ.
62) Cooke, N. J., & Myers, C. (2008). Agent-Based Approaches to Macrocognition II: An ACT-R Model of a Synthetic Teammate, June 3, Havre de Grace, MD.
63) Cooke, N. J. (2008). The Wizards of US (Unmanned Systems):Pay Attention to the Humans "Behind the Curtain," September 3, Brest France.
64) Cooke, N. J. & Gorman, J. C. (2008). Measuring Interaction. Invited lecture for ASU's Biomedical Informatics Foundation class, November 18, 2008, Phoenix, AZ.
65) Cooke, N. J. (2008). Measures of Team Cognition in the Context of Unmanned Aerial Systems Ground Crews, December 16, MIT Colloquium, Cambridge, MA.
66) Cooke, N. J. (2009). A Tale of Two SEAs: Lessons Learned from Building Synthetic Environments for Team Research, January 30, 2009. ONR Synthetic Environments for Assessment Workshop, Arlington, VA.
67) Cooke, N. J. (2009). Coal Mining Safety: Failures in Human Systems Integration, Presentation to the Committee on Human Systems Integration, National Research Council, February 12, Washington, DC.
68) Cooke, N. J. (2009). Coordination of unmanned aerial systems ground crews, March 9, 2009. Heterogeneous Unmanned Networked Teams Workshop, Tempe, AZ.
69) Cooke, N. J. (2009). Team Cognition in Unmanned Aerial Vehicles. Invited lecture presented at the 2009 American Psychological Association Annual Convention, August 6, 2009, Toronto, Ontario, CA.
70) Cooke, N. J. (2009). UASs from a Human Factors Perspective. Human Factors of UAVs workshop: AUVSI North America Conference, August 11, 2009, Washington, DC.
71) Cooke, N. J. (2009). Interactive Team Cognition. Keynote at the Cognitive Research Exchange (CoRE) Workshop, Annual Meeting of the Association of Information Systems (AIS), December 15, 2009, Phoenix, AZ.
72) Cooke, N. J. & Hallbeck, S. (2009). Human Factors. Presentation at the Veterans Engineering Resource Center Leaning Event, September 17, 2009, Omaha, NE.
73) Cooke, N. J. (2009). Interactive Team Cognition. Board of Behavioral, Cognitive, and Social Sciences, National Research Council, National Academy of Science, October 8, 2009, Woods Hole, MA.
74) Cooke, N. J. (2009). Unmanned Aerial Systems: Pay Attention to the Humans "Behind the Curtain." Presentation to the Good Ol' Boys (retirement community), October 15, 2009, Scottsdale, AZ.
75) Cooke, N. J. (2009). The Art of Getting Published. Presentation at Student Development Day, Annual Meeting of the Human Factors and Ergonomics Society, October 19, 2009, San Antonio, TX.
76) Cooke, N. J. (2009). Human Factors of Unmanned Aerial Systems. Presentation at the Stakeholders Workshop for the Proposed Unmanned Aerial System Center for Simulation and Training in Mesa, AZ. October 23, 2009, Chandler, AZ.
77) Cooke, N. J. (2009). The Science of Psychology, Presentation to SRP Student Group, November 4, 2009, Mesa, AZ.
78) Cooke, N. J. (2009). Applied Cognitive Psychology, Presentation to Gilbert High School Career

Development Class, November 13, 2009, Gilbert, AZ.

79) Cooke, N. J. (2009). Interactive Team Cognition. Keynote at the Cognitive Research Exchange (CoRE) Workshop, Annual Meeting of the Association of Information Systems (AIS), December 15, 2009, Phoenix, AZ.
80) Cooke, N. J. (2010). Interactive Team Cognition. Invited lecture at Charles River Analytics, March 29, 2010, Cambridge, MA.
81) Cooke, N. J. (2010). Interactive Team Cognition. Invited lecture at MIT Lincoln Labs, March 30, 2010, Cambridge, MA.
82) Cooke, N. J. (2010). Human Systems Integration, Team Cognition, and Designing for Collaboration. Biomedical Informatics class lecture, April 22, 2010, Phoenix, AZ.
83) Cooke, N. J., Rajivan, P., Venkatanarayanan, S. (2010). A Testbed for Studies of Team Cognition in the Cyber Security Domain. Invited panel lecture at ASU's Third Annual Workshop on Information Assurance Research and Information, May 5, 2010, Tempe, AZ.
84) Cooke, N. J., Rajivan, P., Venkatanarayanan, S. (2010). A Testbed for Studies of Team Cognition in the Cyber Security Domain. Invited talk at ARO-MURI on Cyber Situation Awareness Review Meeting, August 23-24, 2010, UCSB, Santa Barbara, CA.
85) Cooke, N. J. (2010). The Case of Bored Teams. Invited panel presentation at 54th Annual Meeting of the Human Factors and Ergonomics Society, September 28. 2010, San Francisco, CA.
86) Cooke, N. J. (2011). Human Factors and Healthcare. Invited panelist for Continuing Quality in Parallel Circuits: HSR&D and VERC Collaboration, HSR&D National Meeting, National Harbor, MD.
87) Cooke, N. J. (2011). A Human Systems Integration Approach to Integrating "Unmanned" Systems into the National Airspace. Presented at Human Factors UAS in the NAS workshop, May 23, 2011, Washington, DC.
88) Cooke, N. J. (2011). Interactive Team Cognition. Presented at SMACS Brown Bag, August 31, 2011, Arizona State University, Mesa, AZ.
89) Cooke, N. J., Rajivan, P., Champion, M., & Jariwala, S. (2011). Applying cognitive engineering to cyber situation awareness. Presented at ARO MURI Review, September 8, 2011, George Mason University, Fairfax, VA.
90) Cooke, N. J. (2011). A Panel Session on Human-Automation Challenges for the Control of Unmanned Aerial Systems. Invited panelist for the 55th annual meeting of the Human Factors and Ergonomics Society, September 22, 2011, Las Vegas, NV.
91) Cooke, N. J. (2012). Combining teams with technology to solve global challenges. ASU President's Community Enrichment Program, ASU Poly, March 27, 2012.
92) Cooke, N. J. (2012). Lightening the Information Load through Team Cognition. Naval Research Advisory Committee on Lightening the Information Load, July 26, 2012, San Jose, CA.
93) Cooke, N.J., (2014). HFES Fellows Panel. *At the 58th Annual Conference of the Human Factors and Ergonomics Society,* Santa Monica, CA: Human Factors and Ergonomics Society.
94) Cooke, N. J. (2014). Simulations as research testbeds. Modeling and Simulation Conference, March 12-13, 2014, Scottsdale, AZ.
95) Cooke, N. J. (2014). Five out of five stars: Writing to the Reviewer. Panelist, Arizona State University, March 28.
96) Cooke, N. J. (2015). How the Science of Teams Can Inform Team Science. Invited Lecture, Team Science Retreat, Wake Forest School of Medicine of Wake Forest Baptist Medical Center, March 13, Wake Forest, NC.
97) Cooke, N. J. (2015). Enhancing the Effectiveness of Team Science. Briefing at the National Science Foundation, April 22, Washington, DC.
98) Cooke, N. J., Cummings, J, Fiore, F., Hall, K., Jackson, J., Kozlowski, S., Olson, J., Stokols, D., and Hilton, M. (2015). Featured Panel: National Academy of Sciences Report: SciTS. Science of Team Science Meeting, National Institutes of Health, June 3, Bethesda, MD.
99) Cooke, N. J. (2015). Keynote Lecture: Interactive Team Cognition: Focusing on Team Dynamics, 14th European Congress of Sport Psychology, July 18, Bern Switzerland.
100) Cooke, N. J. (2015). What is Human Systems Integration and How It Does and Does Not Relate to Human Factors and Ergonomics? Keynote Address. Meeting of the Houston Chapter of the Human Factors and Ergonomics Society, May 29, Houston, TX.
101) Cooke, N. J. (2015). Enhancing the Effectiveness of Team Science. Briefing at the National Academies, September 18, Washington, DC.

102) Cooke, N. J. (2015). SciTS NRC Report Review: Key Challenges Facing Team Science, Team Science Summit, Arizona State University, September 25, Tempe, AZ.

103) Cooke, N. J. (2015). Tackling Difficult Research Problems via Application of Transdisciplinary Methods. Panel presentation at APLU Annual Meeting, November 15, Indianapolis, IN

104) Cooke, N. J. (2016). Growth of Team Science: Challenges and Opportunities. Panel Presentation at AAAS 2016, February 12, Washington, DC.

105) Cooke, N. J. (2016). Interactive Team Cognition: From Remotely Piloted Aircraft Systems Control to Healthcare. Invited Seminar talk at University of Wisconsin-Madison, March 4, 2016.

106) Cooke, N. J. (2016). Measuring Team Performance. Invited talk to the National Academies of Sciences, Engineering, and Medicine's Board on Human System Integration, April 20, 2016.

107) Cooke, N. J. (2016). Interactive Team Cognition: Making Teams Work. Invited Seminar at the Georgia Institute of Technology, November 15, 2016.

108) Cooke, N. J. (2016). Interactive Team Cognition: Making Teams Work. Invited talk to the Southern Ohio Chapter of the Human Factors and Ergonomics Society, December, 8, 2016.

WORKSHOPS ORGANIZED

Cooke, N. J. & Pringle, H. (2004). Human Factors of UAVs Workshop: Manning the Unmanned. CERI hosted workshop, sponsored by AFRL, AFOSR, NASA, and US Positioning, May 24-25, Chandler, AZ.

Cooke, N. J. & Pringle, H. (2005). Second Annual Human Factors of UAVs Workshop: Manning the Unmanned. CERI hosted workshop, sponsored by AFRL, AFOSR, FAA, and Microanalysis and Design, May 25-26, Mesa, AZ.

Chair of Team Cognition session for DARPA Augmented Cognition workshop, July, 2005, Las Vegas, NV.

Cooke, N. J. & Andrews, D. (2006). Third Annual Human Factors of UAVs Workshop: Manning the Unmanned. CERI hosted workshop, sponsored by AFRL, AFOSR, FAA, & Research Integrations, May 24-26, Mesa, AZ.

Cooke, N. J., Pedersen, H.K., & Winner, J. L. (2007). Fourth Annual Human Factors of UAVs Workshop: Manning the Unmanned. CERI hosted workshop, sponsored by AFRL, AFOSR, L3 Link, & Research Integrations, May 21-23, Chandler, AZ.

Cooke, N. J. (2008). Fifth Annual Human Factors of UAVs Workshop: Manning the Unmanned; Human Factors Issues in Imagery Analysis Using Unmanned Aerial Vehicles, CERI hosted workshop, sponsored by AFRL, May 15, 2008, Apache Junction, AZ.

Cooke, N. J. (2009). Sixth Annual Human Factors of UAVs Workshop: AUVSI North America Conference, August 11, 2009, Washington, DC

Cooke, N. J., & Gorman, J. C. (2009). Communications Analysis for Assessing Collaboration. Workshop at the 53rd Annual Meeting of the Human Factors and Ergonomics Society, October 19, 2009, San Antonio, TX.

Cooke, N. J. & Shope, S. S. (2009). UAS Simulation and Training Center Stakeholders Workshop, October 23, 2009, Chandler, AZ.

Cooke, N. J. (2010). Communication Analysis Workshop. February 16-18, Tempe, AZ.

Cooke, N. J., & Gorman, J. C. (2010). Communications Analysis for Assessing Collaboration. Workshop at the 54th Annual Meeting of the Human Factors and Ergonomics Society, September 27, 2010, San Francisco, CA.

Cooke, N. J., McNeese, M, & Hall, D. (2011). A Cyber Situation Awareness Workshop. February 8-11, Gilbert, AZ.

Cooke, N. J. (2013). ARO Cyber Situation Awareness MURI Review, October 2013.

Cooke, N. J. (2014). Remotely Piloted Aerial Systems: A Summit, August 4-5, 2014, Dayton, OH.

SCIENCE ADVOCACY

APA Science Advocacy Training Workshop, Human Factors and Aviation Safety Research, July 18-19, 1999, Washington, D.C.

APA Science Advocacy Training Workshop, Psychological Science and the Military, September 27-29, 2003, Washington, D.C.

Homeland Security Science Forum sponsored by Human Factors and Ergonomics Society and the Federation of Behavioral, Psychological, and Cognitive Sciences. November 17, 2005, Washington, DC.

White House Office of Science and Technology Policy Briefing on Human Factors of UAVs, April 6. 2006.

APA 2007 Science Leadership Conference: Adventures in Advocacy: Training the Civic Scientist, October 13-15, 2007, Washington, DC.

American Psychological Association facilitated Congressional meetings on Unmanned Aerial Systems in the National Airspace and human systems integration, August 13, 19, 2014, Washington, DC.

Visit to Congressman Matt Salmon's Office on behalf of the American Psychological Association's *Stand for Science* program., April 22, 2016, Gilbert, AZ.

Congressional Briefing speaker on Autonomous Systems and the Role of the Human, May 31, 2016, Washington, DC.

NOMINATION FORM FOR IEA FELLOW AWARD 2017

For use by IEA Member Societies to nominate an individual for the IEA Fellow Award

Submission Instructions:

Please complete this form electronically and e-mail as an attachment (together with other attachments such as CV, letters of support, etc.) to: **PastPres@iea.cc and vpsg@iea.cc**

Deadline: April 30, 2017

Nominee for IEA Fellow: Knut Inge Fostervold

Person submission nomination: NES President Kasper Edwards

The Nomination:

1. Eligibility

Full Name (and title):
Knut Inge Fostervold, dr. psychol./Associate professor.

Address:
Department of psychology, University of Oslo
Box 1094, Blindern. N-0317 Oslo, Norway

E-mail:
k.i.fostervold@psykologi.uio.no

Tel:
+47 22 84 50 57 / +47 90 94 78 27

Membership IEA-associated society:

Full member of the Norwegian Society for Ergonomics and Human Factors (NEHF) since 1996.

International Appointment

2015: Conference Chair and Head of Organizing Committee NES2015 - Nordic Ergonomics Society 47nd annual conference 01 – 04 November 2015. Lillehammer, Norway.
2015: IEA Council member, Nordic representative, International Ergonomics Association.
2014 –2015: Board member, Nordic Ergonomics and Human Factors Society.
2012-13: Head – The Nordic Visual Ergonomics Network
2012: Council member, Federation European Ergonomics Societies (FEES)
2010: Conference Chair and Head of Organizing Committee, NES2010 - Nordic Ergonomics Society 42nd annual conference 06 – 08 September 2010. Stavanger, Norway.
2009: IEA Council member, Nordic representative, International Ergonomics Association.

2005: Conference Chair and head of Scientific Committee, NES2005 - Nordic Ergonomics Society 37th annual conference 10-12 October 2005. Oslo, Norway
2003 – 2006 Council member, Federated European Ergonomics Societies (FEES)
2000 – 2003 Representative for the Nordic Ergonomics Society in the development committee of the Federated European Ergonomics Societies (FEES)
2000. IEA Council member, Nordic representative, International Ergonomics Association.
2000. Conference Chair and Head of Organizing Committee, NES2000 - Nordic Ergonomics Society 32nd annual conference 23 - 25. October 2000. Trondheim, Norway
1997 – 2006 Board member, Nordic Ergonomics Society.

National appointments
2016 – Board member, Norwegian Society for Ergonomics and Human Factors
2013 – 2016: President, Norwegian Society for Ergonomics and Human Factors
2007 – 2011: Chief advisor, Norwegian Society for Ergonomics and Human factors
2004 – 2006: President, Norwegian Ergonomics Society.
1997 – 2000: President, Norwegian Ergonomics Society
1996 – 1997: Board member, Norwegian Ergonomics Society

2. Distinction
See appended CV and list of publications.

Endorsement by Nordic Ergonomics and Human Factors Society:
The Nordic Ergonomics and Human Factors Society hereby endorse Knut Inge Fostervold as IEA Fellow. Knut Inge Fostervold has through his career contributed to advancing human factors and ergonomics in both practice and research.

Knut Inge Fostervold has been very active member of the NES board for years. Knut Inge Fostervold has organized the NES conference no less than four times (2000, 2005, 2010, 2015). As member of NES he has served as IEA council representative. He has further served as president of the Norwegian Ergonomics Society for 9 years.

Knut Inge Fostervold has advanced the field of visual and office ergonomics and sought to connect ergonomics to other scientific fields such as psychology which has shaped the discipline.

Knut Inge Fostervold is dedicated to advancing ergonomics and human factors and we believe he rightly deserves to become an IEA Fellow. We also believe the IEA fellowship is an important peer recognition that will support his future work and career and in turn benefit the IEA and ergonomics.

President of NES Kasper Edwards

Letters of support from IEA fellows (attached)

- Pierre Falzon, Professor, Ergonomics and neurosciences of work, Director, Research Center on Work and Development, Conservatoire national des arts et métiers, Paris
- Michelle M. Robertson, Research Scientist, Liberty Mutual Research Institute for Safety
- Jan Dul, Professor of Technology and Human Factors Member of Human Factors.NL, Erasmus University Rotterdam
- Clas-Håkan Nygård, Professor, School of Health Sciences , University of Tampere

CV: Associate professor Knut Inge Fostervold

Department of Psychology, University of Oslo, Norway

Present position:
2007 - Associate professor, Department of psychology, University of Oslo.

Previous academic positions:
2004-2007. Associate professor, Lillehammer University College.
2002-2004. Associate professor, Department of Psychology, University of Oslo.
1998-2002. phd-candidate, Department of Psychology, University of Oslo.
1992-1998. Research Fellow. The Man-Machine-Systems Programme, Oslo Innovation Center.

Academic degree (university and year):
Dr. psychol. 2003. Department of Psychology, University of Oslo.
Cand. Psychol. (Licensed psychologist) 1992. Department of Psychology, University of Oslo.

Educational appointments:
2016 – Head of MAKS section (Scientific methods, social psychology, community psychology, Work and Organizational psychology) Department of Psychology, University of Oslo, Norway.
2013. Director for the Bachelor and Masters programs in Psychology, Department of Psychology, University of Oslo, Norway
2009 – 2011. Director for the Bachelor and Masters programs in Psychology, Department of Psychology, University of Oslo, Norway
2008 – 2009. Director of the Professional Psychology program (licensed psychologists), Department of Psychology, University of Oslo, Norway.
2007: Member of the development committee of a master program in ergonomics and universal design, Lillehammer University College.
2004-2006: Member of the interdisciplinary development committee of a master program in scientific methods, Lillehammer University College.
2005: Member of the development committee of a master program in user centered design Gjøvik University College.
2000- 2002. Member of the development committee of a master program in ergonomics, Norwegian Ergonomics Society.

Number of completed PhD-candidates supervised the last 5 years: 3

Reviewing

Scientific Journals.
Applied Ergonomics, BMC - Public Health, Ergonomics, European Psychologist, International Journal of Environmental Research and Public Health, International Journal of Industrial Ergonomics, Ophthalmic and Physiological Optics, Perceptual and Motor skills, Scandinavian Journal of Psychology, Tidsskrift for Norsk Psykologforening.

Research proposals
The Icelandic Research Fund: evaluation of research proposals.
Peder Sather Center for Advanced Study, Berkeley University: evaluation of research proposals.
The Research Council of Norway: evaluation of research proposals.
Research reports published by the National Research Centre for the Working Environment, Denmark.

Publication list:

Associate professor Knut Inge Fostervold

Department of Psychology, University of Oslo, Norway

Present position: Associate professor, Department of psychology, University of Oslo.

International Publications:

International journals:

Steinbakk, Renata Torquato; Ulleberg, Pål; Sagberg, Fridulv & Fostervold, Knut Inge (2016). Analysing the influence of visible roadwork activity on drivers' speed choice at work zones using a video-based experiment. *Transportation Research Part F: Traffic Psychology and Behaviour, 44*, 53- 62 . doi: 10.1016/j.trf.2016.10.003

Fostervold, Knut Inge; Watten, Reidulf G. & Volden, Frode Strand (2014). Evolutionary adaptations: Theoretical and practical implications for visual ergonomics . *Work : A journal of Prevention, Assesment and rehabilitation, 47*(3), 387- 397. ISSN 1051-9815. doi: 10.3233/WOR-131771

Fostervold, Knut Inge (2012). Cognitive components and the ability to ignore and adapt to irrelevant stimuli: a key factor in open plan offices? *Work : A journal of Prevention, Assesment and rehabilitation*, *41*, s 6024- 6030. ISSN 1051-9815doi: 10.3233/WOR-2012-1055-6024

Bjørnstad, Anne Lise; Fostervold, Knut Inge & Ulleberg, Pål (2011). Effects of Cultural Diversity on Trust and its Consequences for Team Processes and Outcomes in Ad Hoc Distributed Teams. *Scandinavian Journal of Organizational Psychology*, *3*(2), s 3- 15 ISSN 1891-473X

Halberg, Anne-Marie; Teigen, Karl Halvor & Fostervold, Knut Inge (2009). Maximum vs. minimum values: Preferences of speakers and listeners for upper and lower limit estimates. *Acta Psychologica*, *132*(3), 228- 239. ISSN 0001-6918. doi: 10.1016/j.actpsy.2009.07.007

Fostervold, KI & Nersveen, Jonny (2008). Proportions of direct and indirect indoor lighting - The effect on health, well-being and cognitive performance of office workers. *Lighting Research and Technology*, *40*(3), 175- 200. ISSN 1477-1535. doi: 10.1177/1477153508090917

Watten, Reidulf G.; Fostervold, Knut Inge; Kleiven, Jo; Fauske, Halvor & Volden, Frode (2008). Gender Profiles of Internet and Mobile Phone Use among Norwegian Adolescents . *Seminar.net : Media, technology and lifelong learning*, *4*(3), 1- 10. ISSN 1504-4831.

Teigen, Karl Halvor; Halberg, Anne-Marie & Fostervold, Knut Inge (2007). More than, less than, or between: How upper and lower bounds determine subjective interval estimates . *Journal of Behavioral Decision Making, 20*, 179- 201. ISSN 0894-3257.

Teigen, Karl Halvor; Halberg, Anne-Marie & Fostervold, Knut Inge (2007). Single- Limit Interval Estimates as Reference Points . *Applied Cognitive Psychology, 21*(3), 383- 406. ISSN 0888-4080.

Øvergård, Kjell Ivar; Fostervold, Knut Inge; Bjelland, Hans Vanhauwaert & Hoff, Thomas (2007). Knobology in use: an experimental evaluation of ergonomics recommendations. *Ergonomics*. *50*(5), s 694- 705 . ISSN 0014-0139. doi: 10.1080/00140130601168046

Fostervold, Knut Inge; Aarås, Arne & Lie, Ivar (2006). Work with visual display units: Long-term health effects of high and downward line-of-sight in ordinary office environments. *International Journal of Industrial Ergonomics. 36*(4), s 331- 343 ISSN 0169-8141.

Fostervold, Knut Inge (2003). VDU-work with downward gaze: the emperor's new clothes or scientifically sound? *International Journal of Industrial Ergonomics*. 31(3), s 161- 167. ISSN 0169-8141.

Fostervold, Knut Inge; Buckmann, Erik & Lie, Ivar (2001). VDU-screen filters: Remedy or the ubiquitous Hawthorne effect? *International Journal of Industrial Ergonomics. 27*(2), s 107- 77. ISSN 0169-8141.

Aarås, Arne; Fostervold, Knut Inge; Ro, Ola; Thoresen, Magne & Larsen, Stig (1997). Postural load during VDU work. A comparison between various work postures. *Ergonomics. 40*(11), s 1255- 1268. ISSN 0014-0139.

International books and book chapters

Fostervold, Knut Inge; Husby, Thor; Olsen, Kai. (Eds.). (2010). *Proceedings of NES 2010 "Proactive Ergonomics Implementation of ergonomics in planning of jobs, tasks, systems and environments".* Oslo, Norway: Norwegian Society for Ergonomics and Human Factors 2010. ISBN: 978-82-995747-2-3.

Larsen, P.J., Lillelien, E., Fostervold, K.I., Mjøs, T. & Berg, M.O. (2010). Energy efficient lighting systems – consequenses for environment, health and human factors. In, (CIE) *Selected papers of the Light and Lighting Conference with Special Emphasis on LEDs and Solid State Lighting* (pp 79-88). ISBN: 978 3 901906 79 4.

Fostervold, Knut Inge & Ankrum, Dennis R. (2008). Visual ergonomics for children. In Rani Lueder & Valerie J Berg Rice (eds.), *Ergonomics for children designing products and places for toddler to teens.* pp. 65 – 108, Taylor &Francis. ISBN 97-80415304740.

Veiersted, B., Fostervold, K.I., Gould, K.S. & Bakkeli, W. (Eds). (2005). *Ergonomics as a tool in future development and creation*. Proceedings of NES2005 - Nordic Ergonomics Society 27th annual conference 10-12 october 2005. Göteborg : Nordic Ergonomics Society. ISBN: 82-995747-1-4

Fostervold, K.I. og Endestad, T. (Eds) (2000). *At the gateway to cyberspace -ergonomic thinking in a new millennium*: Proceedings from Nordic Ergonomics Society 22th annual conference, Britannia hotel, Trondheim, Norway, 23 - 25. oktober 2000. Göteborg: Nordic Ergonomics Society. ISBN: 82-995747-0-6.

Lie, Ivar; Watten, Reidulf G. & Fostervold, Knut Inge (1998). Accommodation/vergence/-fixation disparity and synergism of head, neck and shoulders, In O. Frantzén; H. Richter

& L. Stark (eds.), *Accommodation/-Vergence Mechanisms in the Visual System*. Birkhäuser Verlag, Basel.

Aarås, A., Fostervold, K.I. Thoresen, M. and Larsen, S. (1995). Postural Load at VDU work. A comparison between different workplace design. In: Kumashiro, M. (ed), *The Paths to Productive Ageing,* Taylor & Francis, London. pp. 151-156.

Lie, I. & Fostervold, K.I. (1995). VDT - Work With Different Gaze Inclination. In: A. Grieco, G. Molteni, B. Piccoli and E. Occhipinti (Eds.), *Work with Display Units 94, Selected papers of the fourth international scientific conference on work with display units.* (pp. 137-142), Amsterdam, Netherlands: Elsevier Science.

International conference proceedings with full paper.

Mysen, Mads; Hammer, Hugo Lewi; Nersveen, Jonny; Fostervold, Knut Inge. Kampen School - Evaluation of pupils' performance and perceived health and well-being before and after school retrofitting. (2012). In, *Healthy Buildings 2012 : 10th International Conference 8-12 july 2012 Brisbane, Australia. Queensland: Queensland University of Technology* ISBN 978-1-921897-40-5

Fostervold, K.I. & Husby, T (2012). Lighting quality in learning environments: premises for new guidelines. In, A.B. Antonsson & Hägg. G.M. (eds.), *Proceedings NES2012. Ergonomics for sustainability and growth. Saltsjöbaden, Sweden, August 19-22. Stochholm:* KTH Royal Institute of Technology, School of Technology and Health, Division of Ergonomics. ISBN: 978-91-637-1150-3.

Nilsen O.V. Fostervold, K.I. & Koren, P. (2012). Stress and systems in the work environment. In, A.B. Antonsson & Hägg. G.M. (eds.), Proceedings NES2012. *Ergonomics for sustainability and growth. Saltsjöbaden, Sweden, August 19-22. Stochholm*: KTH Royal Institute of Technology, School of Technology and Health, Division of Ergonomics. ISBN: 978-91-637-1150-3.

Watten, R. & Fostervold, Knut Inge (2010). Some visual and peceptual factors in universal design. In, K.I. Fostervold, T. Husby & K. Olsen (eds.). *Proceedings of NES 2010 "Proactive Ergonomics Implementation of ergonomics in planning of jobs, tasks, systems and environments".* Oslo, Norway: Norwegian Society for Ergonomics and Human Factors 2010. ISBN: 978-82-995747-2-3.

Fostervold, K.I., Larsen, P.J., Lillelien, E., Mjøs, T. & Berg, M.O. (2009). Retrofitting lighting installations: Consequences for environment, health and human factors. In, *Proceedings of the 17th Triennial Congress of the International Ergonomics Association, IEA 2009,* Beijing, China.

Mysen, M., Fostervold, K.I. and Schild, P.G. (2006). An intervention study of the impact of supply air filters on perceived air quality in a primary school. *Proceedings of Healthy Buildings 2006, Lisbon, 06-08 June.*

Halberg, A.M. and Fostervold K.I. (2005). Person - environment fit: a modern organizational theory that bridge the needs of the organization and their employees. In: B. Veiersted, K.I. Fostervold, K.S. Gould and W. Bakkeli (eds). *Ergonomics as a tool in future development and creation. Proceedings of NES2005 - Nordic Ergonomics Society 27th*

annual conference 10-12 october 2005 . (pp. 180-183). Göteborg: Nordic Ergonomics Society.

Fostervold, K.I. (2004). Open-plan offices: a current review In, K. B. Olsen & O.J. Teller (eds.), *Working Life Ethics, Nordic Ergonomics Society 36th Annual Conference Kolding, Denmark 16 - 18 Augus*t. Kolding, Denmark: Nordic Ergonomics Society and Danish Society for Work Environment.

Fostervold, K.I. (2003). VDU-work and the preferred line-of-sight after long term exposure to different monitor placements. In: D. Harris, V. Duffy, M. Smith & C. Stephanidis (eds.), *Human-Centred Computing. Cognitive, Social and Ergonomic Aspects. Volume 3 of the proceedings of HCI international 2003, Crete, Greece,* (pp. 28-32). London: Lawrence Erlbaum.

Fostervold, K.I. (2001). Near-work and visual ecology: is there a connection. In: Korsnes, M. S., Raftopoulos, A. & Demetriou, A. (eds.), *Studies of the mind. Proceedings of the first Norwegian-Cypriot meeting on cognitive psychology and neuropsychology. Nicosia, may 31-June 1. (pp. 11-16),* Nicosia, Cyprus University Press.

Fostervold, K.I. (2000). Vision And Body, Integrated Systems In Systemic Interplay. *Ergonomics for the New Millennium. International Ergonomics Association, 14. Triennial Congress (pp. 4-746 – 4-749),* San Diego, California, USA

Fostervold, K.I. and Lie. I. (1999). Variation of sitting posture in work with VDUs. The effect of downward gaze. In, H.J. Bullinger, and J. Ziegler, (eds.), *Human Computer Interaction: Ergonomics and User Interfaces Volume 1 HCI International'99*, (pp. 56-60), München Tyskland.

Fostervold, K.I. and Lie, I. (1997). The Ecological Viewpoint –A new Ergonomic Construct, In, Miyamoto, H., Saito, S., Kajiyama, M. & Koizumi, N. *Proceedings of the fifth International Scientific Conference on Work With Display Units*, (pp.147-148), Tokyo: NORO Ergonomics Laboratory, School of Human Sciences, Waseda University.

Lie, I., Fostervold, K.I., Aarås, A. and Larsen, S. (1997). Gaze Inclination and Health in VDU-operators, In, Seppäla, P., Luopajärvi, T., Nygård, C.H. & Mattila, M (Editors) From Experience to Innovation. *Proceedings of the 13th Triennial Congress of the International Ergonomics Association. Vol.5, Tampere, Finland*, (pp.50-52), Helsinki: Finnish Institute of Occupational Health.

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Leiden, March 28, 2017

Dear Board of the NES,
In this letter I would like to express my full support for the nomination of Knut Inge Fostervold to become a Fellow of the International Ergonomics Society (IEA). For many years Knut Inge has been a reliable partner in the development of ergonomics in different (inter)national settings. Besides being a leading researcher and thinker in the field of visual ergonomics, his broad insights on the role of ergonomics in society and his effort to connect ergonomics to other fields (e.g., psychology) has helped to shape our discipline and profession. He has been a driving force in the promotion and professionalization of ergonomics.
Kind regards,

Jan Dul
Professor of Technology and Human Factors
Member of Human Factors.NL (formerly Dutch Ergonomics Society)

Rotterdam School of Management
Erasmus University Rotterdam
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Centre de recherche sur le travail et le développement le cnam

Paris, April 18, 2017

I am pleased to endorse the nomination of Knut Inge Fostervold for an IEA Fellowship. I first met Knut in 2000, at a meeting of the IEA Council in San Diego. He was then representing the Nordic Ergonomics Society (NES), I was representing the SELF and I was elected that same year as Secretary General of the IEA. Since then, I have regularly interacted with him in various occasions, during IEA congresses, at meetings of the IEA Council and at NES conferences.

Knut has been very much involved in the development of ergonomics at an international level. In Scandinavia, he served as a board member and President of the Norwegian Ergonomics Society (three times, nine years!), as a board member of NES, as chair of NES conferences (4 times) and as a board member of NES for more than ten years. At the European level, he served as a board member of FEES for seven years. An impressive record…

To me, this dedication to HFE amply justifies its nomination as IEA Fellow, a nomination that I am glad to support.

Pierre Falzon

Professor, Ergonomics and neurosciences of work
Director, Research Center on Work and Development
Conservatoire national des arts et métiers, Paris

Past President of the IEA

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To the IEA Award Committe

Endorsement for an IEA Fellowship to Knut-Inge Fostervold, Norwegian Society for Ergonomics and Human Factors.

I learned to know Dr Fostervold in mid 90´s in the Nordic Ergonomics Society (NES) and have had contacts with him ever since that. Dr Fostervold was very active in the foundation of the Federation of European Ergonomics Society (FEES) and has been an active member of NES board for years. Fostervold has been extremely active by organizing (chair of the organizing committee) the International Annual NES conference four times (2000, 2005, 2010, 2015). He has been a Nordic representative in the IEA council several times. He is an active researcher in important ergonomics topics (psychology, visual ergonomics) as a faculty member at Oslo University. I´m very happy to endorse the IEA Award committee to nominate Dr Fostervold as an IEA Fellow.

Tampere 29.4.2017

Clas-Håkan Nygård, Professor

IEA Fellow (2012)

Past president of the Finnish Ergonomics Society, the Nordic Ergonomics Society, secretary of the Federation of European Ergonomics Society and representative for NES in IEA council

Liberty Mutual.
RESEARCH INSTITUTE FOR SAFETY

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International Ergonomics Association
IEA Awards Chair: Professor Dr. Eric Min-yang Wang
Ergonomics Society of Taiwan
Department of Industrial Engineering and Engineering Management
National Tsing Hua University

Dear IEA Awards Chair and Committee,

The intent of this letter is to endorse the nomination of Professor Dr. Knut Inge Fostervold for IEA Fellow. Given my current role as Research Scientist at the Liberty Mutual Research Institute for Safety, where we conduct business relevance research in a peer-reviewed environment pertaining to occupational safety and health concerns, as well being a Standing Committee Chair for the IEA, I believe that I am in position to fully support the nomination of Professor Fostervold to be inducted as an IEA Fellow. I also lecture at the Harvard School of Public Health in the area of human factors and ergonomics as well as conduct research in the area of computer and office ergonomics, which all provides an appropriate perspective and background to best understand the unique research and design contributions of Dr. Fostervold with regards to his work on the theoretical and practical implications of visual ergonomics. Our scientific interactions consisted of serving on invited panels regarding the effects of office design and workload on the cognitive and physical abilities of knowledge and computer workers. Professor Fostervold innovative research and publications in the area of visual and office ergonomics has made significant, international scientific contributions in applying work systems approaches to the design of office environments to enhance employee's well-being, quality of work life and performance.

Regarding Professor Fostervold 20 years of professional and community service at both the national and international level, including serving as President and board member of the Norwegian Ergonomics Society (NES) and board member of the Federated European Ergonomics Society (FEES), demonstrates his commitment and dedication to the human factors and ergonomics profession and society at large. He also served as a delegate representing NES at several of the IEA EC meetings over the years, further providing substantial evidence of his professional service. Furthermore, he led the efforts to chair four successful international conferences hosted by NES, supported and endorsed by IEA.

On a personal note, I have had the opportunity to collaborate with Dr. Fostervold in several capacities from participating on international scientific panels as well as working on IEA Executive Council initiatives, specifically outreach activities. Being aware of Professor Fostervold's dedication to the cause of Human Factors/Ergonomics, especially as reflected in NES and FEES initiatives, as well as internationally throughout IEA provided the impetus to submit this nomination package for consideration to be recognized and inducted as an IEA Fellow.

As a supporter for Dr. Fostervold IEA Fellow nomination, I kindly request the IEA Fellow selection committee to consider Prof. Dr. Knut Fostervold for this prestigious IEA recognition. Given Dr. Fostervold legacy in conducting research in visual and computer ergonomics and the theoretical basis for designing office workplaces demonstrates his exceptional scientific abilities and practioner contributions along with his exceptional dedication and outstanding service to the human factors and ergonomics profession and society provides the evidence to support being recognized as an IEA fellow.

In closing, it is without hesitation that I strongly support Dr. Fostervold for IEA Fellow. His demonstrated scholarly excellence in conducting theoretical and applied visual and office ergonomics as related to office work systems design and have had a profound influence on doctoral students and other researchers around the world. Moreover, his Human Factors/Ergonomics community outreach activities are internationally well recognized. Thus, it is evident that Prof. Dr. Fostervold is well qualified to be considered for becoming an IEA Fellow. Thank you for considering him for IEA Fellow and the committee's effort in presenting IEA Fellowships.

Sincerely,

Michelle M. Robertson, Ph.D., CPE
Research Scientist
Centre of Behavioral Sciences
Liberty Mutual Research Institute for Safety
Hopkinton, MA 01702 USA

Nomination for IEA Fellow Award 2017

Nominee for IEA Fellow
Name: Mr. Martti Launis
Address: Lehtotie 1, 00630 Helsinki, Finland
Email: martti.launis@gmail.com
Tel: +358 40 7526 348

Person submitting nomination
Name: Risto Toivonen
Address: Hietastentie 18, 37800 Akaa, Finland
Email: risto@ergonomiaa.fi
Tel: +358 44 2979 229

The Nomination

1. Eligibility

Martti Launis has been a member of the Finnish Ergonomics Society ERY (which is a part of the Nordic Ergonomics and Human Factors Society NES) since its establishment 1984. He has served the society as the president for 4 years from 2006 to 2010. He has been a member of the European standardisation committees CEN TC/122 WG1 Anthropometry and CEN TC/122 WG2 Ergonomic design principles from 1995 to 2009, and have had an active role in these committees as project leader and in drafting the standards documents. He has also been the representative of the Finnish Ergonomics Society in the Council of the Federation of European Ergonomics Societies FEES from 2006 to 2016, and a member of its Communication and Promotion Committee from 2007 to 2016. Martti Launis has acted as a course leader and lecturer on the international courses on Participative Approaches to Workplace Design in 1990, 1992, 1995 and 1999, arranged by the NIVA, Nordic Institute for Advanced Training in Occupational Health. He has authored articles to the international publications in the field of ergonomics. He has been a lecturer on several international courses arranged by the Finnish Institute of Occupational Health FIOH. He has also given lectures on several international ergonomics (or ergonomics-related) conferences (35 times).

2. Distinction

Martti Launis has worked on the field of ergonomics for over 40 years. Still after his retirement from his professional work he has been an active expert member of the board of the Finnish Ergonomics Society. In Finland his contribution to the dissemination of ergonomic knowledge and design principles including participatory approaches to workplace design has been spectacular.

Martti Launis is one of the two editors and the main author of the first and only Finnish handbook of ergonomics of present times. As a member of Unit of Ergonomics and later Team for Ergonomics and Usability in the FIOH he has been responsible for the training of several generations of Finnish ergonomic experts and practitioners.

During his whole professional career Launis has been extremely consistent with his aim. The focus of Launis's ergonomic work has always been in line with the spirit of the definition of ergonomics by IEA: "Ergonomics ... applies theory, principles, data and methods to design".

Launis's special field of activity during his career has been to develop ways of workplace design. Designing a workplace should be a collaborative process. To achieve ergonomically sound results different stakeholders and personnel groups have to interact and participate to bring their views and specific needs into the design at the right stage of the process. Possibilities to achieve good results in workplace design can be greatly improved by following well analysed processes.

The other one of his main concerns has been the development of the information given to designers. It is important that the ergonomic information given to the designer is relevant and easily understandable, implementable and easy to utilise. This is especially important in technical design where the designer can not be expected to be an expert in ergonomics and human factors. For a designer relevant information should be given in a form of checklists, technical recommendations and well-established criteria.

The above mentioned conditions are necessary for the success of workplace design, and have been in the centre of Launis's interests. Launis has concentrated himself on studying and developing ways of design and on developing tools (checklists, recommendations etc.) to be used during design processes in order to incorporate ergonomics into workplace design.

ergoSHAPE man-model system is a good example of his way of thinking and coherent approaches he has taken. In addition to the anthropometrically accurate manikin to be used with AutoCAD the ergoSHAPE system includes a number of well-thought and easily available dimensional recommendations for typical cases. Thus it provides the designer just the information he/she needs, not more, not less.

For Martti Launis European and international standards have been a major way to spread knowledge about good design practices among designers. Launis have had an important role in the preparing of standards "Ergonomic design principles" part 1 and 2 (CEN 614-1 and CEN 614-2). In addition, his experience of computer based man-model systems had an outstanding role in the formulation of European and international standards on Computer manikins and body templates.

For a ten years period of time Martti Launis has been a representative of the Finnish Ergonomics Society in the Council of the Federation of European Ergonomics Societies (FEES). During this time he has been responsible for preparing yearly introductory material for each European Month of Ergonomics (EME) based on the corresponding topics of the EU-OSHA Healthy Workplace -campaigns. The material has been used to introduce and promote methods and possibilities of ergonomics to the OHS representatives and other personal groups at the European workplaces.

For a more detailed description of Martti Launis's professional activities, see his curriculum vitae.

Endorsement by a Federated Society

Name of endorser: Elina Parviainen
Position held: President
Name of Federated Society: Finnish Ergonomic Society, member of the Nordic Ergonomics and Human Factors Society (NES)
Email: elina.a.parviainen@humanprocessoy.com
Phone: +358 40 5455871

Attached documents

Curriculum Vitae of Martti Launis

Launis, M., Lehtelä, J.: Man models in the ergonomic design of workplaces with the microcomputer. In: Computer aided ergonomics. Ed. by W. Karwowski, A. M. Genaidy and S. S. Asfour. Taylor & Francis, London - New York - Philadelphia, 1990, pp. 68-79.

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Launis, M., Jones, P.R.M. and Örtengren, R.: A European and international standard on the anthropometric characteristics of computer manikins and body templates. Proceedings of the CAES´99 International Conference on Computer-Aided Ergonomics and Safety, May 19th-21st, 1999 Barcelona, Spain. (CD-rom)

Launis. M.: Participation and collaboration in workplace design. International Encyclopedia of Ergonomics & Human Factors (ed. Waldemar Karwowski), Volume II, Taylor & Francis, London and New York, 2001, pp. 1274-1277.

Launis M, Ala-Laurinaho A. 2006. Investment handbook for facilitating collaborative designing of production lines. 16th World Congress on Ergonomics, International Ergonomics Association IEA; 2006 July 10-14; Maastricht, NL. [CD-ROM].

Ergonomics for managing work-related stress, a Power Point presentation for introducing European Month of Ergonomics EME 2014-2015, initiated by the Federation of European Ergonomics Societies FEES, prepared by Martti Launis.

25. 4. 2017

Curriculum Vitae

Martti Johannes Launis

Born:	22. 5. 1946, Helsinki, Finland

Qualifications

5/1973	Industrial Designer, University of Industrial Arts, Helsinki, Finland
5/1984	MA (industrial design), University of Industrial Arts, Helsinki, Finland
9/1989	Certified competency for associate professorship in industrial design, University of Industrial Arts, Helsinki, Finland

Professional activity

6/1971 - 12/1971	Research assistant, Department of Physiology, Finnish Institute of Occupational Health, Helsinki, Finland
1/1972 - 12/2006	Industrial designer, Department of Physiology, Finnish Institute of Occupational Health, Helsinki, Finland
1/2007 - 12/2010	Senior specialist, ergonomics, Center of Expertise for Human Factors at Work, Team for Ergonomics and Usability, Finnish Institute of Occupational Health
1/1972 - 5/2014	Part-time teacher, Course on Ergonomics, University of Industrial Arts, Helsinki, Finland (from 2010 Aalto University)
9/1990 - 12/1990	Substitute associate professor, Department of Industrial design, University of Industrial Arts, Helsinki Finland
1995 - 2009	European standardisation committee memberships: - CEN TC/122 WG1 Anthropometry - CEN TC/122 WG2 Ergonomic design principles
2006 - 2010	President of the Finnish Ergonomics Society
2007 - 2016	Member of the Communication and Promotion Committee of the Federation of European Ergonomics Societies (FEES)

A description of the professional activity

General about my activity in the Finnish Institute of Occupational Health

My activity in the Finnish Institute of Occupational Health covered the entire working career, from the study years from 1971 to the retirement in 2010. The Institute was during this period the major actor within ergonomics in Finland. From its establishment in 1969/1971 the Unit of Ergonomics was responsible for initiating systematic research within ergonomics in Finland, as well as for promoting ergonomics activity in enterprises. It was also responsible for carrying out systematic nation-wide training of ergonomics (during the first decades, four-week courses to experts, one-week courses to practitioners, and company-specific courses in enterprises) and, for disseminating information on the field of ergonomics by the bulletin 5 times/year. In addition, the tasks of the unit included preparation of supportive material, e.g. litterature reviews, training packages, checklists, work analysis methods, design tools, guides, booklets and handbooks.

The established multidisciplinary group employed specialists in technological sciences, in medicin and physiology and, in behavioral sciences. After joining the group in 1971 my primary task was to act as the specialist in design and design activity within the above-mentioned activities.

An overall description of my central activities, examples

1. *Case studies and projects in enterprises*

   Evaluation and determination of the dimensions and arrangements of the workplaces, in some cases also adjustment experiments (fitting trials) in an adjustable mock-up. Examples of the design objects: ticket-selling worksites, VDT-work-stations, control rooms, cabins (in truck, forklift, crain, train), and operator's worksite in visual grading of the products in sawmills (1979).

2. *Preliminary research for an anthropometric survey*

   A research project to prepare a population survey on the anthropometric measurements of the Finnish adult population for the design of equipment and spaces (1980). The litterature study was carried out, the measurement devices (traditional ones and those based on the photogrammetry) were constructed, and a test sample of 200 randomly chosen subjects were measured. Unfortunately funding for the measurement of a larger population could not be acquired. In spite of statistical insufficiency, the results of the test sample have been utilized in variuos situations. My contribution in the project: planning of the project, executive researcher, planning and construction of the measurement devices.

3. *Preparation of the course material*

   Preparation of the so-called "training packgages" (consisting of the written material and visualizations), a comprehensive package on ergonomics (1972, 170 slides, and written material 174 pages) and a package for workplace design (1973, 50 slides, written material 32 pages). My contribution for the package on ergonomics was to edit the written material and prepare the visualizations, and for the package on workplace design to prepare the entire package, both the written material and the visualizations.

4. *Planning, managing and leading courses and giving lectures on them*

   My contribution: in the beginning of the career, mainly to give lectures in the expert field of my own, later more often to take the responsibility for the planning and leading of the courses.

5. *Preparation of the ergonomics assesment tools*

   - Preparation of the ergonomics checklist (1972) for identifying the obvious shortcomings of the workplaces and for proposing short guides to correct them. The checklist was targeted to the personnel of the enterprises in general, but especially to those acting at the workplace level, i.e. supervisors, workers' safety representatives, etc. My contribution: edition and visualization.
   - Preparation of the ergonomic assesment system (1984) for grading the ergonomic quality of the workplaces. This tool was targeted for the use of the occupational health personnel, which had become responsible for the ergonomics at the workplaces after the new law on the occupational health in 1979 (also in English: EWA Ergonomic Workplace Analysis, published by the FIOH). My contribution: participation in the project group, authoring the pages for evaluation of the dimensions and arrangements of the workplace, and for the evaluation of the use of working tools.
   - Preparation of the checklist to support computer-aided workplace design, integrated in the ergoSHAPE man-model system (1988, see clause 7). My contribution: authoring a half of the list.

6. *Authoring guide books and text books on ergonomics*

   During my career I have been one ot the authors in several books dealing with ergonomics. The following can be considered important in their impact to the application of ergonomics in Finland:

   - Work at video display terminals (VDTs), 1984 (in Finnish, 110 pages). My contribution: authoring and preparation of the visualizations for the parts dealing with workplace design (one third of the entire book).
   - Towards participative design, 1991 (in Finnish, 68 pages). My contribution: a member of the authoring group.
   - The book on ergonomics, 2010 (in Finnish, 406 pages). My contribution: the other one of the two editors, authoring one third of the text, design a half of the visualizations.

7. *Development of computer-aided design tools*

   Development of the man-model system ergoSHAPE (1988) into the widely used design program called AutoCad. The system consisted besides of an anthropometric man-model, also an integrated biomechanical calculation of postural load, dimensional recommendation charts for various design objects, and a checklist including ergonomic design criteria and guidelines. My contribution: project leader, overall system design and determination of the anthropometric specifications of the man-model.

   The entire project icluded also a study on the use of the man-models in workplace design , and a study on the reliability of the determinations of the workplace dimensions done by using a static man-model, in relation to such determinations done with the help of a real test-person in real circumstances (1990).

Also a sophisticated man-model system "Jack" (developed in the USA) was acquired later to the Institute. My contribution: determination of the anthropometric dimensions of the man-model to match those of the Finnish population as far as possible (1997).

8. *Development of the workpace design practices in the enterprises*

Several projects on the workplace design practices were carried out, focusing e.g. on the design process, on the setting of the goals, on use of ergonomic knowledge and, on the collaboration between different personnel groups in the process. The projects aimed at determining "the building blocks" of a good design practice in general, and to create collaborately a new mode of action specifically in each individual enterprise. My contribution: project leader, researcher.

Also a large project called "Good design practices for workplace design" (1996) comprising several subprojects carried out by different universities and research institutes in Finland. The project comprehended, among others, a litterature review, research and development of design activities in different fields of work, experimenting participative design processes and design methods (1993) and, development of a training package of the good design practice for the use in technical universities. My contribution: litterature review, leader of some of the subprojects.

The latest project in this field "Investment handbook" (2005-2006), leading to an extranet application of the company, was carried out in the sawmill industry. All the needed tools to ensure a collaborative investment design process of the sawmill machinery were developed (the detailed description of the design process, checklists and guides for different design stages, all the needed forms and other documents to ease paperwork). These were inserted in the extranet in order to be readily available for anyone in the enterprise during the design projects. My contribution: project leader, one of the researchers.

9. *International communication and training*

In general, this included hosting the international visitors of the FIOH interested in design issues, lecturing in the international courses or seminars arranged by the FIOH, and, giving lectures in international conferences. Worth special mentioning is the series of four international courses (1990, 1992, 1995 and 1999) on the Participative Approaches to Workplace Design, arranged by the NIVA, Nordic Institute for Advanced Training in Occupational Health (funded by the Nordic Council of ministers). In these courses, targeted to the experts of the OHS, the nordic lecturers (e.g. Jörgen Eklund from Sweden), together with European experts representing different cultural views to participation (John R. Wilson from the UK and Francois Daniellou from France) enlighted and analysed various ways to carry out participation in different situations. The course aimed at a more advanced understanding of this emerging approach, which is, however, still rarely applied in technical design processes. My contribution: planning of the course, course leader, one of the lecturers

10. *Preparation of the European (and international) ergonomics standards*

Ergonomics has become one of the criteria in the normative European standards concerning the design of machinery. They are a new means to convey ergonomics into technical design, thus having potentially a wide impact to the outcome of designing. As a member of two committees (on the topics of Anthropometry and Ergonomics design principles) I was working specifically for the following standard documents:

- 614-1 Ergonomic design principles: Part 1. General principles. My contribution: preparing the first draft for the description of the design process
- 614-2 Ergonomic design principles, Part 2. Interactions between the design of machinery and work tasks. My contribution: participation in the subgroup drafting the document
- ISO/FDIS 15536-1 Computer manikins and body templates, Part 1. General requirements. My contribution: project leader, preparation of the first draft for the document
- ISO/FDIS 15536-2 Computer manikins and body templates, Part 2. Verification of functions and validation of dimensions for computer manikin systems. My contribution: project leader.

11. *Activity in the Federation of European Ergonomics Society (FEES)*

As a member of the Communication and Promotion Committee of the FEES I was given the task to prepare the introductory material (a Power Point presentation) for the European Month of Ergonomics (EME), in the years from 2010 to 2017. In these years it was decided to choose the topic which supports the yearly Healthy Workplace - campaign of the EU-OSHA, in order to achieve the synergy benefits of such a cooperation. The basic idea was to introduce the concept of ergonomics, determined by the IEA, and to demonstrate the potential of ergonomics in each yearly campaign topic of the EU-OSHA. The topics of the EME in 2010-2017 have been the following:

- Ergonomics in maintenance 2010 – 2011
- Ergonomics for risk assesment 2012 – 2013
- Ergonomics for managing work-related stress 2014 – 2015
- Ergonomics for all ages 2016 - 2017

Publications

Martti Johannes Launis

International publications 1990-2004:

Launis, M., Lehtelä, J.: Ergonomic design of workplaces with a two-dimensional micro-CAD system. in: Work design in practice. Ed. by C. M. Haslegrave, J. Wilson, E. N: Corlett & I. Manenica. Taylor & Francis, London - New York - Philadelphia, 1990, pp. 110-118.

Launis, M., Lehtelä, J.: Man models in the ergonomic design of workplaces with the microcomputer. In: Computer aided ergonomics. Ed. by W. Karwowski, A. M. Genaidy and S. S. Asfour. Taylor & Francis, London - New York - Philadelphia, 1990, pp. 68-79.

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Launis, M., Lehtelä, J.: Semi-three-dimensional man model system in the micro cad program. In: Designing for everyone. Vol 3. Proceedings of the 11th Congress of the International Ergonomics Association, Paris 1991. Ed. By Y. Queinnec and F. Daniellou. Taylor & Francis, London, New, Philadelphia, 1991, pp. 103-104.

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Launis, M.: Integrating ergonomic planning and evaluation to AutoCAD. In: Orpana V, Lukka A, editors. Production research 1993. Proceedings of the 12th International Conference on Production Research; 1993 Aug 16-20; Lappeenranta. Amsterdam-London-New York-Tokyo: Elsevier, 1993:93-94.

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Launis, M., Vuori, M. and Lehtelä, J.: Good workplaces by collaboration throughout the design process. In: Book of Abstracts of the Golden Jubilee Symposium of the Finnish Institute of Occupational Health, 1995.

Launis, M., Vuori, M. and Lehtelä, J.: Who is the workplace designer? - Towards a collaborative mode of action. International Journal of Industrial Ergonomics 17 (1996) 331-341.

Launis, M. and Lehtelä, J.: Participative redesign of the train cabin. Proceedings of the 13th Triennial Congress of the International Ergonomics Association, June 29-July 4, 1997, Tampere, Finland. Volume 2, pp. 217-219.

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A European and International Standard on the Anthropometric Characteristics of Computer Manikins and Body Templates

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ABSTRACT

CEN, in cooperation with ISO, is preparing a standard to ensure that computer manikins for the design of work spaces are appropriately accurate and reliable in their anthropometric aspects. This paper gives an overview of the present stage of development of this standard in order to enhance the exchange of information between the working group drafting the standard and the developers of the manikin systems. The draft standard provides only general requirements for the dimensions and construction of the manikins, but specifies requirements on the documentation of the manikin systems for the user. For making accurate evaluations, the user must be aware of the limitations and errors of the manikin and be able to use it in a correct way.

Keywords

Anthropometry, standard, computer manikins, human models, body templates

INTRODUCTION

Anthropometric accuracy of computer manikins

Computer manikins are intended for different types of use, and the need for their anthropometric accuracy varies accordingly. Typical fields of application are dimensioning of work spaces or equipment, evaluation of strength requirements by means of biomechanical calculation, simulation and assessment of physical work activities, and, plain visualisation of humans in their environment by illustrations or animation. In some of the applications mentioned, especially in the first one, an anthropometrically accurate and reliable manikin is required to represent the variation in body sizes of the intended user population, and to mimic the natural postures and movements of humans.

The anthropometric accuracy of the manikin itself is not the only aspect to consider; also the results of the evaluations and analyses done with the help of the manikin should be accurate, i.e. be in accordance with those done by real persons in real test situations. The usability features, together with guidance on the correct use of the manikin system, are important too, e.g. how easily the desired size and posture can be set, or the outcome visually perceived and assessed in relation to the geometry of the physical environment. Also all automated functions provided, such as movement patterns, reach testing, balance control, collision detection, or strength evaluation, must be as reliable as possible.

At the current stage of development manikins are not always sufficiently accurate in the above respects. They may emphasize differently the above features, and the anthropometric accuracy may not be appropriate for design purposes. Even though computer manikins may have modifiable anthropometric dimensions, the outcome, when the manikin is adjusted to represent a certain percentile value of a measurement, may deviate considerably from the initial percentile value determined from given data.

The poor accuracy of some measurements is the result of several factors, such as too rough or inappropriate a link structure, too rough surface geometry, lack of soft tissue deformation (for example in the buttock and thigh area when sitting), inappropriate structure of the shoulder joint, poor consideration of the effect of the natural slump on the height, as well as the known anthropometric problems regarding the extreme sizes of the so-called common-percentile manikins, determined from stature. The user of the manikins may not be aware of these inherent sources of error. The errors may also be difficult to detect, and the links to their origin difficult to trace, due to the complex structure and geometry of the manikin.

The present draft standard is aimed to ensure that the manikin, as a mediating tool from anthropometric data to the dimensioning of work spaces, does not constitute a considerable source of error in itself.

The European and international standards on ergonomics

The European and international standards on ergonomics are being prepared in cooperation by the Committee for European Standardization (CEN) and International Standardization Organization (ISO), in their technical committees (TC) devoted to ergonomics, i.e. in CEN TC122 and ISO TC159. According to the Vienna Agreement, these committees coordinate their work in preparing standards which should have a common basic content wherever they are applied, in Europe as well as in other parts of the world. The standards on anthropometry and its generic application belong to this group. Within this coordination the preparation of the standard on anthropometric computer manikins and body templates has been assigned to the working group of CEN, to CEN TC122 Working Group 1 "Anthropometry".

The standard on anthropometric computer manikins and body templates

The preparation of this standard was iniated in CEN TC122 WG1 as a standardization project in 1991 under the title "Structures and function of computer manikins for design and evaluation of work space at machinery". The initial concepts for the development of the standard have been discussed by Örtengren [1] at the first CAES'92 Conference. The tentative scheme presented have been changed only little since then. The core idea was to start from setting requirements for the specifications on the presumptions and structures of the manikin, and when enough experiences on manikins has been gathered, take the structures and dimensions themselves as subjects of standardization.

The prerequisites for completing the work within the above scheme and for obtaining the required data have been lacking, however. Presently, it has also been considered that any specified requirements on the structures of manikins would probably restrict the rapid development in this field, or, the development of the appropriate types of manikins for varying purposes. Therefore, it has been decided in the working group, at the first stage, to set only general requirements on the factors affecting the anthropometric accuracy of the manikins and analyses done with the help of them, and, to set specific requirements on the documentation of the manikin systems.

Thus, the standard does not provide absolute values for dimensioning or structuring the manikins.The aim is to make the developers take the anthropometric accuracy of their products into account, and to guide the users to choose manikins appropriate for their needs and use them in an appropriate way.

DESCRIPTION OF THE CONTENT OF THE DRAFT STANDARD

General requirements on the accuracy of the manikins

The accuracy of the manikin depends on its anthropometrical, structural, functional and biomechanical characteristics. All these together are important for the fidelity and accuracy of the manikin, e.g. how well it mimics the natural human postures and movements, and consequently, how accurately the dimensions of the manikin conform with measurements of real humans in different postures. The present draft sets, however, requirements on the static accuracy only, but provides recommendations on the other factors influencing the anthropometric accuracy of the manikin.

The basic requirement is that the manikin conforms with the shape and anthropometric measurements of the human body. In particular, the dimensions have to conform with the anthropometric measurements when the posture is changed between the relevant postures, for example, from standing to sitting position.

In addition to the above, the requirements take certain specific issues of anthropometric accuracy into account. One of them is the effect of slump, which should be considered by relevant reduction of the stature, or, by allowing the needed fine adjustment in the posture of the trunk. A second one is soft tissue deformation, which is needed especially for the thigh and buttock area in order to make the sitting height and thigh clearance conform with the given data. A third one is how the large mobility of the shoulder joint affects the reach distances. This could be taken into account by informing the user about the type of reach incorporated, or, by letting the user adjust the location of the joint rotation centre within the range of its movement.

General requirements for the usability of manikin systems

The manikin systems should be easy to use in order to be accepted and implemented into the design process. The usability of the manikin systems affect also the accuracy of the analyses performed with the help of them.

The requirements on usability concern e.g. clarity of the system, consistency of the software interface within the applications used together, effectiveness of the interface routines, including e.g. access routines needed to move from one software application to another, or, to transfer the manikin or the environment from one application to another. As a general requirement on versatility, it should be possible to manipulate the manikin (size, posture) and modify the environment within one and the same software application. Moreover, the manikin system should allow the user to specify the viewing fields, reach zones and comfort zones of movements.

Requirements are set in particular on the ease of changing the anthropometry of the manikin. The anthropometric measurements shall be readily changeable e.g. by selecting percentiles or by changing them directly; in both cases the percentiles should be indicated to the user. Also combinations of different body segment percentiles should be available, relevant to the design needs.

The other special requirements concern ease of changing postures. The postures should be easy to change, and it should be easy to revert to the initial posture. The system should allow easy selection of, or change to, relevant basic postures, e.g. standing, sitting, stooping and kneeling. In addition, the manikin should be easily positioned in relation to objects in the environment.

Also the ease of visual judgements of the measurements or postures have been dealt with. Sufficient indication of the surface of the body, indication of the joints to be moved, indication of the direction and magnitude of the movement, and the use of landmarks and reference lines to facilitate these have been considered.

Requirements for the documentation of the manikins

The specification and documentation of the characteristics of the manikin and manikin system constitute the core requirement of the present draft. The developer of the manikin system is responsible for this documentation, as well as for the description of the intended use and the guidance to the user.

According to the present draft, the developer shall specify the intended user population of the manikin system. The requirements concerning experience in anthropometry, workplace design and computing techniques should be specified as well. In addition, the field of intended use of the manikin system shall be specified, e.g. animation, anthropometry, and biomechanics. The types of analysis for which the manikin system is intended shall be specified, too, e.g. automated evaluation functions or evaluation by visual judgement only.

The sources of anthropometric data used in the dimensioning of the manikin shall be specified. If these data are combined from different sources or pooled gender data, the resulting data should be documented and tabulated in 5th, 50th and 95th percentile values.

For assessing static accuracy, the conformity of the manikin with the population data (original, combined or pooled) shall be checked in a sitting and standing position as defined in the ISO 7250 "Basic human body measurements for technological design". In this comparison, 5th, 50th and 95th percentile values of a specified selection of core anthropometric measurements have to be compared to the outcome measured directly from the manikin, when the measurements are set to represent 5th, 50th and 95th percentiles, respectively. The difference between these values shall also be documented as a percentage of the initial value, which represents the degree of error. This documentation shall be done also concerning possible common-percentile manikins set from stature, showing inherent errors due to compromises on the stature path and possible choices concerning body types.

Any assumptions and corrections concerning the dimensional differences between the measurements in standardized and actual postures of the manikin shall be documented as well (e.g., the effect of slump, and movement of the shoulder joint). If they are an integrated feature of the manikin, they should be taken into account in the comparison described above.

All characteristics of the manikin which influence the anthropometric or biomechanical accuracy, but are not visible or obvious (like the number of segments), should be specified. These include the link structure and the construction of the joints, as well as the type of co-ordinate system used to describe the link orientation, and whether any constraints of the movement are imposed. In addition, it shall be specified how the anthropometric geometry of the model is given, if a database of the anthropometric measurements of a specific population is provided, if other databases can be incorporated and if it is possible to specify the measurements of a certain individual.

When the manikin is used in biomechanical analyses, the details of the biomechanical models and equations used for calculations should be specified, as well as the sources of data and quantities used (dimensions, masses, strengths, moments of inertia, etc.). Also the methods to control posture, balance, movements and interaction between the manikin and the environment should be specified.

In addition, the developer of the manikin has to provide the needed guidance for the user in order to ensure appropriate selection of percentiles and correct use of the manikin with respect to the design task.

General information on the manikin systems and their use

The draft standard includes an informative annex, which briefly describes and discusses typical features of manikins and manikin systems, their benefits, limitations and fields of use, especially with respect to the anthropometric accuracy. This part of the standard is intended to guide the developers of the manikin systems as well as their users, to consider practical aspects of accuracy which have to be taken into account in order to fulfil the general requirements presented in the body of the standard.

Geometric representation is one of the topics. Two-dimensional body templates (or 2D computer manikins) have been discussed together with 3D computer manikins in their different representations (e.g. wire frame, surface models). Structural features is the other topic, which includes discussion of the needed number of the segments and joints in different applications, degrees of freedom of the joint movement, and possible angular limits for specific purposes. The third topic concerns functional features, including the ways of setting and changing postures, ways of indicating reach zones, work areas and viewing fields, principles of accomplishing movement patterns, and principles of incorporating biomechanical calculation into the modelling of humans.

For the purpose of this standard, anthropometric features of the manikin obviously constitutes the most important topic of discussion. The main concern is the integration of percentiles in the dimensioning of the manikins. The principle of using 5th, 50th and 95th percentiles (1th and 99th for safety considerations) of pooled gender data, adopted in the new European and international standards on anthropometry (EN 547-3, ISO/DIS 15534), is identified as a new requirement. However, when the genders are represented separately, the basic geometry representing both men and women should be available. A particular issue is the need to facilitate designing by readily dimensioned size options representing extreme sizes, and the associated problem in determining appropriate dimensions for these. The impossibility of anthropometrically correct common-percentile large or small manikins is identified, and different ways to combine percentiles in different body dimensions is discussed.

The availability of detailed, reliable, and representative data for dimensioning of the manikin is a big problem currently. This has been discussed in order to bring the essential prerequisite of making accurate and reliable manikins to the general consciousness. Population data required in the detailed modelling of the body surface as well as those for biomechanical modelling are not available, e.g. widths and depths of body parts, link lengths, body segment mass data, distributions of masses of the segments and moments of inertia, and joint torque data. Also basic anthropometric data in standardized postures are lacking for many populations of interest, and to a great extent the existing data are out-dated. In practice, often only estimates for these parameters are used.

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A European standard for improving work tasks at machines

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ABSTRACT

This presentation introduces a draft European standard for the design of work tasks associated with the use of machinery. The standard consists of ergonomic criteria for work tasks, a description of the task design methodology, and guidelines for the evaluation of the designs. It comprises the systems approach to task design, including e.g. the stages of function allocation and task analysis. As the standard tackles the work activity in the use of machinery, on the one hand, and the design activity, on the other, questions understandably arise on its use; some of these are discussed in this presentation. The new European standards on ergonomics, due to their linkage to European regulations, will have a considerable effect on the design of machinery. As they represent also a new approach to standardization, wide discussion on their content is needed.

1. Introduction

The new European standards for incorporating ergonomics into machine design
European standards on ergonomics are currently being prepared by the Committee for European Standardization (CEN), in the technical committee CEN 122 "Ergonomics". New standards are intended to support the safety requirements of the Machinery Directive of the European Union. According to the European regulations and agreements, the new European standards will have an important role as they explain Directives, which, in fact, replace the national legislation on their part.

The relationship of the standards to the Directives has been determined by the principle of the "New Approach": the machine fulfils the essential requirements set forth by the Directives if it is designed to meet the requirements of the relevant European standards. The standards are not obligatory, however, but by following them the manufacturers can be ensured about compliance with the Directives. The basic idea is to keep only the essential requirements in the Directives and to present the more practical matters in the standards, which are easier to change.

The health and safety aspects of the work environment are regulated separately by the Directives concerning the machinery and equipment (i.e. products), and by the Directives on work and working conditions. This separation is based on basic principles of the EU: harmonizing of the regulations on the products, and setting of the minimum requirements on the working conditions. The responsibilities are thus also divided between the manufacturers and the employers. This situation has implications on the European ergonomics standards, too. As they support the Machine Directive they are limited to the design of machinery only.

The European standards related to the safety of machinery are set forth according to a three-level hierarchy: (A) basic safety standards, (B) standards concerning safety qualities, e.g.

ergonomics, and (C) standards on a piece of machinery or equipment. Ergonomics standards fall under the B-standards, and are intended to be utilized when C-standards are prepared. If there is no C-standard available for a particular machine or equipment, the designer shall use the B-standards. Therefore, the ergonomics standards must be generally applicable for all types of machinery. Hereby also the broad definition of machinery has to be recognized; it covers even the simplest machines comprising only one moving part with control and power circuits.

Ergonomics standards on designing human activity related to machinery

The new practice of making ergonomics standards is challenging when it comes to human activity at machines. Ergonomics, as a broad approach to the complexity of the human-machine relationship, does not bend easily to rules or requirements. On the other hand, the new way of keeping standards as explanatory in relation to the Directives, allows the presentation of various types of knowledge and information, not only requirements but also principles, guidelines, examples, etc. Also methods, procedures and ways of action can more easily be described in standards.

In the new European ergonomics standards dealing with the designing of human activity related to machinery, the systems approach has been applied to the usage of machinery. This approach has been inherited from the corresponding standardization of the International Organization for Standardization (ISO) (Nachreiner 1995). In the field of ergonomics, ISO and CEN aim at coordination of their work. The ergonomics standardization of the ISO has been started from the standards providing a general frame and overall requirements for the work systems, in order to cover all possible conditions and applications. In this global approach it is clear that the workers' safety and well-being is entwined with work performance and functioning of the systems they operate with. Therefore, instead of concentrating on the properties of the machine, it has been seen necessary to establish criteria, guidelines, etc. on human activity and design procedures. Similarly, the focus is shifted from the traditional protective approach to a proactive one.

The ISO standards cover the design of the work system as a whole, including both the machinery and the working conditions. As described earlier, in the European ergonomics standardization, these two are separated, the local working conditions being excluded. This distinction may be clear at a conceptual level, but it is artificial from the ergonomic point of view. It is, and will be, a problem in preparing practical requirements and guidelines.

Aim of this presentation

This presentation aims to expose a draft standard concerning the design of machine-related work tasks for wider discussion. The draft has been completed by the working group for the first commenting round to national standardization bodies, and therefore also an evaluation by specialists would be needed here. There are different views on how such design tasks can be carried out, and what kinds of design procedures can be generally required for the variation of machinery, for instance in respect to the time and costs of designing.

2. Description of the draft standard

The context of the standard

The topic of this article is the draft standard prEN 614-2, "Interactions between the design of machinery and work tasks". It is the second part following European standard EN 614-1, "Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles". This ratified first part of the standard series describes the ergonomic principles and requirements incorporated into the design of machinery on the whole. The present draft, in other words the second part, focuses on the design of work tasks performed at, or with, machines.

This standard supports one of the essential health and safety requirements of the Machine Directive, documented also in EN 292-2:1991, in Annex A.1, 1.1.2(d): "under the intended conditions of use, the discomfort, fatigue and psychological stress faced by the operator must be reduced to the minimum possible taking ergonomic principles into account". As these effects are, to a great extent, transmitted to the operator through task performance, compliance with this requirement can only be achieved by the design of the machinery and the associated work tasks in interaction with each other.

This implies that the work tasks associated with the use of machinery (called "operator work tasks" in this standard, i.e. operating, maintaining, cleaning, repairing, etc.) can be considered a "property" of the machinery, in contrast to the actual work tasks in the ultimate use of the machinery. It is not possible for the designer to consider all the actual work tasks, but he or she has to make sure, however, that the machine can be used as intended in an ergonomic (i.e. efficient, safe and healthy) way.

The scope and overall content of the draft standard

This standard establishes the ergonomic principles and procedures which have to be followed during the design process of machinery and operator work tasks. The actual work tasks or jobs are not of concern, and thus the standard is directed mainly at designers and manufacturers of machinery and other work equipment.

The standard aims at ensuring ergonomic considerations of the work tasks in the design of the machinery in three ways: (i) by presenting the ergonomic objectives and criteria for planning the work tasks, (ii) by presenting the work task design methodology to be followed, and (iii) by presenting the means of evaluation of the plans in different phases of designing.

The standard includes also informative annexes, one giving information on job design principles, and another providing an illustrative example of appliance of the work task design methodology.

The objectives for the design of work tasks

The first section of the standard explains the ergonomic objectives for the design, entitled "characteristics of well-designed operator work tasks". This list of ten criteria consists of well-known principles of task design, many of them presented in major ergonomics literature. These are intended to be followed by the designer in the design process. It is stated in the standard, however, that taking into account the applicability and the state of the art, it may not be possible to meet all the objectives completely. In this case they have to be taken into account as far as possible.

The "characteristics of well-designed operator work tasks" are presented here in abridged form, in the standard they include also an explanation and description in practical terms. The standard requires that, in the design process, the designer shall

(a) recognise the experience, capabilities and skills of the existing or expected operator population
(b) ensure that work tasks are identifiable as complete and meaningful whole units of work
(c) ensure that work tasks are identifiable as a significant contribution to the total output of the work system
(d) provide for the application of an appropriate variety of skills, capabilities and activities
(e) provide an appropriate degree of freedom and autonomy to the operator
(f) provide sufficient feedback on task performance in terms meaningful to the operator

(g) provide opportunities to practise and develop skills and capabilities as well as to acquire new ones
(h) avoid overload as well as underload of the operator, which may lead to unnecessary or excessive strain, fatigue or to errors
(i) avoid repetitiveness, which may lead to unbalanced strain and thus to physical disorders as well as to sensations of monotony, satiation, boredom or to dissatisfaction
(k) avoid working alone without opportunities for the operator for social and functional contacts.

The methodology of work task design

The second section of the standard, methodology of work task design, describes the systematic procedure for work task design in relation to machine design. It consists of the following stages (presented here abridged):

(1) *Establishing design objectives*, including design specifications, performance requirements and evaluation criteria for the system. These tasks are preceded by gathering information on comparable existing machinery.
(2) *Function analysis*, i.e. identifying functions and subfunctions and specifying them in their hierarchy and functional relationships. The functions are also specified together with their performance criteria, and evaluated against the design specifications.
(3) *Function allocation*, i.e. allocating functions and subfunctions to the operator or to the machine, or to both. The suitability of the functions is evaluated as human activity or machine operation. In this stage also alternative design solutions are outlined and analysed, and the one which best meets the specifications and criteria is selected for further development.
(4) *Work task specification*, i.e. detailed specification of the operator work tasks. This stage includes also evaluation of the work load each task imposes on the operator. These tasks are preceded by gathering information on comparable existing work tasks.
(5) *Assignment of work tasks to operators*, including specification of the number of operators required, and evaluation of the total workload on each operator and fulfilment of the "characteristics of well designed operator work tasks".

The standard requires that these stages be carried out by the designer, and that they be documented so that the compliance of the requirements of the standard can be verified. Also when minor changes of an existing work system are being planned, at least the first stage has to be carried out, in order to check whether the changes in the design will involve essential changes in the operator work tasks.

Despite this systematic view of the task design, it is noted that designing is usually an iterative process, and that division between the stages may not be distinct. The design solution of one function interacts with the solutions of other functions, and therefore moving back and forth in the process may be needed.

It is explained in the standard that this systematic stepwise procedure helps the designer (i) to base the design decisions on the relevant information, (ii) to make the decisions perceivable to all persons concerned, (iii) to predict the consequences of the decisions on human operations and activities, and (iiii) to check the adequacy of the decisions as early as possible in the design process.

It is also suggested that representatives of all groups possibly affected by the work system be involved at these task design stages, e.g. the management, supervisors, operators and customers.

The evaluation of work task design

The third section of the standard deals with the evaluation of the work task design. In the evaluation phase the solutions - technical applications together with the work tasks - will be evaluted in the whole, in interaction with each other. The evaluation is intended to be performed in three phases:

(1) during the above-mentioned task design process, in order to show to what extent the design objectives have been reached and to help judge the need to improve solutions,
(2) during implementation, e.g. trial runs and other tests, to assess the design solution as a whole and to make the necessary adjustments and corrections, and
(3) under operative conditions to provide feedback for forthcoming designs and to establish compliance with this and other relevant standards.

In the early phases of designing, the suggested methods of evaluation include modelling and simulation e.g. with the help of graphical illustrations, small scale models, scenarios, etc. When the design solution can be actualized, e.g. as a full-scale model, mock-up, setting of elements, etc., it should be assessed through real simulation of the tasks. In the simulations, the representatives of the operators need to be involved to provide their comments or to serve as test persons. For these purposes, means of ergonomic analysis and means of gathering information from the operators are suggested, e.g discussions, checklists, observational studies, etc. Again, the results of the evaluation have to be documented so that the fulfilment of the established requirements can be verified.

3. Discussion

3.1 Possible benefits of the standard for incorporating ergonomics to machine design

The requirements presented in this draft standard complement each other in such a way as to obviously ensure the ergonomic considerations in machine design. They can also, as learning effects, enhance the ergonomics skills of the users of this standard. Some arguments for this conclusion are presented in the following.

Sound basis for designing and cooperation

The *Characteristics of well-designed work tasks* can serve as heuristic rules guiding thinking processes in the search for good solutions. As they are based on scientific knowledge and widely accepted ergonomics concepts, and set at a general level, they will form a sound basis for designing. They will be generally applicable and will not restrict open and creative thinking, however. When formulated in terms of familiar from ergonomics textbooks, they may at first be difficult for purely technically educated users of the standard, but may in time begin to deepen common understanding of the relationship between the human being and complex systems, and encourage cooperation between ergonomics specialists and designers.

Ergonomics considerations for conceptual design

The *Methodology of work task design* for its part considers the critical stages of the design process. Technologically driven design of machinery has often neglected the role of the human operator, especially in the stage of conceptual design.

First, the stage of *establishing objectives* of the work system requires consideration of all necessary aspects, including human ones, already in the beginning of designing. In the present design practices, designers may aim at more automated systems in the beginning, and only as designing proceeds, may the need for the operators become obvious. It is then often too late to consider their tasks in a proper way. The designers are, humanly however, fulfilling the expectations set to them, and they may better consider human activity if only it is set in the beginning as equal criteria to the technical ones.

Secondly, the stages of *function analysis and function allocation* require focusing on the role of the human operator in the system, and evaluation of the suitability of tasks to man. In this stage the most essential choices in the ergonomic sense are done, stressing the importance of this stage in the design process.

Thirdly, the very detailed consideration of work tasks in the stages of *work task specification and their assignment to the operators,* starting from the gathering of information from other comparable work tasks and ending in the evaluation of the workload and fulfilment of the objectives, inevitably completes the ergonomic considerations of task design. The task specification requires a description of what the operator has to do, how, with whom, when and with what kind of equipment in order to operate the machinery, and recommends to focus also on indirect productional activities such as preparation, adjustment, reprogramming, incidents, change of tools and products, cleaning, etc. These actually serve as checklists of the vital ergonomic considerations in machine design.

Cooperative testing of solutions
In the *Evaluation of work task design,* in modelling, simulation and testing of various solutions, the functioning of the entire system can be ensured. The recommended participation of the user representatives, in particular, offers good opportunities to ensure consideration of human activities and users' skills and capabilities in the design during this phase.

Combination of different approaches .
All in all, the standard combines different task design approaches. Following the described procedures in detail is likely to lead to double-checking of the same aspects at different stages of the entire process. At least three broadly determined traditions of work task design exist: the systems design methodology (setting objectives, function analysis and allocation, etc.), experimental task design (modelling, simulation, rapid prorotyping, etc.), and the development of work activity (gathering information on existing comparable work tasks, i.e. analyzing real work activities as a reference for designing new ones). Added to these, the psychologically and physiologically oriented approach to evaluate and optimize the workload is an integral part of the standard.

3.2 Possible difficulties in machine design practices

The standard has, however, some inherent problems in its application. Due to the defined wide field of use, the required procedures may be seen too demanding in many cases. Designing work tasks in work cultures different from those in which they are to be ultimately performed, may be a confusing task. Differences in the existing design cultures may pose difficulties in the application of the standard, too. Due to the descriptive nature of this standard, the verification of the compliance with the requirements may not always be clear or easy. These issues are discussed in the following. It seems that some amendments and clarifications to the present draft are needed.

Applicability over the wide range of machine complexity
Due to the definition of machinery in the Machine Directive, this standard covers a vast range of machine complexity, from powered hand tools to large-sized machinery operated by a team of operators. The described methodology of work task design can obviously be best justified when new designs of complex systems are being generated, and especially when there is risk

associated with the performance of the operator work tasks. In this type of design, e.g. the fairly abstract, and thus difficult phase of function analysis, can be justifiable, and can help the designer to perceive the alternative ways of arranging the tasks and to find appropriate solutions.

For many manufacturers in this wide range of machinery, however, the required procedures are likely to be new and demanding. The manufacturers may improve their products, intended for limited and well-defined use, continuously via evolution of the versions. In many cases this can be described as simple redesign of the existing machinery. The functional properties of the machinery may have been designed so far only by experience and by intuition, inspired by the observed new needs. As a relief for these manufacturers, the methodology of the work task design need not always to be carried out thoroughly, but the other requirements of the standard nevertheless apply also to this type of design task.

Applicability over the variation in work cultures

The principles of organizing work may vary within Europe, and so may the level of education of the operators, as well as the acceptance of adverse effects among operators. These differences in culture and conditions may affect the design of operator work tasks. The machine is always used within a work system, and the operator work tasks are always a part of the entire jobs of the operators. This constitutes a special problem when we think of the suggested participation of the representatives of the users and other groups concerned in design. How can the cultural influence that these representatives bring to the designing be avoided? Separation of specific universal "operator work tasks" at the machines from the work tasks determined by local use will certainly be a challenge in the application of this standard.

Applicability over the variation in design cultures

The other possible cultural controversy concerns design culture. The different design domains, presenting also nation-wide differences, have developed their own specific ways of designing. Systematic design methodology has not always been favoured, rather, practical procedures and the adoption of "natural" design thinking have been typical. This issue has also been intensely discussed in the working group preparing the draft. In its present form the draft standard is compromising in trying to take these cultural differences into account by combining different task design approaches.

There is one question of special interest, in which the different design approaches seem to contradict, i.e. the question concerning the relation of generating design solutions to the process. In the systematic task design methodology presented in this standard, it is recommended that the function analysis be performed separately from working out design solutions, in order to avoid premature solutions and to ensure the best possible solution for the tasks, machinery and their interactions. In "natural" design thinking, in contrast, elucidated in design methodological literature (Cross 1984, 1989), the designers do not seem to follow systematic procedures, they rather test their ideas and concepts in attempts to solve the problem, and in this way study the design problem.

Actually, it is not clearly determined in the standard in which phase of the entire process the design solutions should be generated. The work task design process is obviously parallel to the entire design process including technical and other functional aspects, and it may simply be impossible to foresee in which phase the technical solutions are actually generated, or determined. In some cases the work task design is connected to a separate design process of the user interface (e.g. computer control), and then these processes can be seen as simultaneous ones. In some other cases the control devices are integral parts of the construction of the machinery (e.g. traditional mechanical control), and there may exist time or place barriers between engineering design and task design. In both cases, and in general, the work task design can be seen as something which should be performed, as much as possible, in interaction with engineering design processes, in order to achieve ergonomic results in a rational way.

Verification of the compliance with the requirements
One problem of this standard, common to other similar standards including guidelines, is the problem of verifying compliance with the requirements. These requirements include those explicitly expressed in the standard as well as the objectives and criteria established during the design process. As a general rule set in the standard, the designer has to document each stage of the process in order to verify the above-mentioned compliance. Just how, and how carefully this should be done in order to be sufficient is not clear. This is a general problem, and is connected also with the problem of variation in machine complexity. The more complex that the machinery is, and the more risks that are involved, the more careful performance and detailed documentation of the processes would seem reasonable.

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Keywords
Ergonomics standardization (2), Ergonomic design principles (3), Work task design (3) Design methodology (7)

EME

European Month of Ergonomics
October, 2014 and 2015

Ergonomics for managing work-related stress

What is EME ?

- **The European month of ergonomics (EME)** is an annual campaign for the promotion of ergonomics in Europe.

- The **EME** was initiated by the Federation of European Ergonomics Societies (**FEES**) and it is implemented by the national ergonomics societies, who are its members.

- The **FEES** is an official partner of the European Agency for Safety and Health at Work (**EU-OSHA**).

- The **EME 2014 and 2015** support the annual Healthy Workplace Campaign of the **EU-OSHA.** In 2014 and 2015 the topic of this campaign is:

  Managing work-related stress and psychosocial risks

- The **EME 2014 and 2015** focus on the role of ergonomics in managing work-related stress, with the title:

  Ergonomics for managing work-related stress

EME 2014 and 2015

- This year the **EME 2014** will be started with an **introduction** to the topic, highlighting the ergonomic aspects.
- Next year the **EME 2015** will focus more on **practical applications**, research and development projects, case studies, methods, etc.
- The aim of the **EME** is to **encourage discussion and collaboration** between ergonomics experts, safety experts, occupational health and safety authorities, and managers and employees in enterprises, so that the **knowledge and methods of ergonomics** for managing work-related stress and psychosocial risks are considered.

- This presentation has been prepared as **supportive material** for use in lectures, training events, seminars or written articles for dissemination of the message of the **EME** by the national member societies of the **FEES**. It is recommended that this presentation is translated into the local language and, if needed, modified to local circumstances, e.g. enlarged or shortened, addition of own examples and illustrations, etc.

EU-OSHA campaign 2014-2015 "Healthy workplace - Manage stress"

- The **EU-OSHA campaign "Healthy workplace - manage stress" for managing work-related stress and psychosocial risks** aims to reduce the negative consequences both to the health of the employees and to the efficiency of the organisations. **"Managment of health and safety is good for workers, good for business and good for society as a whole".**

- **Why this topic?**
- Studies suggest that 50-60% of all lost working days can be attributed to work-related stress and other psychosocial factors. Stress is the second most often reported work-related health problem in Europe after musculoskeletal disorders.
- The total costs of mental health disorders in Europe (both work and non-work-related) are estimated to be 240 billion euros per year. More than half of this sum (136 billion euros) is due to lost productivity, including sick leave.

For more information on the campaign, see www.healthy-workplaces.eu.

What are work-related stress and psychosocial risks?

Work-related stress occurs when the demands of the job exceed a worker's ability to cope with them. Psychosocial risks can lead to this situation.

Situations that may involve psycho-social risks:

- excessively demanding work / not enough time to complete tasks
- a mismatch between the demands of the job and the worker's competence, i.e. over-using or under-using a worker's skills
- lack of influence over the way the job is done
- conflicting demands and lack of clarity over the worker's role
- working alone / being subject to violence or threat of violence
- lack of support from managment and colleagues / poor interpersonal relationships / harrashment and isolation
- unjust distribution of work, rewards, promotions or career opportunities
- poorly managed organizational change / job insecurity / ineffective communication
- difficulties in combining commitments at work and at home

EME in relation to OSHA-campaign - support and highlight

Many of the psychosocial risk factors mentioned are not directly related to the work requirements and workplace. In many cases, they can be attributed to inappropriate behaviour of human beings, e.g. inadequate leadership or poor interpersonal conduct. These risks are general to all workplaces, not depending on the field of work. Such risks are included in the EU-OSHA campaign but are not the focus of the EME campaign.

The EME campaign will support the EU-OSHA campaign by highlighting the risk factors which are **related to the work activity and the technical arrangements** of the workplace, such as:

- organisation of the work
- design of the work tasks
- design of the work equipment
- design of the worker-system interface
- design of the physical work environment.

These topics are core fields of ergonomics (see the next slide)**. Ergonomists have experience dealing with them and can contribute this knowledge to the EU-OSHA campaign.**

What is ergonomics?

- **Ergonomics provides the knowledge and skills for fitting the environment, equipment and activities to people** (For the IEA[1] definition of ergonomics, see www.fees-network.org)
- The dual aims of ergonomics are to improve the **well-being of people** and to enhance **productivity of work systems**
- For the practical application of ergonomics, the following subfields are identified:
  - **physical ergonomics** – e.g. postures and movements, physical workload, manual material handling, workplace design
  - **cognitive ergonomics** – e.g. information processing, mental workload, human-computer interface, applications for transmitting information
  - **organisational ergonomics** – e.g. coordination of work processes, such as assembly lines, combinations of work activities, work-rest schedules, collaborative development of work activity
- **Ergonomics is a scientific discipline and development tool to create highly effective work places - and also to prevent risks in the workplace!**

[1] IEA – International Ergonomics Association, www.iea.cc

Why ergonomic aspects of psycho-social stress need to be highlighted?

- **Stress factors related to inappropriate work activity or inappropriate work equipment** (i.e. stress factors related to inappropriate application of ergonomics) are sometimes not obvious. They are, therefore, not always identified as stress factors, and often get ignored. In many cases, the work activity involving such stress factors is regarded as a "normal situation" or just an unavoidable condition. Highly repetitive work performed at a high pace in numerous factories is a typical example.

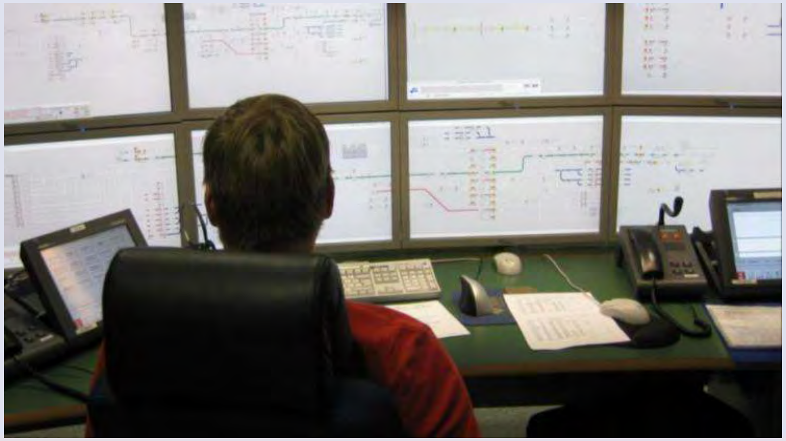
- However, these stress factors have gradual adverse influences on the health and well-being of individuals, e.g.:
  - feelings of monotony, boredom or dissatisfaction, resulting in lack of commitment and motivation to work
  - mental fatigue, lack of initiative, burnout and depression
  - disturbed nervous and hormonal functions of the body and
  - subsequently various diseases of the internal organs.

Example 1: repetitive work

- Repetitive work is one of the most common modes of organising work, e.g. in assembly industries or in the food industry. It involves a risk of work-related stress, especially when tasks are **partitioned into very short cycles, without the possibility of additional rest breaks or adjustment of the pace by the worker.**
- This type of work has been under scrutiny for decades, and many initiatives to ease the stress have been proposed and tested in companies, e.g, **job rotation, job enrichment or job enlargement** (see later in this presentation).

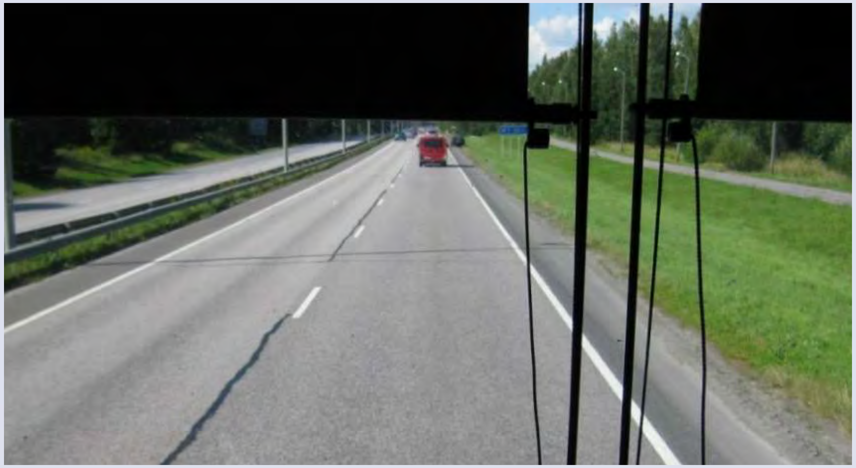
Example 2: monitoring, controlling

- Typically in process industries there are jobs involving intensive **monitoring and controlling of the process by displays**. The process may also be controlled directly on the line, e.g. by **visual quality control**. This seems the light work, but it often requires a **high-level of concentration and uninterrupted attention**.
- This type of work is mentally very demanding and involves a risk of work-related stress, especially when **the system interface is not designed in accordance with ergonomic principles** and when the workers **level of responsibility for possible adverse consequences of his/her errors is very high** (in terms of e.g. economic loss, production disturbances or accidents).



Example 3: operating a vehicle

- Driving a car, or any other vehicle (e.g. truck, train, boat, airplane) is a demanding task, generally requiring constant vigilance. **Varying circumstances** (heavy traffic, icy roads, passenger requests, etc.), poor design of the **displays and controls of the vehicle**, poor design of the **driving environment** (lighting, traffic symbols, navigation devices, etc.), **high levels of responsibility** for the safety of people or materials, and **long periods** without rest, can make the mental load even higher.
- An additional stress factor is the **difficulty of maintaining arousal (vigilance)**, especially when driving at night, as this is not inaccordance with normal bio-rythms. To ease this problem, ergonomists have produced new technical means to monitor the level of activation of the driver.
- To reduce the risk of cumulative stress, the working hours must be suitably designed and this is also the focus of ergonomic research.



Example 4: customer service

- The work at customer service desks (e.g. retail cashiers, ticket selling) becomes mentally demanding at peak hours when the length of the queues of customers grow. As a reaction to the expectations of busy customers, **the pace of work is increased and this raises the risk of errors**. Additionally, **the number of disturbances increases, making concentration more difficult.**
- This work can be stressful for many reasons, not only because of the intensity of the work performance as such, but also because of the psychosocial stress caused by the unexpected behavior of customers.
- Ergonomists have worked for decades on improving the design of such workplaces, the machine interfaces and the organisation of work in the retail industry.

Example 5: modern office work

- In recent times, many additional tasks have been added to the core task of the employee, e.g. administrative tasks are shared by almost everyone, the employees may be engaged to work simultaneously in many projects or teams and direct cooperation with customers is more frequent. The work may become, on the whole, **too extensive and too varying**, with frequent interruptions and disturbances in activity. This may lead to **difficulties concentrating on important tasks** and **difficulties following the schedules**.
- **New information technology** produce additional burdons: **the constant need to learn** new software applications, or new versions of old ones along with **usability problems** of the software can all produce stress. If the **technology itself is not reliable**, this leads to **disturbances** that also add to the stress on individual worker.

Example 6: very high precision tasks

- Many jobs require working in very constrained postures and operating fine machinery, such as **work under microscopes**. Not only laboratory employees but many process workers need to do this e.g. in electronics industries and watchmaking.
- The need to keep **physically very still for long periods** is a stress factor for the body and mind, as the **effects of pain and discomfort on concentration** can produce costly disturbances and mistakes. Attention to ergonomic design of the equipment and workstations is essential in this type of work.
- Similarly, developments in medical technology have meant that surgeons can operate **with microscopes** to minimise the side-effects of large surgical wounds. Here again, the ergonomic design of such equipment is crucial to avoid errors and to minimise the stress to the surgeon – both physical and mental.

Other examples: something else?

- **Please think for a moment about other types of work wich you have found to be mentally stressful!**
- Think of some specific work task, or, a group of similar work tasks
- What makes the task mentally stressful?
- What are the most important stress factors in the work task?
- Are there any obvious remedies to decrease stress in the work task?
- Would the larger work system (of which the work task is a part) need to be developed to improve the work situation, by for example,
  - re-organizing the work
  - by using more developed technology, or/and,
  - by redesign of the jobs and tasks

How to reduce "ergonomics-related " psycho-social risks?

- As can be seen, **risks related to inappropriate application of ergonomics are connected to fundamental characteristics of the work task**: organisation of the work, work task arrangement and technology used.
- Thus the reduction of these risks requires **an analysis of the entire work system, identification of problems** and **a concept of possible ways to improve** the work situation.
- **This could be a task for an ergonomist, production engineer or work study technician, but anyone involved with the problem can start to do something towards it.**
- For instance, using common measures or "good practices" solutions to improve the work in question will often provide a solution.
- Common measures may, however, only produce small or partial improvements.
- **Ergonomic measures** are best considered and applied **in the design stage** of the work system. However, ergonomists are also trained in **a systematic approach to solving unusual** workplace problems.

Basic ergonomic considerations in the design of the work system

- For analysing the task and for the systematic identification of the problems, **criteria regarding good work tasks** can be used ("Characteristics of well designed work tasks", see later).

- For developing solutions, the appropriate **ergonomic standards and guidelines** need to be consulted and used.

- For utilisation of practically tested solutions, **experiences from similar situations** should be gathered, assessed and used.

- For utilization of all available knowledge and experience, planning must be done **in collaboration with the developers of the work and work system** (e.g. managers and engineers), **the actors of the workplace** (e.g. supervisors and workers) and **representatives of the safety and health personnel**. This approach is also referred to as **participatory design**.

Design criteria: Characteristics of well-designed work tasks (1)

To avoid work-related stress, the following work task design principles should be observed as closely as possible. These principles have been developed over decades from studies on work psychology. The principles, **"Characteristics of well designed work tasks"** are stated in the **European ergonomics standard EN-614:2**:

a) **Use the competencies and skills** of the workers

b) **Create meaningful and "whole" tasks** - not isolated fragments of tasks

c) **Make their contribution to the total output identifiable** to the worker

d) **Use the variety of the worker's skills**, with an appropriate combination of:

- simple routine actions
- acting by application of rules
- reasoning: analysing the process and developing needed actions

Design criteria: Characteristics of well-designed work tasks (2)

e) **Allow an appropriate degree of freedom and autonomy** to the worker, e.g. to choose the method of task accomplishment, or to determine priorities, pace and the procedure for the work task

f) **Provide sufficient feedback on the task performance** to the worker

g) **Provide opportunities to develop existing skills and acquire new ones**

h) **Avoid overload as well as underload** that may lead to unnecessary or excessive strain, fatigue or errors

i) **Avoid repetitiveness**, which may lead to physical disorders as well as to feelings of monotony, loss of motivation, boredom or to dissatisfaction

j) **Avoid working alone** without opportunities for social and functional contacts

(for more details, see European standard EN 614:2)

To summarize, **the work task should promote the mental growth of the worker, and provide a feeling of personal success and progression.** This is necessary for psychosocial well-being at work.

Means of developing repetitive and paced work tasks/jobs

To counteract the deficiencies of highly fragmented, narrowly loading work tasks three basic methods are recommended: **Job rotation**, **job enlargement** and **job enrichment**. These principles are often applied by organizing the activities into **groups** or **teams**:

- **job rotation** (see illustration below) refers to rotating workers between different tasks that load the worker in different ways
- **job enrichment** refers to adding more demanding subtasks to the core task, such as planning the job or controlling the quality of the product
- **job enlargement** refers to adding similar types of subtasks to the work performed by one worker.

FEES federation of european ergonomics societies

Ergonomic guidelines are the basis for risk prevention

Ergonomics guidelines are needed for proper risk prevention in the design stage!

Appropriate guidelines are published in European ergonomics (and safety) standards[1]**,** e.g.:

- Ergonomics design principles (EN 614-1, EN 614-2 and EN ISO 6385)
- Acceptable postures and forces (EN-1005-series)
- Anthropometric workplace measurement (EN ISO 14738)
- Access openings, for the whole body and body parts (EN 547-series)
- Presentation of information (EN 894-series, parts in 9241 series)
- Human work activities in regard to human cognition (EN 894-series)
- Human work activities in order to control mental workload (EN ISO 10075-series)
- Human centred design for interactive systems (EN ISO 9241 Part 210)
- Environmental factors (lighting, temperature etc.) (e.g. EN 12464, EN ISO 11399)
- Passageways and stairs (EN ISO 14122-series)

[1] standards are distributed by the national standardisation associations.

Ergonomics: going beyond health and safety

- By its definition, **ergonomics is not limited to the health and safety aspects of work** (the dual aims of ergonomics are well-being and efficiency).
- By the comprehensive development of the work activity **human resources can be appropriately utilized, and the total output of the work-system optimized.**
- **Well-functioning and productive work-systems are important to the well-being of workers**. They support the stable development of enterprises and their workplaces, and consequently personal development of workers, their feelings of success and progression and ultimately the welfare of their families.
- As they take the effectiveness of the systems into account, **ergonomics applications should be attractive for managers**, who make the decisions on the workplace investments.

FEES federation of european ergonomics societies

Ergonomics in workplace design: good for health and good for business!

By application of ergonomics in workplace design, the production systems and workplaces can be improved **both for the worker and for the organization.**

To summarise, the following outcomes are typically achieved:

- Better **satisfaction, motivation and commitment** of the worker
- Lower rate of **accidents** and fewer **sickness absences**
- **Less disturbances and losses in production** due to human error
- Better **quality**, less careless work
- **Fluent operation**, the right operations in the easiest way
- **Less need for corrections** later: Less costs of late changes

Experiences of the EME 2014-2015

- Following the **EME 2014**, please gather information on the actions related to the EME (events, articles, initiatives, etc.) that took place in your country

- This information will be used to develop future EME campaigns and, to share your experiences amongst the national societies of the FEES

- **PLEASE REPORT** this information to the Communication and Promotion Committee of the FEES, via
  Martti Launis, e-mail: martti.launis@ttl.fi

Thank you

Let us work together for the prevention of work-related psycho-social risks – ergonomists together with other OHS specialists and with the people at work!

Let us show the role and potential of ERGONOMICS in such risk prevention!

Thank you for your interest!

The FEES-campaign European Month of Ergonomics to promote ergonomics in Europe

FEES – Federation of European Ergonomics Societies
www.fees-network.org

ergoSHAPE - a design oriented ergonomic tool for AutoCAD

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Abstract

In order to widen the use of computer-aided man model systems, the practical needs of designing should be taken into account when these systems are developed. The paper discusses the principles of such development and describes the construction of a man model system into a well known professional CAD program.

1. INTRODUCTION

1.1. Requirements for the development of man models

Along with the increased use of computer-aided designing (CAD), the graphic and geometric man models have become a self-evident tool in ergonomic planning and evaluation. The man models serve as a tool for several ergonomic tasks, e.g. anthropometric dimensioning of the workplace, evaluation of the postures, illustration of plans, etc. Their feasibility in ensuring ergonomic consideration in planning has been stated generally.

The man model systems have been available for years, but assumably they still play a marginal role in industrial planning. If the widest possible use of man models is aimed at, their usability should be as great as possible. Properties of such usability have been proposed in an earlier paper [1]. According to the authors the man models should

- be easily and quickly accessible from the designers' own CAD system
- fit the existing ways to documentate the plans
- be easy to perceive and manipulate
- have a distinct indication of body surface and joint location
- have a pleasant, simple and credible appearance
- have a simple and logical operating system.

In other words, the man model system should motivate usage, have no obstacles to usage and require no special training.

A study of the utilization of such systems in industrial workplace designing [2] showed that there are considerable shortcomings in the design practices and the design documentation, which affect the introduction of the man model systems in designing. For example, the planning of workplaces is done in the easiest way possible and the documentation of the plans is minimal, most often restricted to reduced layout drawings. Accurate and detailed drawings of the workplace are rare. The available drawings are prepared mainly for technical purposes, e.g. for manufacturing or maintenance. In general, the designers are not enthusiastic about any separate ergonomics design system. They favour the integration of all necessary design aspects, e.g. technical, functional, ergonomic, legislative, economic etc., into the same design system.

In the mentioned study the designers carried out practical design tasks with both two-dimensional (2D) and three-dimensional (3D) man models. They considered the 2D model most suitable for accurate ergonomic evaluations in the design phase, and the 3D models suitable only for overall visualization of the ready plans.

1.2. Questions concerning alternative developments

At present one of the basic questions of the man model development concerns the relationship between the man model system and the design system. In practice, a man model system can be constructed in two ways, as an element of a general design program or as an independent modelling program. Both solutions have advantages and disadvantages, which should be discussed.

Programming of the man model as an independent software allows developing of a great many sophisticated features and a logical interface for the system. The system may have advanced properties for modelling the environment, too. Such a system does not, however, work interactively with widely used professional CAD programs, although the drawings may be transferable as such from one program to another.

The possibilities are limited in the development of man model system as an element of a professional CAD program, but the system will be more easily accessible and more convenient for the user of this program.

The choice between these two alternatives depends, for example, on the nature of ergonomic design activity, on whether the system is used for specific intensive ergonomic evaluations or as an everyday tool in routine designing.

The majority of the man model systems available so far are independent software packages. This paper describes one example of the other alternative, i.e. an ergonomic design system which have been created inside the AutoCAD[1] design program by using the properties of this program.

2. DESCRIPTION OF THE ergoSHAPE SYSTEM

2.1 Linkage to the AutoCAD program

The ergoSHAPE system has been constructed in the AutoCAD program as drawing files, menu files and AutoLISP program files. Basically, the structure of the system is similar to other supplementary software packages of AutoCAD (e.g. engineering and architectural packages). The body segments of man models are constructed as subdrawings (blocks in AutoCAD), similarly to any technical element of the plan. The man models are chosen, inserted and manipulated by the ready made macrocommands which are compiled of normal AutoCAD commands.

This is the basis of the interactive use of the man models in designing. It implies that the full capacity of the design program is in the use at all times, for detailed technical drawing and for manipulating the man models. The system is accessible at any time of designing by picking up the command menu in question. There is no need to move from one program to another. The models and their parts can be edited in many ways (copy, scale), they can be taken into the current drawing and switched off easily, several models can be used at the same time at the same place and viewed differently (layer on/off), the executed changes in posture can be cancelled in a long chain (undo), and the intended change of posture is visible when the body segments are moved with the pointer device (drag mode). In fact, for manipulating man models, an advanced professional CAD program provides a lot of useful features which may not be feasible in a separate specialized program. From the user's point of view the question is not only one of flexibility or ease of use, but also of the logical similarity to the other design activity which the designer is used to.

2.2. Elements of the ergoSHAPE system

The ergoSHAPE system includes 2D man models constructed in different projections (an example in figure 1), and a 3D man model (figures 2 and 3). For evaluating postural stress, there is also a specific 2D model for biomechanical calculation (figure 4).

The needs for various kinds of information are being fulfilled by other ergonomic data, which can be presented in graphic form. These 'recommendation charts' include direct guidelines for working zones, maintenance space, specific work situations, etc. (an example in figure 1). This set of charts can be completed by the user's own applications, too.

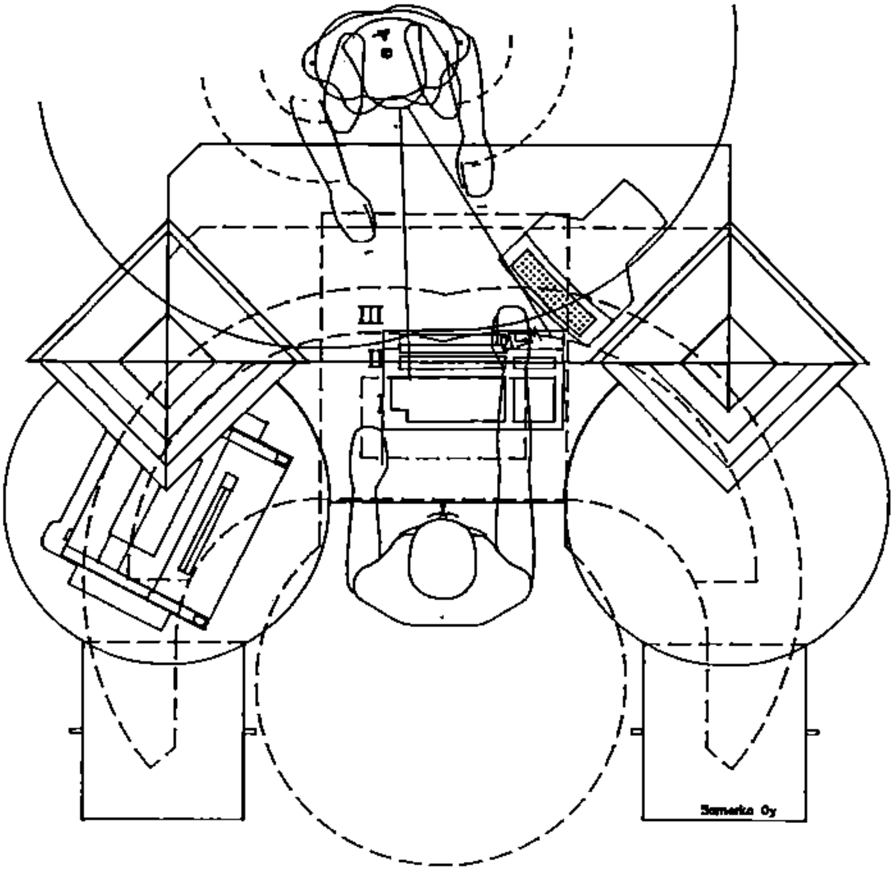


Figure 1. The use of the ergoSHAPE system in the designing of a customer-service workstation in top projection; a two-dimensional movable man model (above) and a recommendation chart indicating working zones and space for the legs and the chair.

In addition, the system includes an ergonomic checklist, i.e. basic ergonomic design guidelines in textual and numeric form. This is an application of a small text editor, which is accessed from the ergoSHAPE menu, without the need for ending the current drawing. The user can complete this text file with his own remarks or recommendations, and can modify the original checklist, too.

2.3. 2D man models for varying design situations

As noted earlier, two-dimensionality is still preferred in detailed designing. There are many practical reasons for this. The traditional 2D projection drawings are sufficient in most cases and allow a richness of details with a minor amount of work and with low costs. In introducing ergonomics into planning, two-dimensional man models are easy to learn, use and perceive.

In order to ensure the ease of adoption of man models, the system provides 2D man models of different levels of movability, from man models consisting of 9 movable body segments to a set of fixed models constructed in several postures. The fixed models (one block) are intended to be used for rapid testing of the plan.

The man models can be supplied with lines and arcs indicating maximal reach, the easy movement of visual axis and some references for reading distances.

2.4. 3D man models of the ergoSHAPE system

Although the 3D modelling is used, the actual designing is obviously done two-dimensionally most of the time. Designers prefer to view design objects right-angularly in respect to their structure in order to define their dimensions accurately. Oblique viewing directions are favoured only when the overall view of the plan is needed.

The 3D man model of the ergoSHAPE system is based on the assumption that the most important viewing directions of the man model are still the right-angular ones, i.e. the side, front and top view. The body segments are constructed by combining the corresponding two-dimensional body segments right-angularly together.

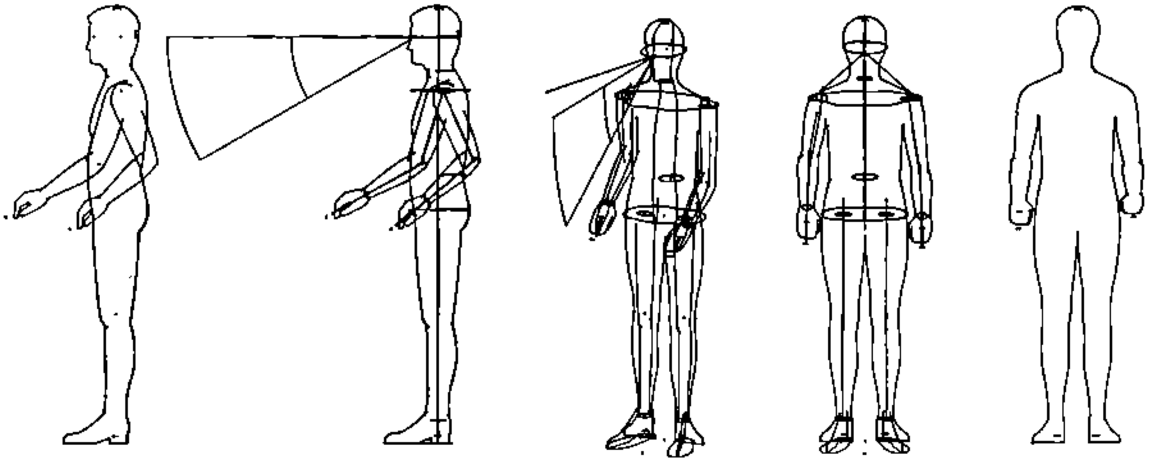


Figure 2. A three-dimensional man model viewed from different directions. In the right-angular projections (side, front and top) the unnecessary lines can be turned off.

The model has only the basic contour lines and no surface, and thus it may be called 'semi-three-dimensional'. When the man model is viewed from the above-mentioned main directions, it resembles the corresponding 2D man model. In this situation, the unnecessary lines belonging to other projections can be turned off with a macrocommand to simplify the visual appearance (figure 2).

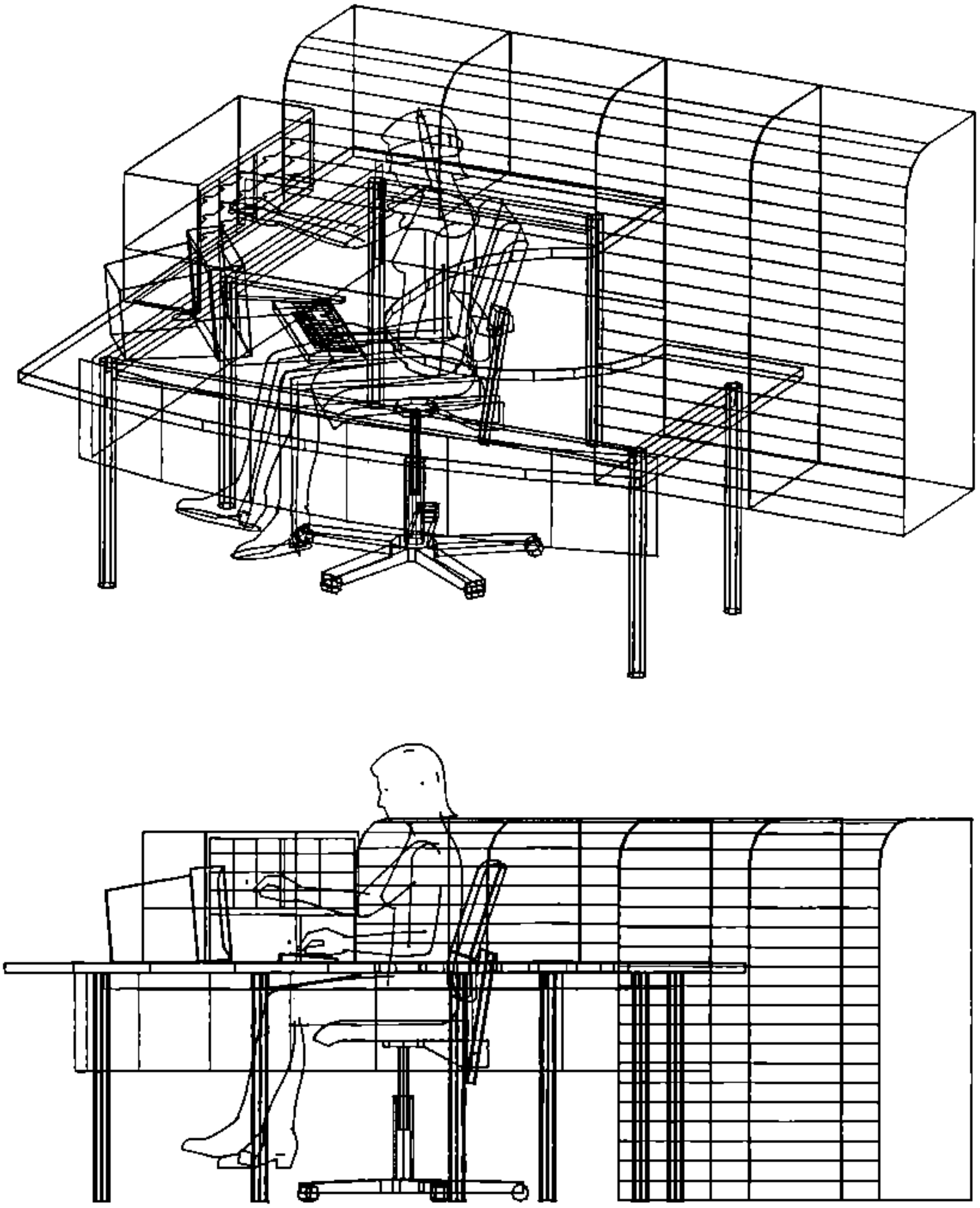


Figure 3. The evaluation of an office workstation with the help of a three-dimensional man model; comparison between an oblique projection (above) and the side view projection (below).

An advantage of this structure is that the contour lines can be defined unambiguously to meet the actual body surface, as compared to the structure of geometrically simplified 3D models. Moreover, this reduced structure of the man model ensures the rapid and interactive work with the microcomputer.

An obvious disadvantage of the structure is that the model looks too thin when it is viewed from an oblique direction. As a striking curiosity, the female model has only one breast on the centerline of the body (figure 3).

The 3D models are manipulated in the specific way of the 3D modelling of the AutoCAD program. The operating plane is determined first (UCS, user coordinate system) and then the man model is moved two-dimensionally by the pointer device. The usual operating planes are determined by macrocommands. For rotating a body segment around its axis, this plane is indicated by a circle (figure 2).

As the radical changing of the posture (e.g. from standing to squatting) is generally time consuming in 3D modelling, the ergoSHAPE man models are inserted to the plan in a selected posture. A set of postures are predefined, but they can be defined by the user, too.

2.5. Structure and dimensioning of the man model

The designing includes constant testing of variations and changing of design parameters and requires constant changing of the posture, too. This is why the anatomic structure have been kept as simple as possible, and the dimensional properties unambiguous.

The number of body segments is restricted to a minimum, to 9 (2D model) and to 15 (3D model), from which it follows that the trunk is compiled of only two segments. This restriction is compensated by conforming the upper trunk to an estimated slump of the spinal column, and by locating the 'back joint' relatively close to the contour line of the back. Thus in the varying bent sitting postures the distance between the hip joint and shoulder joint will vary in relation to the bending of the trunk [3].

For practical reasons, the shoulder joint is a fixed point. This point is, however, located so as to fulfill the assumed anthropometric demands of the normal working situations. The point is located few centimeters higher than the respective anatomic centerpoint of movement and the upper arm is correspondingly lengthened. By doing so, the elbow height of the model corresponds to the relaxed elbow height, and the forward and upward reaches of the model correspond to the stretched reach of anthropometric data.

Both sitting and standing versions of the models are available to ensure accurate fitting to the seating constructions. In the sitting version it is assumed that the rear sides of the thigh and the buttocks are compressed against a flat, hard surface.

The top projection of the 2D ergoSHAPE man model is compiled of five cross sections of the body. The lower arm is assumed to be near horizontal. The guiding arcs help to locate the elbow joint according to the projected length of the upperarm elevated 30 or 90 degrees (figure 1).

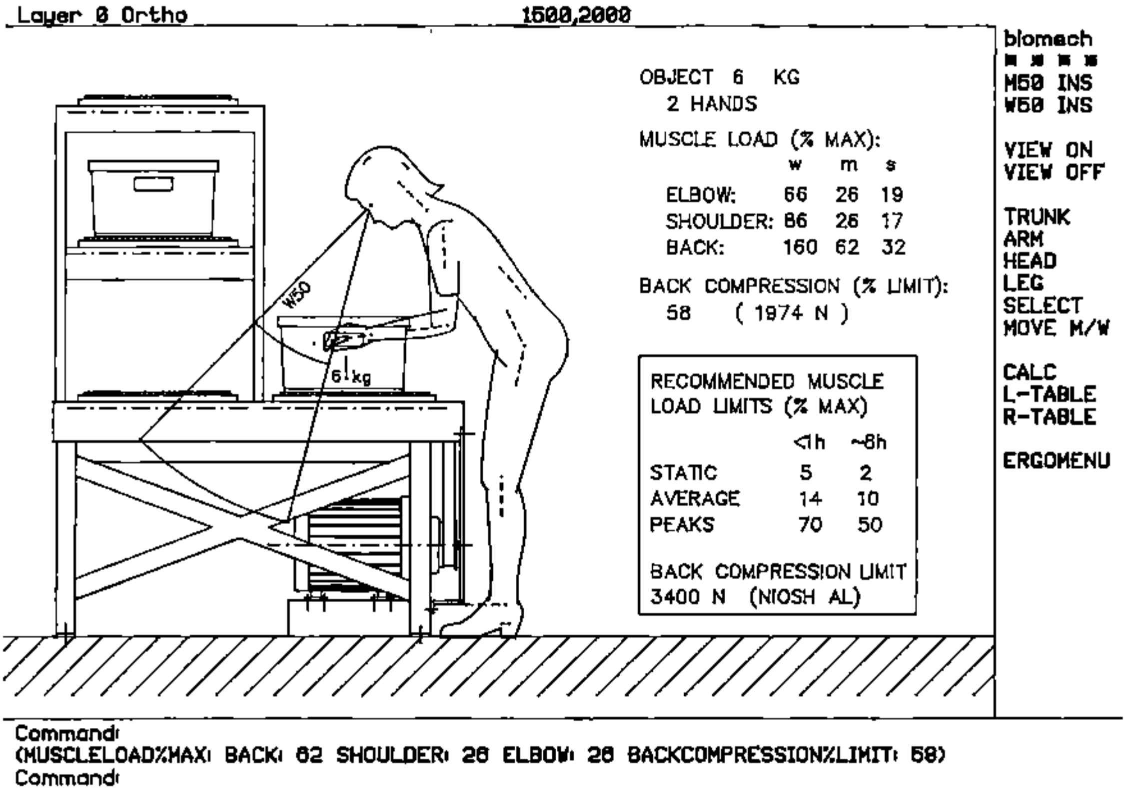
2.6. Anthropometry of the man models

The anthropometric dimensions of the man models are based on anthropometric data concerning the 50th percentile man and woman of several North European and North American sources. The small and large models (5th and 95th percentile) are scaled from the medium size model in relation to differences of the overall height. The user can specify the height also individually by giving the overall height in centimeters. For special purposes, each body segment can be scaled separately by using the scale factors tabulated in the manual.

2.7. Biomechanical modelling

The biomechanical modelling is done with the AutoLISP programming language, which allows running programs interactively with the execution of the commands of AutoCAD. Specific macrocommands and a 2D man model are constructed to update the location of each body segment (centers of gravity), when the posture is moved. The program calculates the strength required in a defined posture, taking into account a given external mass. The formula and data applied in the program are adopted from Chaffin and Andersson [4].

The program displays the results as a percentage of the maximum isometric strength of a weak, a medium strong and a strong person (5th, 50th and 95th percentiles). These values can be compared to the displayed recommendations [5] for a wide range of loading situations, from light static work to heavy momentary stress (figure 4).



```
Layer 0 Ortho                1500,2000
```

```
OBJECT  6   KG
  2 HANDS
MUSCLE LOAD (% MAX):
                 w    m   s
  ELBOW:        66   26  19
  SHOULDER:     86   26  17
  BACK:        160   62  32
BACK COMPRESSION (% LIMIT):
  58     ( 1974 N )
```

```
RECOMMENDED MUSCLE
LOAD LIMITS (% MAX)

              <1h   ~8h
STATIC         5     2
AVERAGE       14    10
PEAKS         70    50

BACK COMPRESSION LIMIT
3400 N   (NIOSH AL)
```

```
Command:
(MUSCLELOAD%MAX: BACK: 62 SHOULDER: 26 ELBOW: 26 BACKCOMPRESSION%LIMIT: 58)
Command:
```

Figure 4. The screen of the AutoCAD program when the biomechanical calculation of the ergoSHAPE system is used: the menu with the set of macrocommands for the execution of calculation (on the right), the results of the calculation (above), and the concerning recommendations (in the box).

The biomechanical application of the ergoSHAPE system is intended to provide the designer an analytic tool to evaluate the stress in various work situations, instead of giving a fixed value.

3. DISCUSSION AND CONCLUSION

The described system is only one possible way of constructing an ergonomic system into AutoCAD. This development has been based on the concept of the major needs of designing, and has followed gradually the development of the AutoCAD program and the growth of the capacity of microcomputers. Up to now, the work done has shown that this kind of development can lead to a functioning result which simultaneously fulfills the basic demands of designing. And more than this, the development work itself has revealed the endless expansion possibilities of such a system, which can be extended flexibly by institutions or experienced designers themselves.

The future trends will give support to this approach more and more. As the use of such a professional CAD program increases, the number of various application packages will increase, too. The designers' wish for the integration of all design data in one system will thus be coming true. Only then can one anticipate the wide use of a man model system in designing. As an example of this trend, the essential part of the ergoSHAPE system has recently been integrated into an engineering package of AutoCAD, as well as to another professional CAD program.

[1] Autocad is a registered trademark of Autodesk, Inc.

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Investment handbook for facilitating collaborative designing of production lines

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Abstract

The development of the designing of production lines and associated machinery was carried out in the sawmill industry. The aim was to incorporate ergonomics and work environment considerations into the entire investment design process and to promote the involvement of personnel groups in designing. The development project involved the representatives of both the personnel of a Finnish sawmill company, and the two manufacturers of the sawmill machinery. Together with the researchers of the FIOH they analysed and improved design practices through a series of workshops and group sessions. As a result, to support different design events, a set of tools was generated; guidance on the control of the investment project, checklists and guidelines for work task design and workplace design, work environment factor specifications, and forms to be filled in for carrying out risk assessment of both the machinery and the workplace. The tools were compiled into an 'investment hand book', accessible from the company's intranet, with the purpose of spreading the use of the tools within the organization.

Keywords: design process, participatory design, work task design, workplace design, work environment design, sawmill industry

1. Introduction

In the technology-driven industry, the investment process is crucial in determining the quality of the work environment and work activity. As a general notion, in technical design the work activity is poorly considered, the main emphasis being on the increase of production capacity and the decrease of human resources [1, 2]. In the investment process, an additional problem is the confusion between the responsibilities of the buyer and the manufacturer of the machinery, especially when it comes to work activity and the work environment [3]. According to European regulations, manufacturers are responsible for managing the safety (including human work activity) of the machinery. In practice, the machinery is increasingly adapted to the client's specific needs, and much communication on local requirements is needed. The production line may also consist of separate components of machinery, and in this case the buyer is responsible for the safety of the entire machinery, but may not however be sufficiently prepared for this.

While investment projects are realised mainly by technical experts, the understanding of the consequences of the solutions on the health, safety and well-being of the employees is dispersed throughout the organization. This knowledge and experience should be gathered and utilised in the investment projects in order to design sustainable solutions. Participatory and collaborative actions have been introduced [4, 5], but the means of successfully accomplishing them in the limited time schedule of the projects are not yet well established.

In the sawmill industry, the work tasks typically consist of control and maintenance, and they are determined to a great extent by the choice of automation level, design of the control rooms and interface, and design of the production machinery and associated maintenance objects. The present trend is to minimise the number of operators with the help of automation, camera monitoring of production lines, and remote control of assisting tasks. The tasks of the operators, e.g. the operation of the machinery, monitoring of the production line, adjustments, maintenance, and resolving disturbances on the conveyors, are the responsibility of only a few operators. A possible consequence of this is that the operators become overloaded, resulting in turn in unsafe operation, especially during production disturbances.

The sawmill machinery is ordered from specialised manufacturers, but the requirements and specifications are determined by the buyer, mostly by a local unit of the sawmill company. Within sawmill industry, fairly few resources are typically available for the preliminary design, and therefore the analysis of human work tasks and the setting of human goals on the environment remain insufficient.

The project started in 5/2004 and will end in 12/2006. The project is partly funded by The Finnish Work Environment Fund.

1.1. Aim of the project

The development project was organized in order to improve design practices in the investment projects of the sawmill industry. The main aim was to incorporate ergonomics and work environment considerations into the entire investment process. This requires collaboration within different domains and knowledge areas, and thus we aimed for the involvement of all relevant personnel groups in the development project. Another aim was the generation of practical tools to support each developed practice and new action in order to make them feasible. The ultimate goal was to generate an investment handbook for human considerations, accessible from the company's intranet. The purpose of the handbook was to facilitate the application of the new practices, and to spread them throughout the organization.

Two versions of the tools and the handbook were planned, one specifically for the participating sawmill company, and a generic one for the sawmill industry in general.

2. Material, process and methods

2.1. Participating organizations and persons

The representatives (managers, supervisors, employees, occupational health and safety experts) of three sawmill units of a large Finnish sawmill company participated in the project, together with the representatives of the two manufacturers of the sawmill machinery. The evaluation stage also involved other sawmill units of the company. In addition, experts in ergonomics, work organisations, occupational safety and occupational hygiene from the FIOH also participated in the project.

2.2. The development process

The project consisted of the following stages: 1) evaluation of the present investment design practices, 2) description of an improved investment process and the required actions at each stage, 3) development of tools for carrying out the actions, 4) testing of the tools in the design events and in the investment projects, and 5) development of the investment handbook.

2.3. The collaborative development method

The development project comprised a series of workshops and group sessions. The workshops of the entire project group were held approximately every other month. Discussion on the central principles, decisions on the forms of action in the project, and evaluation of the results took place in the workshops. Between the workshops, working groups gathered to elaborate on ideas and prepare proposals for the workshops. The working groups concentrated on specific topics and developed instructions and tools. Drafts for these sessions were made by individuals or small groups, either in the sawmill company or in the FIOH, depending on the topic. The drafts were also circulated by e-mail for gathering comments in the working group.

The purpose of this procedure was to ensure that every representative of any interested party of the project group had the opportunity to provide his/her contribution to the results.

Every representative was considered a source of important knowledge or experience for the design of work activity and the work environment. They also promoted their own areas of interest (e.g. health and safety, or, fluency of operations). The representatives of the FIOH acted as facilitators and moderators of the workshops and the group meetings. They also acted as experts in ergonomic workplace design, work task design, occupational hygiene and safety, and in the principles of collaborative and participatory design approaches. In such a role they organized and guided the development process, and brought a scientific (e.g. principles and guidelines) and normative (e.g. regulations and standards) contribution to the development of the tools and to the content of the handbook.

In the workshops, the participants received short explanations on different topics to bridge the gap between different knowledge areas, e.g. information on the determinants of the sawmill processes (products, markets, technology, etc.), information on the preconditions of the investment process (legislative regulations, investment instructions of the company), the principles of risk assessment associated with machinery investments, and the principles of protection against typical health hazards within the sawmill branch (wood dust, terpenes, noise).

A follow-up group periodically followed the project, consisting of representatives from the sawmill company, from the FIOH, and from the Finnish Work Environment Fund. The project group also organized events to spread information to other units of the company. These other units participated in the tests of the tools and in the evaluation of other outcomes of the project group. The feedback was utilized in the completion of the tools and the handbook.

3. The results and discussion

3.1. Evaluation of present investment design practices

The present investment practices were analysed and evaluated in three workshops. A realised investment project of a participating unit was described and analysed in detail with the help of e.g. investment plans, schedules, a chart of project organization, and key figures. Also, participants' experiences in other investment projects were analysed and discussed, first in small groups and then with the entire group. The wall-board technique was used for collecting, arranging and discussing the viewpoints.

The major shortcomings identified were too short a time-scale, and insufficient resources allocated to the preliminary design prior to the investment decision and agreement of the contract with the manufacturer. This resulted in poorly determined work tasks and poorly specified requirements for the workplaces and work environment factors. Also, the division of responsibilities between the buyer (the sawmill unit) and the manufacturer of the machinery remained unclear. In practice, the design of the workplace and work tasks were often excluded from the manufacturer's responsibility, but only a few resources were available for this from the buyer's side.

The project group concluded that resources are needed to strengthen preliminary design. At present, there are no full-time designers available in the sawmill unit, and it is the production managers who are nominated to be the project leader, in addition to their daily duties. Also the time-scale is very short - as a tradition in the sawmill industry - only a couple of months are allocated for preliminary design, and less than a year for the entire investment project.

3.2. Description of an improved investment process and required actions at each stage

In collaborative design it is particularly important to have a common understanding of the process and its stages, including the actions to be taken at each separate stage. The project group identified the stages of the investment process based on the investment instructions of the company and the experience of several investment projects. For all these stages the necessary technical and functional actions were described, and were complemented by human-related actions. The company-specific description consists of an extensive table, showing the market-orientated, legislative, technical and contract-associated actions at each stage, added by actions to consider the work environment, work tasks, user interface, workplace and training. This type of description shows the interdependence of these various types of actions, which is essential for ensuring the practical application of the description.

The actions needed at the early stages of the process were emphasized. The level of automation, work task formulation and training requirements, and subsequently the number of operators, needed to be determined already in strategic design before the actual decision of starting the project, as they greatly influence the overall costs of the investment. Before this could be done, these interdependent factors needed to be sufficiently analysed in relation to each other. Similarly, the environmental factor requirements needed to be identified in the beginning. The new requirements on e.g. quality of indoor air, sometimes require costly protection technologies.

Another important stage of the process was the contract negotiations, as all necessary specifications affecting the costs had to be included in detail at this stage. Examples of these are specifications of the work environment factors, work stations and facilitating equipment. If they are not determined clearly in the contract, they may not be taken into account at all by the manufacturers, and additional costs can be expected at later stages.

3.3. Development of tools for carrying out the actions

The project group proposed the tools as a means to carry out the required actions in conjunction with the description of the investment process. The tools consisted of several different means of facilitating design. Some of them were principles and schemes to enhance understanding within the project group; to be later used as information for those having not participated in the development project. Examples of this are: the principles and benefits of collaborative and participative design approach; the principles of risk assessment as set out in the European safety regulations; a descriptive model of interactions between important design factors and the objects of design, such as the determinants of the production process; the level of automation; machine design; interface design; training and work task design, etc. At a later stage, we integrated these general principles and descriptive schemes into the introductory parts of the investment handbook.

The other tools were intended to be used in the design events, i.e. design criteria and guidelines, checklists and excel-forms to make concrete analyses, and instructions and guides to control the process. These practical tools are described and categorised according to their purpose as follows:

1) Illustration of the investment as a whole

- Description of the design process (as described earlier), as a guiding document throughout the investment project

2) Control, guidance and evaluation of the investment project

- Guides for carrying out investment negotiations
- Guides and checklist for dividing the tasks and responsibilities between the buyer and the manufacturer, particularly concerning human work activity
- Guides for evaluation of the project, both the result of the design and the effectiveness and fluency of the modes of design activity
- List of measures and indicators of the success of the investment project, e.g. statistics on sick-leaves and production disturbances, disturbances and breakdowns in the design process, number of corrections required for the designs, results of the workplace surveys and the work climate surveys
- 'Project diary', a tool for gathering data and experiences throughout the investment project

3) Work task design

- Checklist for making the preliminary plan for the work organization
- Checklist for making preliminary plan for the manning of the machinery
- Form (excel) for analysing benefits and shortcomings of the work activity within the existing system
- Form (excel) to perform function analysis and work task specification for the design of the new system
- Description of the work task design process
- List of objectives for the work task design

4) Planning of training

- Checklist for planning the training programme and training events

5) Workplace design

- List of the objectives for workplace design
- Checklist for assessing and improving workstations and for early identification of possible risk factors, to be used throughout the process, from reference workstations and workstation models at the laboratories of the manufacturers (benchmarking) to the gathering of feedback for future design from the actualized workstations
- Design guidelines for the workstations (control stations in cabins and at the process line), including guidelines for locating the operator in relation to the viewing objects (pieces of sawn timber, control monitors, etc.), guidelines for maintenance conditions, e.g. principles for easy operation, access to the objects, design of passage ways, maintenance platforms and facilitating devices

6) Work environment factors

- Specifications of the levels of environmental factors, such as those for wood dust, terpenes, noise and vibration, illumination and thermal conditions, and formulas for different exposure levels (time spent at different locations, e.g. in the control room and at the process line)

7) Risk assessment

- Form (excel) for the risk assessment of the machinery, based on the relevant safety standard of the EU [6]
- Form (excel) for risk assessment at the work place, based on a safety checklist prepared particularly for sawmills and planing mills (part of a larger safety check for different fields, by the FIOH [7])
- Tool for gathering the documents providing conformity with European safety regulations.

The tools should be easy to use in order to be feasible in the busy time schedule of the design project and in the collaboration of different personnel groups. They are short, only from one to a few pages each, and in some cases they include concrete examples showing how to fill the checklists or tables. However as they are simple, they may not be sufficient for complex situations. Therefore they include references to more detailed instructions, and where available, to relevant standards.

We have also incorporated the principles set out in the European standards on the safety of machinery into the tools as far as is possible. They are normative for the manufacturers, and can be also seen as such for the buyer who has to comply with the same regulations when constructing combinations of several machines. As an example, the tool for risk assessment of the machinery is based on the list of hazards and hazardous situations at the machinery, as presented in EN 1050 [6].

It was also important to incorporate some of the European ergonomics standards into the tools. These standard documents have been considered difficult to use in everyday design [8], and thus they needed to be elaborated in the group sessions in order to make them concretely applicable for the design tasks of the company. As examples, the description of the design process follows the principle described in EN 614-1, concerning incorporation of ergonomic principles into the design process [9]. The tools for the design of work tasks follow the principles described in EN 614-2 [10].

3.3. Testing of the tools in the design events and investment projects

The working groups first tested the tools in existing cases, and where available, in concrete evaluation or design events at the participating units of the sawmill company, and modified them accordingly. Next, they were evaluated in other units of the company, by persons having no prior experience or knowledge of them. After the evaluation, these persons were interviewed. They found the tools necessary, useful and feasible, and only minor amendments were proposed. A need for explanatory information on the background was expressed, however, which was obvious when testing single tools separately.

Some of the tests were performed in conjunction with an investment project, but unfortunately the investment projects available during the period of this development project concerned only smaller or partial technical improvements. The testing of the tools in investment projects will continue till the end of 2006.

3.4 Development of the investment handbook

The tools have been compiled and modified to create the 'investment handbook' for human considerations. It has been realised by the Microsoft Content Management Server (CMS) in the extranet of the FIOH, and is accessible from the intranet of the sawmill company (as well as in other companies in the future). Through this arrangement, updating the content will be easy in the future.

The tools can be opened from several places of the handbook. One option is to open them from the appropriate places in the description of the investment process, to be immediately at hand when needed. The other is the list of tools describing their purpose in the design process and giving information on their practical use. The latter option also supports their use in smaller-scale design and improvement projects.

Important elements can be printed as hard copies (e.g. instructions of use), and tools which are meant to be filled in field conditions (e.g. at meetings or at the work place) can be printed and loaded as original word- or excel-files.

The handbook also contains general justification of new ways of collaborative design, and guidance for selecting and using the tools in the projects.

The need for a company-specific handbook appeared to be limited to only a few separate tools. Therefore both the specific one for the participating company and the generic one for the sawmill industry were prepared in parallel. The main differences are in the description of the investment process, and in the connections to the general investment instructions of the participating company. Testing of the entire handbook in real investment projects will continue till the end of 2006.

4. Concluding remarks

The collaboration of the personnel is obviously a way to ensure the usefulness, feasibility and acceptance of the outcomes of the development processes. The new actions and tools are initiated by the representatives of the company, and are based on their shared views and experiences. They are concrete, and tailored to the sawmill context and to the situations of the project, and they take into account the limitations of the company (resources and time limits).

It will, however, be a challenge to apply them to real investment projects in the near future, when time has passed since this period of intensive action. It will also be a challenge for other people to apply it in the other units of the company. The project group developing the tools had an insight into the need for these tools from the beginning, and through the development process, learnt how to use them and experienced the interdependencies of separate actions, and their utility. New users of the handbook and the tools will lack this understanding. Additional training or facilitating activities may be needed in order to carry out future projects successfully.

As widely recognised collaboration may be the only way to achieve real changes and lasting results in organizations. However, collaboration is a very demanding way of developing new practices. It is a challenge to maintain balanced collaboration, as the level of experience and knowledge of important domains vary greatly among participants. Also the willingness and preconditions for providing resources on the lengthy development project vary. On the company's side, time is marginal, and in many cases the role of the researchers of the FIOH was strong in the preparation of the tools, not only in those which were in their expertise area (e.g. ergonomics, occupational hygiene), but also in those in the company's core interest area (processes, reliability, safety). However, the steadily paced, gradually advancing development process made it possible to avoid problems in this respect.

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Computer-Aided Ergonomics

A Researcher's Guide

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Chapter 5

Man models in the ergonomic design of workplaces with the microcomputer

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Abstract. Two man model systems were developed for the computer-aided design of workplaces, i.e. two-dimensional ergoSHAPE to supplement a widely used micro-CAD program, and three-dimensional ergoSPACE as an independent program. The systems are based on the anthropometry and biomechanics of the human body, and also include schematic recommendation charts. The study was carried out in three enterprises to investigate how the systems could be integrated to the present design practice of the workplaces, how the man models suited the different design tasks, and how the different groups were able to use the man models. The methods consisted of interviews, the subjects' assessments of the technical drawings of workplaces, design tasks, and determinations of workplace dimensions. The study revealed that workplaces were poorly documented, being restricted to the layout sketches. The arrangements of the work and workplace were left mainly to the supervisors. In the design of highly mechanized workplaces the documentation was complete, but the physical human work was not experienced as an important or critical design factor. The man models were of great help to the occupational health and safety personnel in assessing the drawings. The planners expected simple, schematic recommendations but, on the other hand, were interested in the most natural and detailed man models. The simplified three-dimensional system is not yet useful for designing workplaces, due to its overreduced unnatural and confusing visual appearance. In general, the man model is a strong reference for workplace measurements, leading to a similar result within different occupational groups.

Keywords: Man models; Anthropometry; Biomechanics; Workplace design; Computer-aided design.

Introduction

The difficulty of conveying ergonomic knowledge, even when it is trivial, to the planning of workplaces has been widely experienced. Constant haste in the design process, constantly changing specifications and demands for the design, and the technical complexity of modern workplaces create a situation in which ergonomic considerations are simply disregarded by industrial engineers. In such a situation, the available ergonomic literature usually only creates confusion by its heterogeneity. The engineers evidently lack coherent and appropriate ergonomic knowledge, or it is in the wrong form to be used in routine design work. The following criteria can be recommended for better ergonomic design tools (Launis *et al.*, 1988):

1. They should be easy and fast to use, at exactly the right phase of designing.
2. They should be universally applicable to different problems and new situations.
3. They should be capable of tackling many design goals and tasks simultaneously, e.g. analysis, synthesis, documentation and evaluation.
4. They should be illustrative in order to facilitate cooperation between different experts and occupational groups.
5. They should have a clear and rational basis in order to be applicable to difficult or critical situations.
6. Special training should not be required of the user but the tools should be utilizable for expert consultations, too.

As a universal ergonomic design tool, two-dimensional anthropometric manikins and drawing templates have been introduced. But this equipment has never been taken into wide design usage, probably because of practical problems caused by different body sizes and various drawing scales. On the other hand, the sophisticated man model programs on the market so far have been too expensive to be widely used in design practice.

Man model systems

To solve the dilemma mentioned previously, two easy-to-use microcomputer-based man model systems have been developed at the Institute of Occupational Health in Finland. The

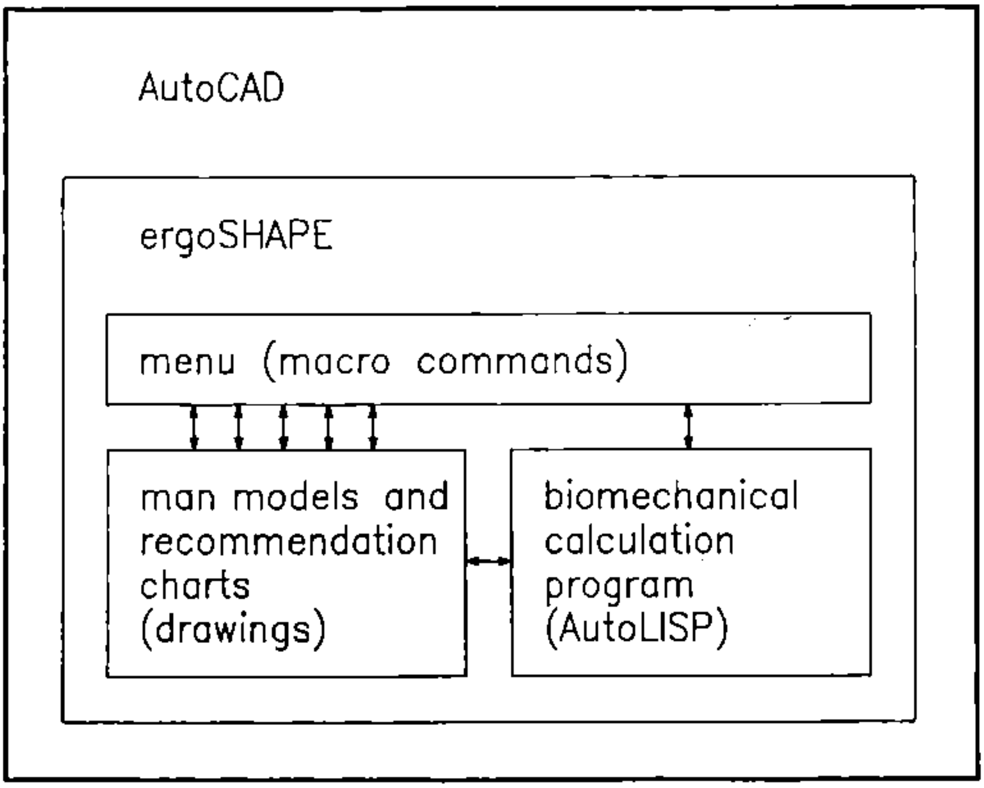

Figure 5.1 Block diagram of the ergoSHAPE system.

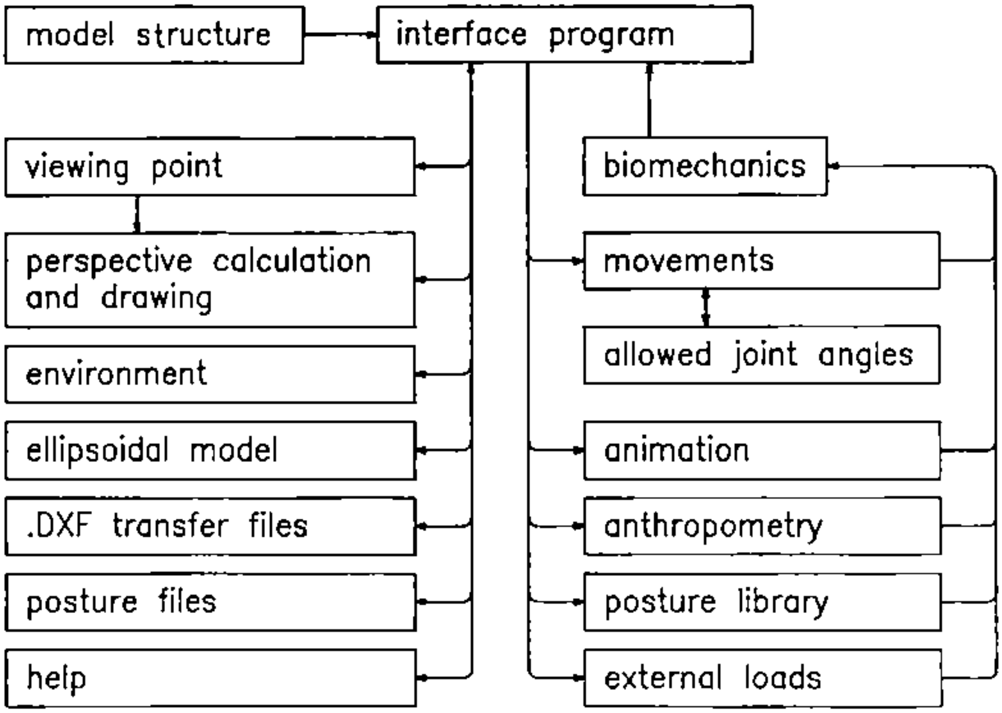

Figure 5.2 Block diagram of the ergoSPACE system.

first one is the two-dimensional ergoSHAPE, which is constructed inside the AutoCAD* design program, as drawing files, menu files and AutoLISP program files. The development of a two-dimensional man model system is supported by practical arguments. Two-dimensional design is easy to perceive, easy to learn and use, and appropriate in normal design work. The ergoSHAPE system is intended to be the engineer's routine working tool.

The other man model system is three-dimensional ergoSPACE, which is an independent microcomputer program programmed by Turbo–Pascal. The system was developed to comply with the restrictions of microcomputers and therefore the graphic presentation of the man models and the environment is greatly simplified. The main aim was to study the possibilities of a three-dimensional design program in designing workplaces.

Functional block diagrams of the systems are presented in Figures 5.1 and 5.2. Both systems have the same anthropometrical and biomechanical basis.

ErgoSHAPE system

The ergoSHAPE system consists of three parts: (i) anthropometric man models, with the help of which working space can be fitted to human dimensions; (ii) biomechanical calculations, which enable the evaluation of postural stress in manual materials handling or in static postures; (iii) recommendation charts, which give direct design guidelines to particular work situations and workplaces.

One hundred and eighty different versions of human models have been constructed. The reason for the great number of models is to assure that the most suitable model can be found for all design purposes. The models combine the following characteristics (Figure 5.3):

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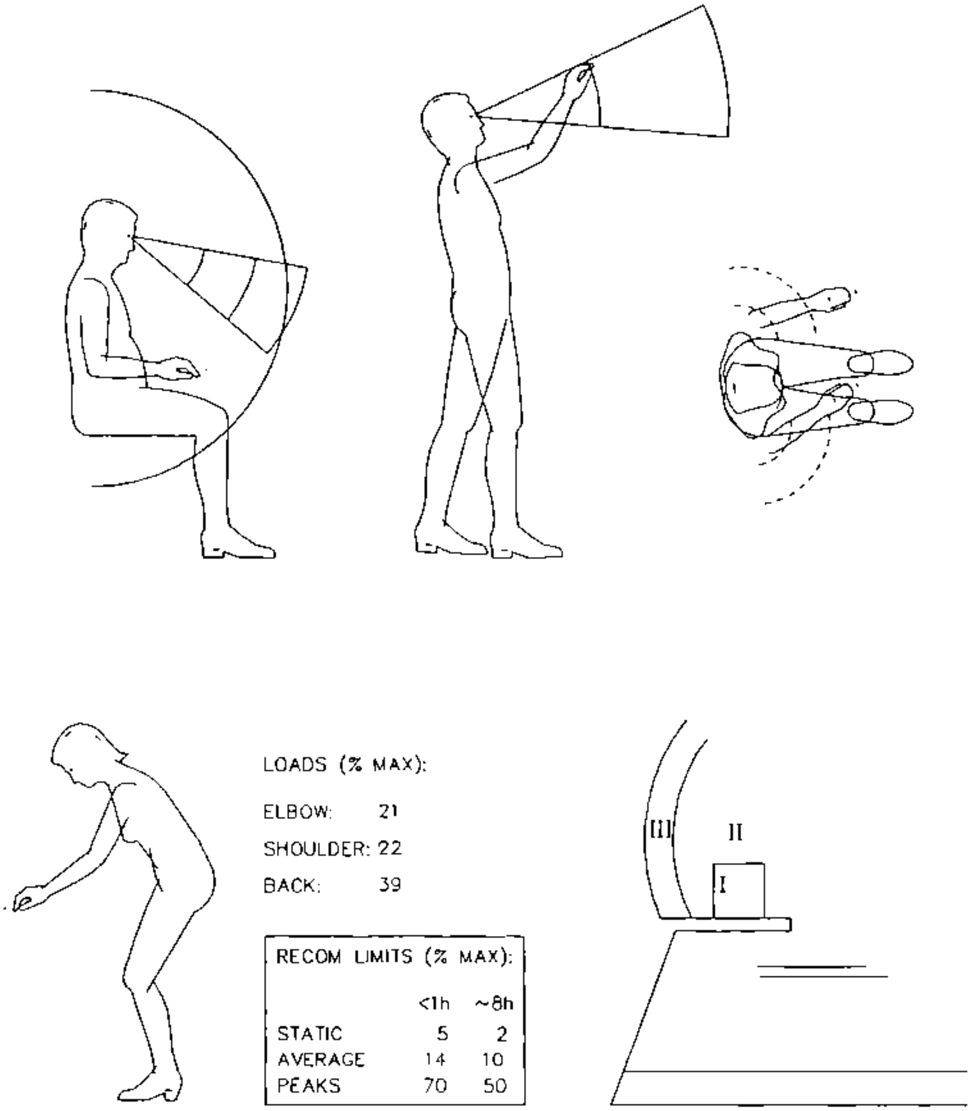
*AutoCAD is a registered trademark of Autodesk, Inc.



LOADS (% MAX):

ELBOW: 21

SHOULDER: 22

BACK: 39

RECOM LIMITS (% MAX):	<1h	~8h
STATIC	5	2
AVERAGE	14	10
PEAKS	70	50

Figure 5.3 Examples of man models, output of biomechanical calculations and recommendation charts of the ergoSHAPE system.

1. Projection (viewing direction): left, right, top and front;
2. Complexity (movability): fixed one-part models in typical working postures, models with six separate parts (trunk, head, two arm and leg segments), or nine parts (lower and upper trunk, head, three arm and leg segments);
3. Basic posture: sitting and standing including some minor anthropometric differences;
4. Sex: male and female;
5. Anthropometric size: small, average and large (5th, 50th and 95th percentiles), and a user-specified individual size.

The models can be supplied with curves indicating the viewing angles and distances and the reach zones. The models and other data can be manipulated by built-in macro commands which are displayed on the screen or on the digitizing tablet. Thus the technical use of the ergoSHAPE system does not require any special training.

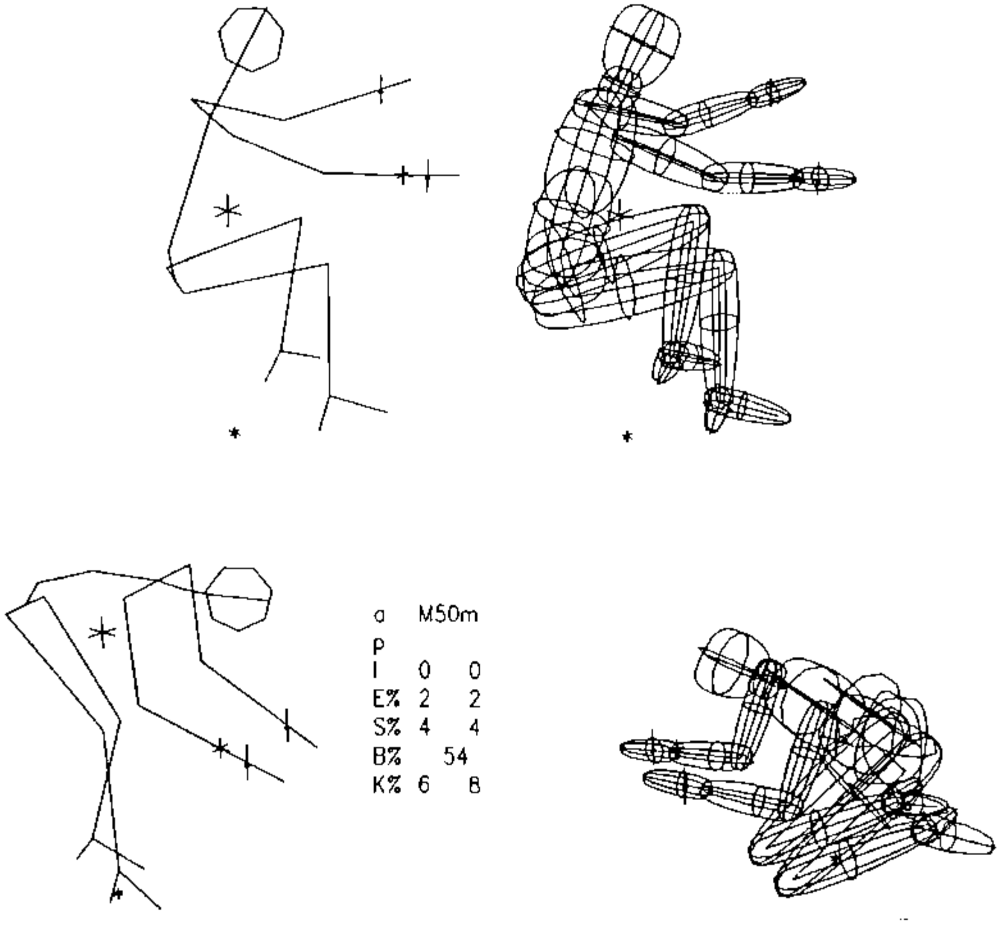
The anthropometric data are based on Finnish, North European and North American populations (e.g. NASA, 1978; Heliövaara and Aromaa, 1980; DIN 33402, 1986). The man models can, however, be easily linearly scaled to other populations.

The evaluation of postural stress is based on mechanical modelling of the human body (e.g. Chaffin and Andersson, 1984; Jonsson, 1984). In the actual posture with the determined external load, the biomechanical program calculates the stress as a percentage of the maximal static muscle strength. The percentage values can be referred to the displayed recommendations for various situations or time ranges. Biomechanical calculation at present takes into account only vertical loads.

The ergoSHAPE system is created with the CAD program and therefore it can be easily expanded by institutions and single users of the system. Special recommendations, such as layout and dimensioning charts for different purposes can be added to the system. In this respect the system differs considerably from earlier computerized man models, which are rather closed programs for the user's own applications.

ErgoSPACE system

The ergoSPACE system is a completely three-dimensional program, in which the environment and human models can be viewed from any direction in real perspective (Figure 5.4) or, simultaneously in three standard projections and in a dimetric projection each in one quarter of the screen (Figure 5.5). To get a fast enough response, a stick model is used



```
a   M50m
P
I   0   0
E%  2   2
S%  4   4
B%    54
K%  6   8
```

Figure 5.4 Examples of man models and output of biomechanical calculations of the ergoSPACE system.

moving the model. The model can be 'filled' to form an ellipsoidal wire model for evaluating space requirements.

ErgoSPACE models have 17 movable joints. A joint can be moved by selecting the joint from the menu, and turning the joint in small steps with cursor keys. Different postures can be chosen from the posture library, too. The postures of the model can be saved in a file and shown as an animation series.

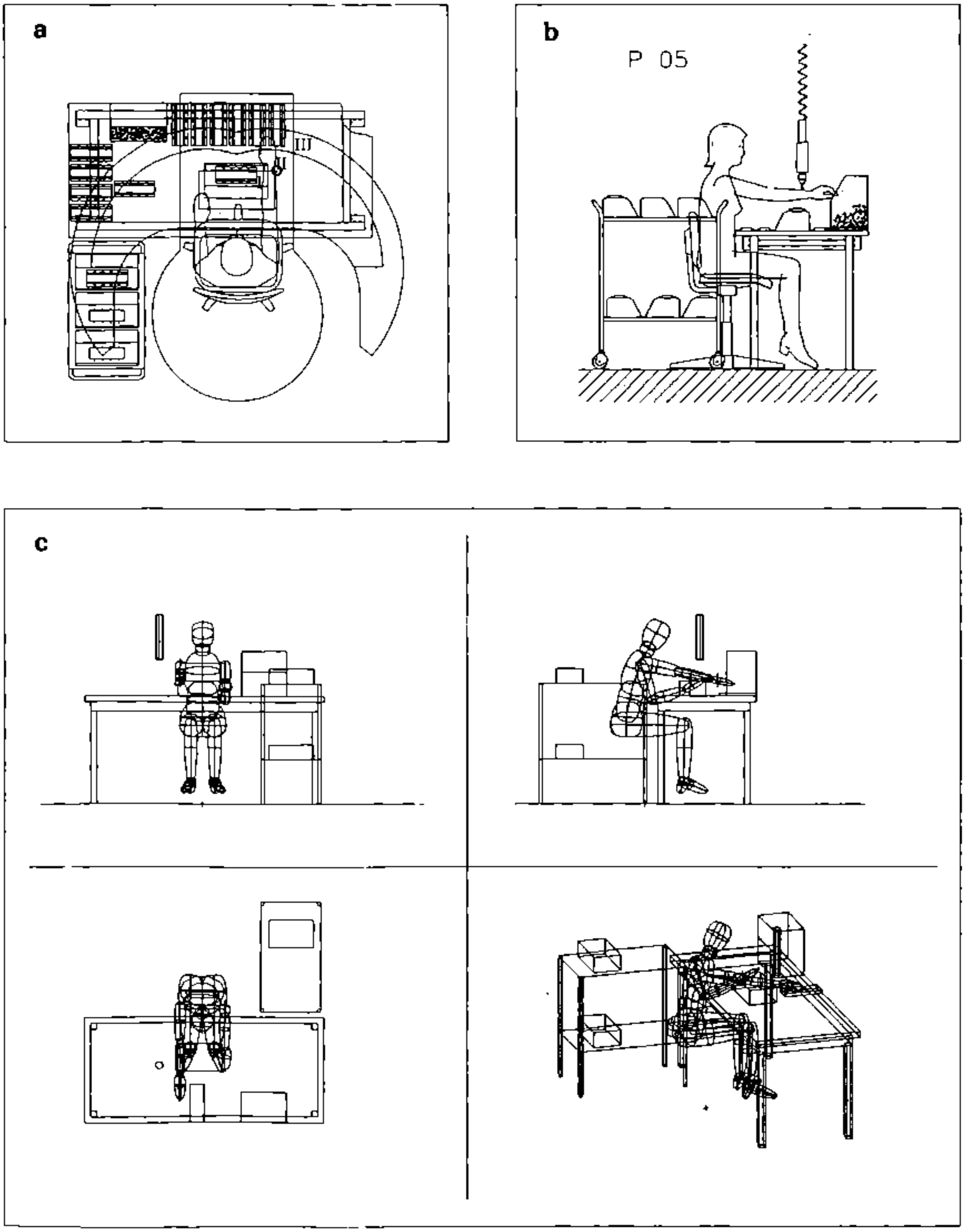


Figure 5.5 Examples of the assessed workplace plans: (a) recommendation chart in top projection; (b) 9-part model in side projection; and (c) quadrant screen of the three-dimensional system. These were also the most preferred models.

The environment is structured as simplified wire models, i.e. as lines, squares and boxes. Hidden lines cannot be removed. Environmental data can be taken into the system also as a DXF-transfer file, and drawings can be saved in the same format. By using these features, the independent ergoSPACE program can be used with a CAD program, too.

Study of utilization

Aim of the study

The development project was intended not only to ensure the ergonomic considerations among the industrial engineers and other planners, but also to promote cooperation between different experts, and to create preconditions for participative design. A study was carried out in three enterprises to evaluate the preconditions for utilizing the man model systems for these purposes, and to gather detailed information for developing the systems. The aim of the study was to investigate:

1. The present design practice of the workplaces (e.g. how the plans are documented and how ergonomics is taken into consideration) and the role of different occupational groups in the design process;
2. How the different types of man models suit the different design tasks;
3. How the different occupational groups are able to use the man models and to assess the plans of the workplaces with them; and
4. How strong a reference the man model is for the dimensioning of a workplace.

Material and methods

The study was carried out in three different metal-product industries, where the so-called just-in-time (JIT) production principle had been adopted. CAD was used for the designing of workplaces only in one enterprise. All those occupational groups which influence the designing of the workplace in one way or another, i.e. industrial engineers, supervisors, occupational health and safety personnel and workers, were represented in the study.

The study was divided into four phases in which the following methods were applied:

Phase I

Interviews of all subjects about the present design practice.

Phase II

Assessment of the technical drawings with all subjects. The technical drawings were supplied with different kinds of man models and recommendation charts. The subjects were asked to generate improvements to the plans and to evaluate the usefulness of the models for this purpose. Some examples of the assessed drawings are shown in Figure 5.5.

Phase III

Design tasks with the computer. The industrial engineers applied the different man models and recommendation charts to their own specific design problem. The subjects were asked to evaluate the models, i.e. the (i) ease of technical use; (ii) reliability in assessing the measurements; (iii) functionality in the intended purpose; and (iv) experienced applicability to their own work.

Phase IV

Experiments to determine the optimal and acceptable workplace dimensions for a particular task with a man model. All subjects participated. One of the experiments concerned working height for a lifting task. The subjects chose the optimal and acceptable alternatives from four comparative series of drawings and photographs, where the man model or an actual man lifted an object from either near or far (Figure 5.6). The series of varying working heights

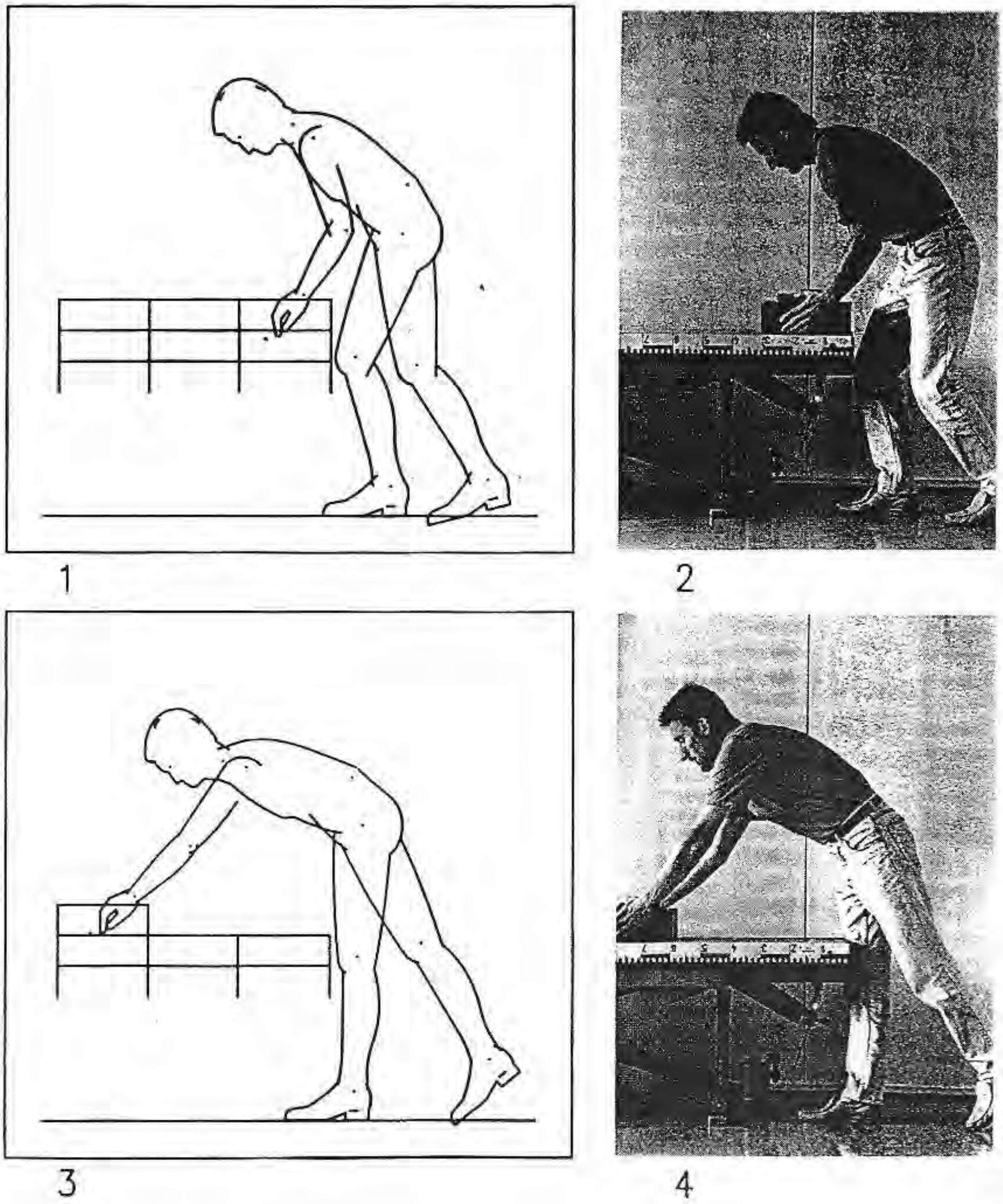


Figure 5.6 Examples of the picture series of the lifting task used in the determination of workplace dimensioning: ergoSHAPE CAD models and photographs of an actual man, lifting from near and far.

(from 10 to 120 cm, each step 10 cm), were presented to the subjects with a slide projector. The task was defined in such a way that it was not practical to adjust the hydraulic table to the optimal height at all times. The subjects applied their own comfort criteria to the determination of the minimal and maximal acceptable lifting heights.

As a reference, a larger group of engineering students participated in the experiments.

Results

Phase I

The interviews revealed that the work task and workplace were not generally well perceived in the design phase. The workplace plans were poorly documented, being restricted to occasional layout sketches. Detailed plans of a workplace were rare, normally the only documentation was some space reserved in a general layout plan. The workplace was a result of separate solutions and detailed plans concerning production technology and material handling. The arrangements of the work and workplace were left mainly to the supervisors.

In the case of designing a highly mechanized workplace, the documentation was complete (including side view projection), but the physical human work was not experienced as an important or critical design factor. The occupational health and safety personnel did not generally participate in the design phase, except in cases known to be problematic.

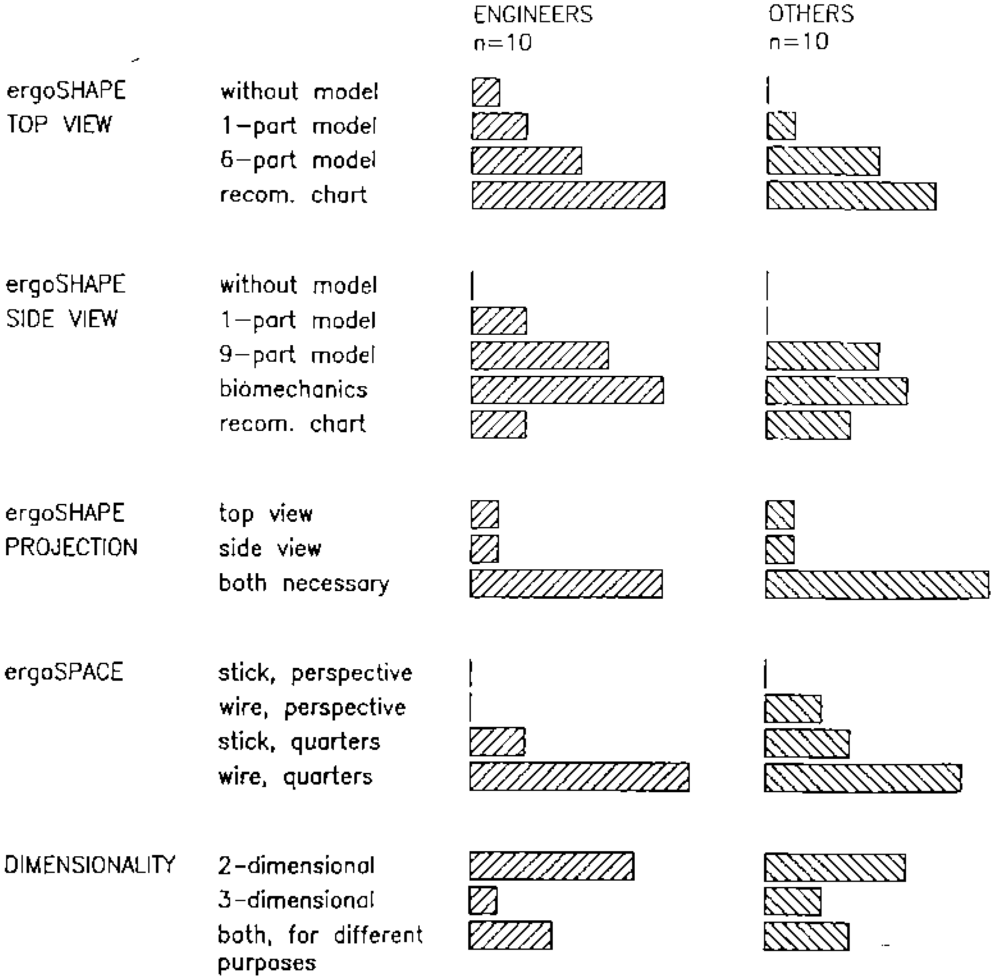


Figure 5.7 Preferences of models according to assessments of the workplace plans.

Phase II

The man models were of great help to the occupational health and safety personnel in the assessment of the technical drawings. The engineers and supervisors were able to find rough ergonomic deficiencies in the drawings even without the man models, which were mainly useful for the fine adjustment of the workplace dimensions.

The preferences concerning the different kinds of man models and different projections were quite similar among the industrial engineers and other occupational groups (Figure 5.7). In the two-dimensional top-view projection of the ergoSHAPE system, the recommendation charts were preferred to the man models, whereas in side-view projection of the nine-part models (including the model for biomechanical calculations) were preferred. Most of the subjects refused to give a priority to top and side views, although in practice they used only top-view plans. They considered both views necessary in ergonomic assessments.

In the three-dimensional ergoSPACE system the simultaneous four projections were found necessary, and ellipsoidal presentation was preferred to stick model presentation. The majority of the subjects found the three-dimensional design confusing, whereas some of them considered it the best way to get an overall picture of the work situation. Generally, the detailed two-dimensional plans were preferred for accurate ergonomic assessments.

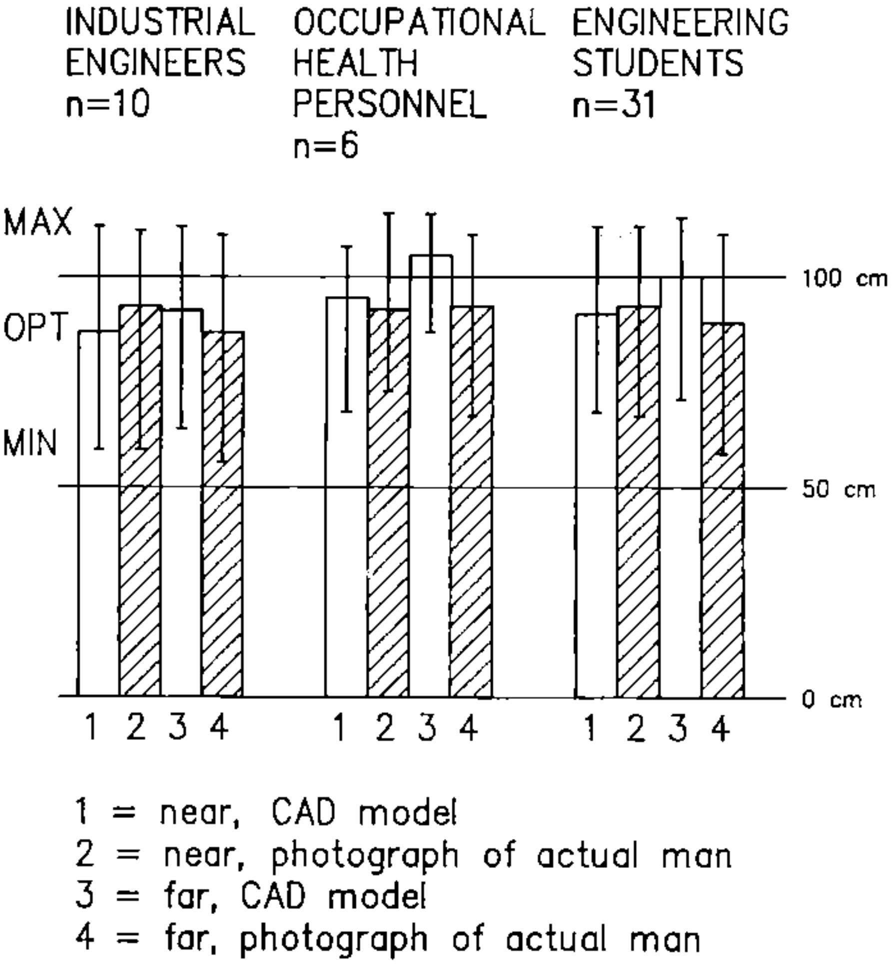


Figure 5.8 Optimal, minimal and maximal heights in lifting work in the determination of workplace dimensioning: means of determinations of three occupational groups in the four experiment series (see Figure 5.6).

Phase III

The results of the design tasks supported the above observations. The dichotomy of preferences was strengthened; the schematic recommendation charts were well accepted but, on the other hand, the most complicated and thus most natural nine-part model and biomechanical calculation aroused great interest. The three-dimensional system was not considered suitable for design purposes in its present form.

Phase IV

In the determination of the optimal and acceptable working height with the man model, only slight differences were found between the different occupational groups (Figure 5.8). The differences between the four different series of pictures within the occupational groups (see also Figure 5.6) were more obvious. The results of the industrial engineers were the most even in all respects, whereas the results of the occupational health personnel were the most uneven (their difference between experiments 1 and 3 was statistically significant, $p = 0.012$, Student's t-test). Ideally, according to the task description, the results should be the same in the different experiments.

Conclusions

The utilization of man model systems is based on graphic design documentation. Although the study comprised only a few cases, it can be concluded that in the enterprises there is considerable discrepancy between the actual design documentation of the workplaces and the ergonomic man model presentation. The design practice in enterprises concentrates mainly on horizontal action (material flow), whereas the main interest from the ergonomic point of view lies often in the vertical dimensioning of the workplace. This implies that the design documentation must be at a more advanced stage before the man models can be utilized.

Because the industrial engineers are generally not very interested in the detailed designing of workplaces, it is obvious that the main area of application of the man model systems is still limited to the designing of workplace products, e.g. big machines, cabins and furniture. On the other hand, there is a trend to use ready-made components and construction entities. Workplace design in enterprises is already to a great extent, and will be more so in future, the buying of machines and equipment and installing them without detailed technical drawings.

The designing of work and workplaces is holistic by nature, and therefore any separate ergonomic system does not motivate the planners. The integration of ergonomic knowledge to the whole of design data, which will be inside the CAD system in future, is therefore essential. The fitting of technical elements to each other and to the worker is the most complicated phase in designing, and it takes place in 'one single head', that of an industrial engineer. Expert cooperation with, for example, occupational health personnel, and also user participation, is natural before and after this phase. The man models in workplace documents are experienced as very useful in facilitating the feedback to the planner.

The man model is a very strong reference for workplace measurements, leading to a quite similar result within different occupational groups. Basic education and general experience have little influence on the ability to assess plans ergonomically and to determine dimensions with the man model. Familiarity with the actual working situation and the work process is far more important. The natural appearance of the man models tends to be more important than the small differences in the ease of their technical use. To cover all design situations, both the most versatile man models and the schematic recommendation charts are needed in the ergonomic design system, most preferably so that they can easily be combined.

The simplified three-dimensional system is obviously not useful for designing workplaces, partly because it is a separate system with no connections to existing ways of documenting the workplaces, and partly because of its overreduced, unnatural and confusing visual appearance. A more detailed modelling of the environment would probably require too much work input, especially if the design problem is not expected to be critical, and the three-dimensional designing is not felt to be necessary.

Although the use of human models releases designers from following rigid recommendations, it presumes a greater understanding of human functions. The biomechanical calculations can be considered as a means to teach the planner a more ergonomic way of thinking, and to activate him to take the human being into better consideration in the design stage.

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Participation and collaboration in workplace design

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Participation and collaboration in workplace design

Martti Launis

1. Introduction

1.1 Reasons for user participation in designing

Involvement of the operators and users in design and development activities has become increasingly important in organizations, in order to improve the quality of production and services, to increase the flexibility of their functions, and to prevent disturbances in systems performance. The enhancement of participation is not only a means for achieving direct gains in the efficiency of major activities, but also a means to improve production technology, the work environment, work content and the employees' well-being.

The idea of the users participating in the designing is not new, but only during the past two decades have the overall preconditions in organizations evolved sufficiently to apply it on a wider scale. Participation in designing is not only a question of design methodology, but it is always an organizational and psychological issue, too, and strongly affected by the work culture. The present trends in organizations, such as a flattening of hierarchies, the establishment of work teams and the expansion of work tasks and responsibilities, support greater participation, as does the general rise in the educational level of the employees. In addition, the production technology and processes have become more complex, requiring the utilization of all available knowledge and experience within the organization.

1.2 Participative design approaches

At present there are several well-established design approaches in which participation is an integrated element. Some of them are aimed to develop production activities, such as quality circles and continuous improvement, some to advance products or systems, e.g. user-centered design and usability testing, and, more emphathically to improve jobs and working conditions, the participatory ergonomics approach. In addition to these, the concept of participative design can be mentioned as a comprehensive term for the basic idea of users' participation in designing. In principle, all these approaches are parallel in aiming at the improvement of activities, equipment and conditions of use by involving operators and users in the development processes.

For more information on participatory ergonomics, see Noro and Imada (1991), and Wilson and Haines (1997).

1.3 Towards a broader collaboration in designing

Development tasks, as a part of the operators' daily activities, such as improving the work tasks in a production team, or as an operator of a complex machine, seem natural expansions of these activities. Workplace design is, however, to a great extent part of an isolated and fragmented process of designing production technology, led by technically oriented designers, and participation in this hasty process does not seems obvious. In the technical design process, the work tasks and working conditions are largely determined, but likely to stem from different starting points and values than those of the people acting in the production. The designers are responsible, first of all, for the technical functioning of the systems at the lowest costs. Thus, in the rigor of the design process the consideration of work activities remains secondary.

The integration of ergonomic impact throughout this design process requires, in addition to user participation, the contribution of many other personnel groups and interest groups in the organization, e.g. that of supervision, of maintenance department, of safety and health specialists, of the human resource management department, etc. Seen from a common viewpoint, it is rather a question of collaboration in the design process instead of participation, which, as a concept, refers to unequal roles of the different actors in the process.

1.4 Aim of the chapter

The aim of this chapter is to give an overview of the arguments for and against participation in workplace design, of its application, of criteria for the methods and tools, and of preconditions for carrying it out.

2. Arguments for and against greater user participation in workplace design

2.1 General

From the ergonomic and human factors point of view there are several arguments in favour of the users' participation in workplace design. Some of them are associated with the results of designing, some with the expected gains in the users' qualification and motivation, and some with the functioning of the entire work organization. When interacting with each other, these effects, if successful, likely cumulate the total advantages of participation.

However, participation is not always beneficial, neither for the outcome nor for the participants themselves. Nor can it be applied in all circumstances. An overall negative aspect of participation can be an obscuring, or even rejection of the role of expert knowledge in the process. The participants' views may be limited to the visible and immediate everyday experience, and seeing the future demands, or the entirety of the design (e.g. in designing entirely new objects or in the development of large systems), may additionally require other forms of expertise.

2.2 Utilization of the users' knowledge and experience

Utilization of the users' experience and knowledge in the activities at the workplace is obviously the first argument for participation. Presently, in complex work processes, it is ever more likely that the user knows best the problems in task execution or the disturbances in the performance of the system. In particular, the user knows his/her own work activity in detail, i.e. the operations and functioning of technical solutions which are potential objects of ergonomic improvements. Furthermore, the load, and difficulty or ease of the work performance experienced by the participants constitute the human criteria for these improvements.

2.3 Accommodation of the design to the individual

In the partipative design process, the work activity and the design can be accommodated to fit the characteristics of individuals or of a specific user group. In tests and evaluations, the demands of the actual tasks are proportioned to the actual users' capabilities, the result of which is beneficial for individuals who are in some respect physically less capable compared to the average, e.g. for women and aging users. Similarly, the users' task-related expert competence are taken into account.

On the other hand, designing for individuals or small groups can lead to generally inappropriate solutions as regards essential variations within the user population, e.g. in respect to the variation in qualifications, anthropometric dimensions or muscle strength. Also over-motivated participants may tend to demonstrate their capabilities in the design sessions, and this may lead to solutions which are not suitable for the others or inappropriate in the long run.

2.4 Expansive learning of all concerned

In participative and collaborative design sessions a lot of essential information is naturally being transmitted between the users and designers, and other groups concerned. The users bring their experience and feedback regarding usage to the designers, and the designers provide understanding of the system's way of operation. This ever-growing general understanding helps the designers to design more operable systems, and the operators to operate the systems more efficiently and reliably.

2.5 Fulfilment of individual needs

Well trained people want to utilize their skills and capabilities and to experience self-realization in their work; participation offers a channel to achieve these. People also generally want to have more control over their work tasks, and to take part in moulding their work environment. Apart from the functional aspects, there may also be aesthetic or self-determining needs concerning the environment, and they become evident, for example, when making the work site home-like or to reflect the personality of the user.

2.6 Achieving commitment and acceptance

One of the greatest benefits of users' participation is the feeling of ownership regarding the solutions, and the resulting increase in motivation and commitment to the usage. This basically positive consequence involves ethical questions of participation, too, especially if the outcome of the design is not expected to be beneficial for the user, or if it does not entail any positive change compared to the earlier design. If the only purpose of participation is the manipulation of users, it is evidently questionable, and forms an obstacle for later initiatives to involve people in these activities.

2.7 Effects on organizational behaviour

Increasing the skills of collaboration, added to improved comprehension of the goals and development processes very likely contributes to the functioning of the entire organization. On the other hand, the participation of selected persons or groups may cause envy among those who cannot participate. The participative process may also be unsuccessful, with no useful results, or results that may be unfavourable to some individuals. All such reasons can potentially cause frustration among the employees.

2.8 Integration of different aims

Generally participation serves many purposes at the same time. All in all, the participants assess their workplaces as functional entities, and it may be even difficult to separate e.g. productional and health-related aspects from each other. As a strategic notion, it may be easier to motivate the management to support participation with all-inclusive gains as compared to purely health-oriented or humanistic ergonomic interventions. This situation may lead to the misuse of participation, however, if the designers or management utilize the multiple outcome of participation at the expense of the users' well-being.

3. Levels and modes of participation

3.1 General

When participation is applied in designing, it should be made clear to all the parties involved what is the object of design, the structure of the design process and design organization, and the goals and limits of participation. Participative actions can be organized by different groups, e.g. designers, the management, occupational health and safety personnel, or the participants themselves. Participation can take place as a separate project, a part of an ergonomics programme, incorporated in continuous improvement activities, or, as part of design projects.

Important issues of participation in these respects are the questions of who should participate, and what are the participants' areas of influence, decision-making power, and responsibility concerning the results. It is also important to find useful and feasible ways of action for different design settings and purposes. These questions need to be solved locally, by mutual consultations of the parties in question, and preferably preceeded by the assessment of the overall situation in the organization (e.g. workplace atmosphere, cultural environment, relations between the management and unions, threats of downsizing, etc.).

3.2 Representative vs. direct participation

In indirect, representative participation only authorized representatives (e.g. shop steward, safety delegate of the union, team leader) of the users participate, in direct participation the actual user of the workplace being improved participates. In some countries it is customary for the union representatives to participate in the meetings of larger workplace design projects. They are not necessarily acquainted with the object of design, however, and their concern is, to a great extent, limited to the general and legally determined aspects of design. As regards the basic principles of participation described earlier, only the direct mode could be considered 'genuine' participation. However, this mode is more vulnerable to misuse as there is less control from the union representetives.

3.3 Influence, power, and responsibilities of the participants

How determining or infuential the participants' role in designing is, varies between two extremes in the different modes of participation. The participants may act merely as sources of information or test subjects, having less power to make decisions concerning the outcome. They may be members of the design team, sharing the decision-making on some level or, form a separate participative team making analyses and generating solutions or suggestions for the designers, normally within prescribed limits, however. At the other end, the users are designers themselves, which is often true in the designing of personal office environments in ready-made components.

Regardless of their decision-making power, the participants have an opportunity to influence the outcome greatly, whenever they can freely express themselves. When they are given power and responsibility, the question of compensation will arise, which is still a largely unsolved issue of participative design.

3.4 Participation varies according to object of design

The appropriate ways to participate or collaborate depend greatly on what is being designed. The object of design may be a large entity or only a small part of it, or, an entirely new design or merely a correction to an existing design. Also the complexity of the work place (geometric, structural, functional) and its relation to the entire work system dictates the design approach and the associated design methodology, and sets requirements or limitations for involving users in the process. For example, the design objects of work places vary from simple furniture and work equipment, allowing easy or even improvised participation, to complex systems requiring the application of special methods with careful guidance.

3.5 Modes of participation in different stages of design

The contribution of the users and other groups concerned is needed in all those stages of the design process in which the characteristics of the work tasks and workplaces are determined. Such stages are e.g. gathering and transmitting knowledge and information, setting objectives, making analyses and evaluations, preliminary sketching of the design, assessing drawings, building models and prototypes, assessing them, trying out and testing the designs or completed workplaces, or, gathering feedback from ready workplaces and transmitting it to the designers.

There are several ways to participate and collaborate in these stages of the design projects, e.g. in design sessions, formal meetings, reviews and audits. Participation in the project requires open flow of information regarding the schedules of the projects, and the object of design at each time, so that the participants (or collaborators) know when and how to contribute. Also it must be made clear to the designers at the beginning of the projects, who can potentially contribute usefully to each design task. The designers can also develop their practices and methods so as to facilitate and encourage greater participation and collaboration (see Launis et al. 1996).

In the design projects, new work systems are usually constructed, but still large parts of them will be mere modifications of earlier designs. The human activity will not change entirely, either, and therefore it is possible to convey earlier experiences to new designs through participation and collaboration. In addition to careful analyses of the earlier designs and associated work activities, also 'reference work sites' similar in some important aspects, can be visited and analyzed to utilizate fully the existing experience in the new designs (see Daniellou et al. 1992).

4. The nature of user knowledge

The conception of the users' knowledge is the essence of participative design. This knowledge is based mainly on experience, and often can not be expressed as concepts, nor even verbally. This tacit knowledge can not always be recalled, either, and therefore e.g. actual walk-throughs of the work processes at the workplace are needed for processing and voicing it. Also the users' mental models of the functioning of the technical systems arise from experience, and therefore they differ considerably from those of the designers.

5. Requirements for the methods of participation

5.1 General

The diversity of the above-mentioned conditions of participation makes it difficult to establish common procedures or even methodology for participative designing. As a matter of fact, in participative design, many well known design methods are applied in a way that takes into account the nature of the participants and the requirements for the participative design situations. From this point of view, some criteria on the procedures and methods of participation will be presented in the following sections.

5.2 Clarification of the basic concepts

The methods used must help to clarify the concepts concerning the work process and functions of the work system. This is a prerequisite for ensuring understanding and fruitful discussion between the designers and the participants. The designing of more complex systems requires also common conceptual models of all functions and their relationships, linked to the associated human activity. This can be done in joint discussions by describing verbally the work processes, the purpose of each task and technical element, and the activities performed by the operators. The use of the wall-board technique can be appropriate for generating such a representation of a larger work system.

5.3 Making invisible visible

Work systems and work processes have to be illustrated clearly, especially if they are not obvious or visible, e.g. chemical processes or information systems. Schemes and diagrams may well serve this purpose. Walk-throughs and task simulations are effective in persuading the users to bring out their hidden knowledge. Sketches of the workplace and simulation of layout with cardboard models are well known illustrative means. Computer-aided design with human models, as well as virtual reality technology, can offer means of illustrating designs of the physical environment for purposes of participation, but this requires additional effort from the designers, which is not always feasible in single-occasion workplace design.

5.4 Focus on interaction between work activity and technology

The emphasis in participative design is on work activity, which is the expertise area of the participants, but the focus must be shifted also to the assessment of the associated technical solutions in their use. Methods of ergonomics for analyzing and restructuring work tasks are useful, but they need to be complemented with user trials and tests of the models, mock-ups and prototypes. In respect to this main consideration, purely technical aspects, as well as such human aspects for which clear criteria and data have been established, e.g. environmental hygiene, anthropometric variability, or maximum recommended weight limits, may be beyond the scope of participative designing.

5.5 Aim at consensus decisions

The users' views and values vary from those of the technical personnel, and in order to achieve appropriate compromises, methods of dealing with different suggestions are needed. Again, the wall-board technique can be applied for gathering ideas, for discussing them, for combining ideas, and for rating alternatives. The resulting group decisions are beneficial for overall acceptance of the design, but they involve the risk of neglecting important factors (e.g. concerning safety) which are not known or only poorly understood in the group. A common understanding of the design goals and the importance of various factors is one prerequisite for a successful group decision process.

5.6 Ease and efficiency

The limited time provided for participation and inexperience of the participants in designing requires that the methods must be exceptionally easy and the threshold of starting the work must be low. Methods requiring much documentation and verbal formulation are less suitable for participative designing. Specific methods intended for participative inquiries, such as mind-mapping and round robin questionnaire, are examples of cost-effective means. Also ready-made tools supporting designing, such as agendas for meetings, forms for gathering information, check-lists and other clear tools can be efficient in participative designing.

6. Preconditions of participation

6.1 General

In addition to favourable overall preconditions of partipative designing (support from parallel activities, higher level of education of the workforce, democratization of work life, etc.), some specific requirements are apparent. User participation is a voluntary extension of people's daily activities, and thus it is sensitive to both positive (support, motivation) and negative influences (resistance, territorial behaviour) prevailing in the organization.

6.2 Commitment of those concerned

Participation cannot be successful unless all the groups involved in the events accept it. Understandably, however, for several reasons, it is not possible to motivate everybody in these activities. Extra effort, unsuitable timing, or threat of losing power are potential reasons for a negative attitude towards participation. The management and the unions have a decisive role in supporting the basic idea of applying participation in workplace design.

6.3 Consideration of cultural differences

In organizations, different groups have adopted different values and principles guiding their action; these may severely hamper the development of workplace design. Designers aim at neat technology with the least use of human work, which makes it difficult for them to consider work activity throughout the design process. The top management is involved with financial survival and marketing processes, and they may experience the development of production activities as remote (see Schein, 1997). Workplace design, and collaborative activities in particular, must therefore prove their beneficiality to the decision makers. A practical strategy that has proven useful is to start from a limited area or project and to spread out to other areas after trying out the methods and obtaining good results.

6.4 Provision of resources

Participation cannot be put into practice without allocating sufficient time for it. This is important especially when involving persons from production duties in the participation. In most cases participation means costs; this stresses the importance of efficient methods. Also extra effort may be needed on the part of the designers and supervisors to take care of additional actions.

6.5 Guidance

Participative design actions need careful planning, organizing, guidance and many other forms of support. The haste inherent in design activities obviously prevents the designers from concentrating on these time-consuming activities. Participation requires the purposeful contribution of a designated person, a 'facilitator' or 'internal consultant'. The qualifications of such a person are crucially important for the success of participative designing.

7. Concluding remarks

Participation in designing has been considered an 'easy way' of applying ergonomics in work organizations, because it seems, at least to some extent, to replace the need to employ ergonomics or human factors expertise in the designing. Experience shows, however, that participation can be a fairly laborious way to proceed, but it nevertheless has many positive effects that go beyond the design output itself. So far this way of promoting conventional technologically oriented designing may have been afflicted by start-up problems, but growing demands and the integration of similar trends are creating pressure to make also designing a more collaborative attempt. The evident goal is a design practice and culture, which incorporates participation and collaboration in continuous activities naturally and unnoticeably.

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Who is the workplace designer? – Towards a collaborative mode of action

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Abstract

Workplace design has been approached as an entire process and activity which leads to the birth of the workplace. The deficiencies of current design practices have been identified: technological orientation of the designers, lack of work-oriented objectives, poor communication and feedback, and improper use of available information and methods. Three projects have been carried out in the assembly industry in order to investigate and develop design practices. Together with the personnel of the enterprises, the new mode of action has been established. The contribution of different occupational groups has been integrated to the entire design process, the knowledge and information about designing has been extended, and collaborative ways of designing have been developed. Computer-based tool packages have been compiled for supporting designing and design projects, and also for carrying out similar developments in other enterprises. The tools are based mainly on word processors in order to be easy-to-use and modifiable to local needs. The new developments were experienced as useful, feasible and effective in the design projects, but the project leadership was usually not sufficient to take care of them, and informal support and guidance was needed.

Relevance to industry

The ergonomic quality of workplaces is to a great extent determined by the designers of the production technology, but their tasks and the information received do not orientate them sufficiently to consider ergonomic aspects. A solution for this dilemma is the collaboration of all relevant occupational groups throughout the design project, supported by all relevant methods and tools available.

Keywords: Workplace design; Design practice; Participative design; Computer-aided design; Design methods; Design tools

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1. Introduction

The designing of a workplace is a complex and many-dimensional task. It is a long process, starting from the product design and the choice of production technology and working methods, and continuing to the choosing and tailoring of machines, tools and other work equipment. In essence, it is technical work done by specialized designers, most often engineers and technicians from different domains. At the same time it requires the contribution of a large number of people in the enterprise. The considera-

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tion of functional, organizational and health aspects requires intensive collaboration between the designers and the user organization, and health and safety specialists, too.

1.1. Studies on workplace design activity

The experiences from industrial practices in different countries show that the reality is far from the fulfilment of the requirements mentioned above (e.g. Evans and Chaffin, 1986, Eklund, 1988, Eklund, 1990, Lenior and Mossink, 1989, Daniellou et al., 1990, Sell, 1990, Daniellou and Garrigou, 1992). As a common feature, communication concerning the workplace is poor in general, and especially between designers and the user organization. This problem is entwined with a number of aspects of the design activity. Firstly, it originates from the general features of the designing of modern workplaces (Shackel, 1980), e.g. complexity and sophistication of the technology used, the time constraints, time and distance barriers from the designing to realization of plans, and separation of the individual design tasks from the total cost evaluation. The increasing competition on the markets and ever-shortening design cycle times are cumulating these difficulties (Kern et al., 1993).

The hierarchy of the design process and design organization do not favor consideration of the workplace, either. The results obtained by Evans and Chaffin (1986) emphasize the paradoxes of workplace design: an ergonomic approach is apparent only in the detailed designing when room for manoeuvering is limited. The essential information needed in designing workplaces is dispersed throughout the organization, and the lateral communication to combine this experience is poor.

Poor communication in designing is explained also by the inherent nature of the design activity, elucidated in design methodological literature (Cross, 1984). The designers do not approach the design problem systematically, nor follow systematical design processes. They rather tend to work by experience and association, and test their ideas and concepts in the attempts to solve the problem, and proceed iteratively with the designs. Lenior and Mossink (1989) recognize negative aspects of this "design behaviour" in industrial design practices: the designers are willing to use information only in the beginning; thereafter their thinking is subjectively stuck to their own conception of the design problem, and collaboration with other designers remains poor.

Under high time pressure and high pressure on design performance, the given main task obviously orientates the designers' working. They concentrate on the planning of the production system and automation, and the planning of the work system and human operations is secondary. Daniellou and Garrigou (1992) stress the failure of designers to consider the work activity, and suggest a distinct change of the focus from the designing of technical system to the designing of future work, which also requires the user's participation in the design meetings. Participative design is currently considered also a general approach for mending the failings of technical design, and for developing activities and organisations, and, in particular, for improving the ergonomic fit and acceptance of the workplaces (Wilson, 1991).

Our own studies done mainly in the assembly industry (Launis, 1991) reveal features parallel to the findings in the literature:

- The workplaces are a by-product of separate design processes;
- No one in the design organization is responsible for the workplace as a functional entity;
- The most important decisions concerning the workplace are done at the early stages of designing, and usually the users' experiences are not considered on these occasions;
- The design process is hasty towards the end, and the workplace is often left unfinished and poorly documented;
- The designer does not get the feedback from the actualized workplace, except in the case of total failure.

This state of affairs hinders the cumulation of the experiences on the workplace, and the utilization of this experience in the new designs.

1.2. Development approach

Although the designing of workplaces seems to encompass a great number of difficulties, the problems originate, after all, mainly from the decisions made in the everyday practices of the people involved in designing. It can be seen that a great many of the workplace design problems are due to obvious simple shortcomings, such as breaks in the information flow between people, and the designers' traditional custom of designing alone. An important way to improve design practices would then be to discover these obvious shortcomings in their organizational and functional context, and establish new practices, taking the prevailing culture of the enterprise into account. Motivational preconditions for doing this exist in most enterprises: good (i.e. healthy, functional and effective) workplaces are experienced at present as vital for the success of an enterprise on the competitive markets.

As the workplace design is a complex process and involves a large number of people, this can reasonably and effectively be done only as a whole process and together with these people. The development of the practice requires also supportive methods and instruments, based on the needs of this practice. Also establishing actions are needed.

Computer technology affords new possibilities to facilitate designing, but, as a limiting factor, all the people involved in workplace design may not be experienced users of computers. The tools developed for workplace design should therefore be easy-to-use. They should also help to master the wide variety of situations met in designing.

1.3. Good design practice – research program

The approach described above was applied in a three-year research program called "Good Design Practice for Workplace Design" carried out in 1991–1994 in Finland. The entire program consisted of several projects and involved four research institutions and several work organizations in municipal, service and industrial branches. In these projects the workplace design practices, methods and information systems were investigated, developed and tested.

1.4. Aim of the study

The present study was a part of the program, carried out in the assembly industry. The main aim was to develop and test new design practices and new forms of design collaboration in enterprises, and, as a conclusion, to formulate the "model of development" to help someone else realize similar developments in other enterprises. This model would consist of the description of the basic principles and the process of development, and the set of tools needed in the development work. An additional aim was to utilize the computer technology appropriately in the development of these tools.

2. Development projects

2.1. Study enterprises

The development projects were carried out in three assembly factories which represented the manufacture of different types of products: industrial furniture, consumer electronics and large electromechanical products. The enterprises differed also in size, type of organization, and technology used. The factory units in question employed from about 50 to 500 workers, and the number of technical designers specialized in production technology varied from a few persons to a group of fifteen people. All the personnel groups concerned with the development of the workplaces, e.g. managers, designers, supervisors, workers and occupational health and safety personnel were represented in the study. About 15 to 20 people in each enterprise participated in the study occasions. All enterprises applied modern lean production principles.

2.2. Development process

The design practices and design collaboration were investigated and developed first in two enterprises. The experiences from these first cases were formulated into the form of a "model of development" and a "toolbox of designing", and were tested in a new enterprise. After the first two cases there was no need to modify the process, and thus the development process was similar in all three cases. The process is described in Fig. 1.

The entire process was divided into two main phases, development of the new mode of action, and testing it in a real design project. In the first phase the work was done together with the people of the enterprise in special meetings led by the researchers. This phase was carried out in two months, and it took time from two to three working days for each participant. In the second phase, the design projects were only followed and evaluated by the researchers, and supported when needed. One purpose was to investigate how the new mode, prepared and agreed upon by all, can be accomplished in a real situation without constant external guidance.

In the beginning, the starting points of the project and the present situation in designing were discussed with the management and the key persons of the forthcoming project, and the first information meeting was held for all the people involved. Thereafter all personnel groups were interviewed concerning the present design practice. The interviews were analyzed by the researchers and they served as a basis for the next meetings. In the group discussions, seminars and group working (meetings of 1 to 3 hours each), the new mode of action was gradually generated, from initial ideas to the description of the design process and the new actions. During every stage, the researchers prepared a brief report of the earlier meeting as material for the coming meeting.

In the design project the researchers participated in the most important project situations, design meetings and evaluation meetings. At the end of the design project the participants were interviewed about the usefulnes and feasibility of the new actions. The design project was thereafter evaluated in a seminar by the researchers together with the representatives of the personnel.

2.3. Development principles

On the basis of the literature and the experiences gained during the study, the list "Building blocks of good design practice" was formulated to serve as the guiding principles for the different phases of the study (Fig. 2). The list was initially prepared by the researchers but it was also discussed and agreed upon by the people of the enterprises. In the beginning of the projects it was used as general information on the aims of development. The interviews for analyzing the present design activities were structured to a great extent in line with it, and it was used also as an agenda to help generate the new design practices.

These principles of development were gradually condensed to a minimum of items in order to be easy to comprehend and learn, and to be practical for the above-mentioned purposes. Therefore the items of the list may not be unequivocal, they rather naturally overlap each other. The headings of the six items describe the essence of the principles; each is supplemented by a list of practical applications, as examples for discussions. When used in the discussions, this list was instructed not to be followed but to be

PROCESS OF DEVELOPMENT FOR WORKPLACE DESIGN

I. DEVELOPMENT OF THE MODE OF ACTION

1. **General information on the principles of the study.** A seminar.
2. **Charting the present design practices and collaboration.** Interviews of the personnel groups and a seminar. Collecting the initial ideas for improvements.
3. **Generating the ideas for new design practices.** Personnel groups generating and discussing the ideas. A seminar for discussing their usefulness and feasibility and for drawing them together.
4. **Establishment of the new mode of action.** Working groups constructing the new mode of action and preparing supportive actions and tools. Closing seminar: agreement on the mode and its application

II APPLICATION OF THE NEW MODE OF ACTION

5. **Testing the new mode in the design project.** Follow-up of design occasions.
6. **Evaluating and correcting the mode of action.** Group interviews on the usefulness and feasibility of the new actions. A seminar: agreement on the changes and decision on the use in the coming projects.
7. **The follow-up after one year.**

Fig. 1. The process of the development of workplace design in the enterprises.

taken as hints in generating practices specifically applied to the enterprise in question.

The underlying concept is that the knowledge needed for improving the ergonomic quality of workplaces already exists in the enterprise. The building blocks describe, on the activity level, the means to transmit this information and experience to the most crucial phases of designing in a useful and feasible way.

2.4. Results of the development process

In all enterprises the progress and outcome of the development of the new mode was basically similar. In the testing phase the differences were bigger because of the differences of the design organisations and of the available design projects. In one case disturbances in the schedules of designing may have partly affected the incomplete application of the new

BUILDING BLOCKS OF GOOD DESIGN PRACTICE

1. *Objectives for designing:* Objectives concerning the workplace and work tasks are set.
- All feedback on the use of previous or similar systems is utilized.
- Experiences of supervisors, workers, and those who develop the human work, are gathered.
- The objectives are practical; they are based on evaluation of the present solutions and other comparable solutions.

2. *Collaboration:* During designing people collaborate in a flexible way: The right people, at the right time, doing the right things in the right way
- Communication between designers is improved in the workplace design.
- Specialists in occupational health and safety are used.
- Specialists of the work task and workplace are used: supervisors and workers.
- Bureaucracy is avoided: people act directly and openly.
- Training and development activities are arranged with a view to planning workplaces.
- The preconditions of participation are developed: responsibilities are delegated and time is provided.

3. *Methods:* The work activity is illustrated in the plans. Trials are done. Evaluation methods are applied.
- Discussions are held on the basis of early sketches.
- The work activity and the workplaces are described with the help of illustrative schemes and models.
- Alternative plans are made for joint evaluation and comparison.
- Simple tests and trials of the work tasks are carried out at the old workplaces, or a mock-up is built to develop the new ways to work.
- Suitable evaluation methods are used: checklists, job analysis methods, and safety analysis methods.

4. *Feedback:* The work activities and their consequences are followed. Feedback is gathered systematically. Experiences are utilized in the coming projects.
- The designer familiarizes him/herself with the workplace when it is in action.
- The surveys and checking tours of the occupational health and safety people are done to serve also designing purposes.
- The feedback systems concerning workplaces are developed: the needs of development are pinpointed and the ideas to solve them gathered.

5. *Information:* Informing is done early enough and to the right people
- Information about the new project is distributed as early as possible to those concerned.
- Information about project organization is given: who will plan, what will be planned, and when.
- People are informed about the current situation and design changes.

6. *Establishment:* The lines of action for workplace design are created. Designing is supported by guidelines.
- A written policy for workplace design is created.
- The agreed principles are integrated into the other directives of the enterprise, e.g. into the personnel policy, quality system, project directives, and training program.
- The ways of action are evaluated and developed continuously.
- Tools are created for planning and evaluation.
- Guidelines for solving typical design problems of the enterprise are gathered and created.
- Documented examples of successful design projects are gathered.

Fig. 2. Building blocks of good design practice. The features of an improved way of designing.

mode. In another case the new mode became too challenging for the few designers because a bigger change in the technology was implemented at the same time, and the overall change in the ways of designing was rather big.

2.4.1. Analysis of the present design practices

The interviews charting the present design practices revealed shortcomings similar to those in earlier studies, dealing mainly with information flow between people. On the one hand, informing people about the design projects was poor, and, on the other hand, the feedback to the designers about plans, prototypes or final workplaces was minimal. Also severe breaks of information occurred between organisation units, e.g. from health and safety, material acquisition and maintenance units to the designers. In particular, the different personnel groups had very different views on what is actually the contribution of each group in designing. The division of responsibilities between designers and supervisors concerning the testing and finishing of the workplace was especially problematic.

In addition, the use of ergonomic information or methods (e.g. trials) was minimal; the workplaces were designed mainly by experience and intuition. Trials on the functioning of the technical arrangements (e.g. machines and logistics, or assembly arrangements) were carried out when necessary, and even mock-ups were built, but no trials on the human operations were carried out. Documentation (drawings, photographs, verbal descriptions and analyses) of the workplace was also minimal, thus hampering the conveying of the experience to the forthcoming projects. As a general result of the cross-interviews of the personnel, the designers seemed to realize the consequences of improper workplace design, and to become motivated concerning the development work.

2.4.2. Creation of the new mode of action

In the discussions, the people appeared to be very capable of creating new ideas together and of developing them into practical form. Outside support in formulating them into written form was necessary, however. An overview of the generated new ways of action is presented in Fig. 3. The actions were divided into two groups: occasions or actions for the managing of the project (inside dashed line box), and supportive or establishing actions (outside the box).

Each action was described on paper briefly in practical terms: why it is needed, whom it concerns, what will be done, and when. The actions were also located into the chart of the entire design process, showing their interrelationships, and also showing the important connections between the different phases of the project. This document was discussed together in the seminar and distributed to all participants of the project.

Two of these actions are especially noteworthy, as they create the important continuity from the old workplace to the new one. The first one is the *collaborative analysis of the workplaces*, done by the group which consists of the designers responsible for the workplace, the supervisor, the worker and a representative of the health personnel. The workplaces are rebuilt quite often in assembly industry, and therefore designing is to a great extent rearranging and applying known elements. After the testing phase this collaborative analysis was evaluated to be the most important source of information for designing a new workplace.

The other action is the *improvement of the workplace documentation*. Complete updated drawings supplemented by evaluative remarks were considered an important means for transferring experiences from the present design to a new one. A proper document of a workplace, which has been carefully analyzed and corrected, actually consists a lot of "invisible" ergonomic information, and can be used as a "model workplace" when the new comparable workplace is being designed. The use of computer aided design (CAD) makes this utilization effective and easy, although this technique was not used by all designers. In places where computers were extensively used, also man-models and the recommendations in the CAD-system were discussed. Furthermore, in one of the study enterprises a separate project was carried out in order to develop a special real-time information system, called "ergoCop", for collecting the documents, workplace analysis data and general ergonomic knowledge applied to the company needs (Kiiskinen and Lehtelä, 1994).

2.4.3. Testing of the mode of action in a design project

When the design projects were started, some confusion arose in the enterprises on how the new

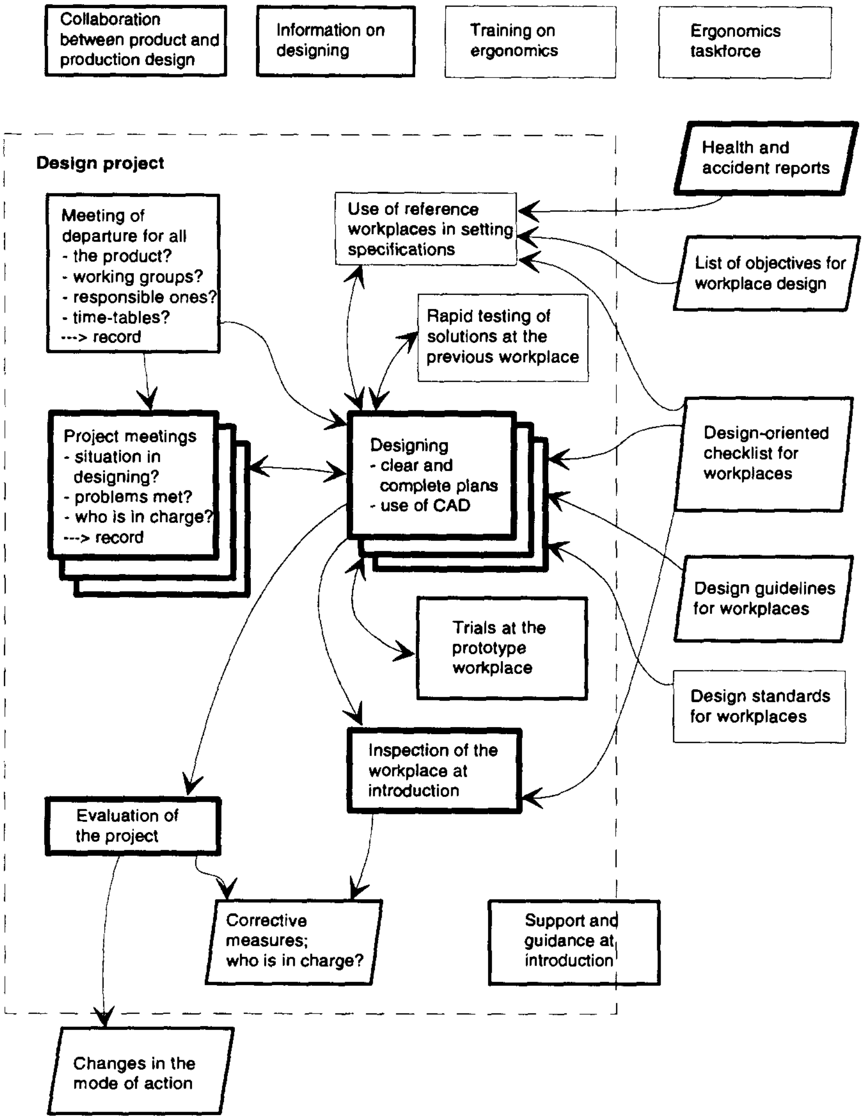

Fig. 3. An overview of the new actions generated in the three enterprises. The three thicknesses of the borderline of the boxes indicate the number of enterprises in which the action in question was taken into use.

actions should be used after all. In this situation the written operational descriptions of the new actions were considered necessary. However, the old design habits tended to dominate in many ways, and efforts were needed from the persons responsible in order to keep the process in line with the accepted principles. The normal project management appeared to be insufficient to consider all of the new actions, and the other persons, to whom some responsibility was given, felt to have too little power for organizing actions in the haste of the design process.

In these first design projects only about one half of the generated and accepted actions were applied. The experiences expressed in the evaluative interviews and seminars were very positive, however. The actions were experienced as useful, feasible and important. Those actions which were not applied in these first projects were stated to be important, too.

They belonged mainly to the group of supportive or establishing actions, and were considered of less current interest, or needing a longer time for development.

The only negative aspects reported dealt with the choice of people in some project occasions. In the evaluation meeting held at the workplace sometimes too many people were present at the same time (from 4 to 6 was considered a maximum because of noise and the limited space). In the weekly project meetings people from production were sometimes invited to listen to purely technical matters of no interest to them. On the other hand, the presence of a large group in these situations was considered important, because every now and then some very essential information was transmitted. This appeared to be a dilemma; in a routine design meeting it is not always possible to foresee the matters that will be dealt with.

Although the actions are based on improving functional, ergonomic and health aspects of the workplace, and on open informal communication between people, it was felt that the new mode gave a backbone for the entire design project. It was reported that effectiveness had increased and turnaround time decreased: the information needed was always available on time, there was less untimely communication, people were more motivated and cooperative, more progress was achieved in each design occasion, and disturbances in the implementation phase were minimal.

3. Development tools

The development projects in the enterprises demonstrated that implementation of the new actions requires support and practical work, such as writing and preparing papers. People in the enterprise are reluctant to attend carefully enough to these matters themselves. The experiences and material from the projects were therefore collected and formulated into two computer-based information and tool packages, "Folder for developing design practices" and "Toolbox for workplace design projects".

The basic idea was to ensure that, for every situation in the development process, the needed knowledge, papers and other tools were readily available. The other basic idea was to make the tools modifiable to the needs of the enterprise. It has been argued that the generally available material, e.g. checklists, are not relevant and useful as such. They are often either far too extensive to be practical or far too simple and obvious to be informative. A solution to this problem would be a flexible and modifiable system. The packages were realized mostly in paper form and as respective text and drawing files in common Windows-based programs.

Both packages are available in Finnish only. These collections of material were created in the specific context of Finnish assembly industries, and they may not be transferrable to other industrial fields or working cultures as such. The description of the basic ideas and overall content of the packages in this article is intended mainly to demonstrate the need for a variety of computer-based tools covering all foreseeable situations of designing. In their present form the packages are still imperfect and not systematically tested in practice. They were partially used in the first two cases by the researchers, and available as ready packages only in the last case. They are being tested and revised continually in connection with future projects.

3.1. Folder for developing workplace design practices

The first package, "Folder for developing design practices" is intended for carrying out the entire development process in the enterprise. It is meant for the use of a consultant, project leader or any person responsible for this process. This "folder" contains the description of the principles and the process of development, guidelines to analyse the preconditions for development in an enterprise, guidelines to conduct interviews, discussions and seminars, and guidelines to carry out other phases of the process. It includes all the necessary practical tools: information leaflets, overhead slides, agendas for the meetings, interview forms, report forms, evaluation forms and examples of ways to produce various documents during the process. The text files are in Microsoft Word for Windows format and the drawing files in Designer format. It is assumed that the user of this package is an experienced user of a word-processing program.

3.2. Toolbox for workplace design projects

The other package, "Toolbox for workplace design projects" is a selection of information and tools needed in the design project and in design work in general. The user group of this package may vary from one situation to another. The toolbox can be used, in addition to the development process described earlier, also in the everyday designing of workplaces.

The toolbox consists of short instructions (one or two pages each) dealing with project meetings, evaluation meetings, ergonomic design methods, feedback information, etc. (Fig. 4). Also forms, lists, checklists or spreadsheet models for various purposes are available. The package includes not only immediately needed information, but also information on other available information and systems. For instance, expert institutions are presented, information sources are listed, available design systems and analysis systems are described, etc.

The toolbox has a graphical front-end program to the tools and documents, which are mostly implemented in Microsoft Windows Write format (a word-processing application included in Windows). The idea is that the user can enter the system easily and find what is needed, then modify the text according to his/her needs with the simple word processor, perhaps add the name of the company, and then print it in paper form. Producing a useful paper easily would thus be a motivating performance for the user of the box.

CHECKLIST FOR WORKPLACE DESIGN

1. **Task entity**
2. **Logistics / Conveyors**
3. **Workplace layout**
4. **Material handling**
5. **Furniture / Adjustments**
6. **Machines and work equipment**
7. **Test devices and displays**
8. **Hand tools**
9. **Surface materials / Conductivity**
10. **Lighting**
11. **Other environmental factors**
12. **Chemical agents used**
13. **Guidance and instructions**
14. **Maintenability / Cleaning up**
15. **Manufacturability of the product**
16. **Department or work area layout**
17. **Overall assessment of the workplace**

Fig. 5. The structure of a design-oriented checklist for the evaluation of the workplace. An example of the modifiable tools of the Toolbox (abbreviated, only headings of the items presented).

An example of the tools is a *design-oriented checklist* for the collaborative evaluation of the workplace. It was first developed together with the people in one of the enterprises. The basic structure of this two-page paper was simply a list of the objects of designing (Fig. 5), instead of pinpointing

Recycling in-house information
- Usable methods for creative problem solving
- How to tutor new employees to design practices
- Use of electronic mail in a project

Search of knowledge
- Literature for good designing
- Use of literature databases
- A list of Finnish experts

Tools for project management
- The meeting of departure for workplace design projects
- An effective project meeting

Setting design objectives
- What is good work / production / manufacturability of a product?

- How to set ergonomic specifications
- Making inquiries and interviews
- Obtaining experiences from reference workplaces
- Use of accident and health information systems
- The work environment cost model

Designing
- Characteristics of good professional design
- Modelling of activities
- Visualization of designs
- Methods of simulation
- Tailoring design
- Safety analysis in designing
- A description of the Ergotext information tool
- A description of the Ergo-SHAPE manmodel system

Getting feedback
- An operating feedback form
- A description of ErgoCop information and feedback computer system
- Use of drawings in feedback
- Workplace evaluation
- Workplace evaluation information systems

Tools for evaluating activities
- The meeting for project evaluation
- A checklist for evaluation of workplace design practice
- A questionnaire for project evaluation
- a form to determine development actions

Fig. 4. Toolbox for workplace design projects. Description of the content.

human functions, e.g. postures, movements, seeing, reasoning, etc., as commonly done in ergonomic checklists. The list thus gave only the landmarks for evaluation; each participant had to justify the importance or the need for the change for the workplace. The discussion at the workplace between the designer, supervisor, worker and health specialist soon led to statements of what was good and what was poor, and why, in the place in question, and to concrete suggestions in their contextual priority. The completed list had a central position in various ways in the projects, as an agenda of evaluation meetings, as a report for effecting corrections, as a feedback to the group of designers, and as a list of objectives for new designs.

4. Conclusions

One of the most surprising observations in the entire project was the difficulty of the people in the enterprises to perceive what the designing of the workplaces is as an activity, and who is actually the designer of the workplace. Most people consider "designing" only as a job done by a technically educated person working in the post of a designer, or a constructor, engineer or technician. In some cases only the designer of the product is a real "designer", the designing of the production techonology is simply doing, buying, making or constructing. In fact, many people participate in the workplace design process – some setting objectives or specifications, some acquiring and constructing furniture or tools or jigs, some planning production or working methods, some evaluating, some correcting: the production management, supervisors, method trainers, maintenance technicians, a physiotherapist, the workers themselves, and many others. It can be concluded from this project that one definite obstacle for developing workplace design is the lack of concept "workplace design activity" or "workplace design process". One of the most important achievements in the enterprises was the recognition of this activity and taking it as an object of development.

During the course of the development projects, it was concluded that the process must be thorough and the entire personnel must be involved in order to achieve changes in design practices. Design practices have their roots deep in the behaviour of people, and changing behaviour requires motivation, time and repeated successful actions. It is therefore essential to start with a special development project, with help of which the local situation can be carefully analyzed, different opinions can be voiced and the locks of communication opened. In an intensive process it is possible to focus effectively on functional aspects and aspects of work activity, as well as on implications of health and welfare of the workforce; this usually remains a very remote point of view for the technical designers.

In this process the guiding principles, "building blocks of good design practice" were an important conceptual tool: understandable, acceptable and always visible. It was a common tool for everybody, and an operation-oriented tool, leading discussion effectively but nevertheless leaving room for any participating party to raise and justify their own points of view.

A prerequisite for success in all group work, meetings and seminars dealing with the difficult topic of design practices, was obviously the special situation for peaceful cooperative discussion. Especially for people working in the production, e.g. production managers, supervisors and workers, it was important to arrange a separate place and provide sufficient time. On the other hand, the design or evaluation meetings concerning the workplace were in most cases recommended to be held at the actual or a comparable workplace.

In the design project it became obvious that it is important to generate new practices in collaboration with all occupational groups in order to get people to accept and to learn them and to become committed to using them. The new ways of action require special arrangements and guidance, however, and it is highly advisable to nominate a person into the role of a facilitator or an in-house consultant, a "shepherd", and to provide him/her with the power needed. A well chosen person is a key to success.

The study of one case provides too little information to draw conclusions about the usefulnes of the computer-based tools in their intended use. The preliminary experiences confirm the basic assumptions on the need of simple to use and modifiable tools to support all needs of designing. What was actually important in this early phase, was the support offered by the computer in producing the required paper material. A more sophisticated use of the computer will come later.

Acknowledgements

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Nomination for IEA Fellow Award 2017

Nominee for IEA Fellow
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The Nomination

1. Eligibility

Professor emeritus Veikko Louhevaara has been a member of the Finnish Ergonomics Society ERY (which is a part of the Nordic Ergonomics and Human Factors Society NES) in good standing since 1984. He has been a member of the Board of the ERY for 15 years from 1996 to 2010 and served the society as a vice-president for 4 years. During 1999-2002 Louhevaara was a member of the Board of the Estonian Ergonomics Society. He has been a representative of the ERY in the board of the NES. Louhevaara has authored articles to the international publications in the field of ergonomics and work physiology. He has been an invited speaker in over 20 international seminars and conferences.

2. Distinction

Professor Louhevaara, PhD (applied physiology), LicSc (physical education), has carried out occupational health and ergonomics related research at the Finnish Institute of Occupational Health in 1974-2008 and at the University of Eastern Finland (UEF) 1995-2012. He was an adjunct professor (work physiology) at the University of Kuopio in 1987-1995 and at Technical University of Tampere (labour protection) in 1988-2008. He was the first person in Finland to hold a professorship in ergonomics (1995-2012, University of Eastern Finland).

Louhevaara's research interests have covered broad areas of ergonomics, work physiology, and occupational health. His main research topics have included heavy physical work, load of manual materials handling, load of safety occupations (such as rescue and police work), ageing workers, utilisation of bio-signals (HRV, EMG) in the assessment of work load, and more recently, sustainable well-being at work. Louhevaara has published about 690 scientific articles, proceedings papers, popular reports and abstracts. He has given over 120 presentations in nearly 100 international scientific meetings in the field of ergonomics and occupational health promoting work ability and well-being at work.

Veikko Louhevaara has had an outstanding role in the development of ergonomics education in Finland. A great achievement of him and his colleagues is a web-based learning program (Ergonetti) about ergonomics and workplace health promotion. Ergonetti is open to all applicants regardless of age, educational aims or previous schooling. Among his students professor Louhevaara is known as a supportive and an encouraging supervisor. He has supervised and reviewed 29 doctoral dissertations and 69 MSc thesis.

Louhevaara has received 10 million euros of external funding for research studies and EU projects and Action programs. He is a funding partner of the Myontec LtD which is specialised for the measurements of electromyography in sports and at work utilising wearable technology.

Endorsement by a Federated Society

Name of endorser: Elina Parviainen
Position held: President
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Attached documents

Curriculum Vitae of Veikko Louhevaara

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18 April 2017

CURRICULUM VITAE

I PERSONAL DATA

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Place of Birth: Helsinki

Citizenship: Finland

Marital Status: Married, two daughters

II EDUCATION AND COMPETENCE

BA University of Jyväskylä, Physical Education and Health	1972
MSc University of Jyväskylä, Physical Education and Health	1974
LicSc University of Jyväskylä, Physical Education and Health	1981
PhD University of Kuopio, Medicine, Dept. of Physiology	1986
Docent/Adjunct Professor (Work Physiology) University of Kuopio, Medicine, Dept. of Physiology	1987
Docent/Adjunct Professor (Technology for Labour Protection) Tampere University of Technology, Dept. of Occupational Safety Engineering	1988
Research Professor Finnish Institute of Occupational Health, Dept. of Physiology	1993
Professor of Ergonomics University of Kuopio, Medicine, Dept. of Physiology	1996

III PROFESSIONAL EXPERIENCE

1973-1974	Training Course for Teacher Education, University of Jyväskylä, Dept. of Education
1974	Teacher of Physical and Health Education, The City of Vantaa
1975-1979	Assistant Researcher, Finnish Institute of Occupational Health, Dept. of Physiology
1980-1985	Researcher, Finnish Institute of Occupational Health, Dept. of Physiology
1986-1988	Special Researcher, Finnish Institute of Occupational Health, Dept. of Physiology
1988-1989	Visiting Research Fellow, National Institute of Occupational Health and Safety, Sydney, Australia
1989-1990	Special Researcher, Finnish Institute of Occupational Health, Dept. of Physiology
1990	Senior Researcher, Finnish Institute of Occupational Health, Dept. of Physiology
1990-1992	Acting Assistant Director of the Department, Finnish Institute of Occupational Health, Dept. of Physiology
1993	Senior Researcher, Director of the FinnAge - Respect for the Ageing Programme, Finnish Institute of Occupational Health, Dept. of Physiology
1994	Visiting Researcher, Institute of Work Physiology, University of Dortmund, Germany
1993-1996	Research Professor, Director of the FinnAge - Respect for the Ageing Programme, Finnish Institute of Occupational Health, Dept. of Physiology
1995-2000	Professor (Ergonomics), University of Kuopio, Medicine, Dept. of Physiology
1996-2002	Senior Researcher, Finnish Institute of Occupational Health, Dept. of Kuopio
2001-2002	Professor (Project Leader), University of Kuopio, University Administration
2001-2003	Professor (Director of the Action Program for Safety Occupations), Finnish Institute of Occupational Health, Dept. of Physiology
2003	Professor (Ergonomics), Professor (Project Leader) University of Kuopio, Dept. of Physiology, University Administration
2004-2008	Senior Researcher, Finnish Institute of Occupational Health, Kuopio
2004-2012	Professor (Ergonomics), University of Kuopio/University of Eastern Finland (UEF), Institute of Biomedicine, Physiology
2009-2016	Senior Adviser, Myontec Ltd

IV MILITARY SERVICE

1967-1968 Battalion of Commando Soldiers, Second Lieutenant

V HONORS AND AWARDS

The 22nd Horse Collar Knight, University of Kuopio, Department of Physiology, 1985

The Best Article in the Journal of Work and People (co-author), 1987

Recognition of the Formation of the Cooper Brothers Jogging Club over 20 years ago by Kenneth H. Cooper, MD, MPH, 1997

The First Rank Knight of White Roses, 1999

The Number One Firefigter of the Year "Vuoden brankkari" (Finnish Institute of Occupational Health, Member of the Team), 1999

The Finnish Ergonomics Association Reward of the Year for the development of the Ergonetti virtual learning program of 15 credit points (Open University of Kuopio, member of the team as Professor of ergonomics), 2000

The First Rank Medal for the Protection of People, 2002

The Team Finland Reward for the Development of Laboratory Jobs at the University of Kuopio (Project leader), 2002

The Second Merit Axe of the Patrix (Association of Occupational Physicians in Fire and Rescue Work), 2003

Kaiku Certification for the Development of Wellbeing at the University of Kuopio (Chairman of the Wellness Group), 2004

Kaiku Reward of Safety for the Development of Safety and Wellbeing at the University of Kuopio (Chairman of the Wellness Group), 2006

Nordic Ergonomics Society's Big Price for the Development of Comprehensive Multidisciplinary Academic Ergonomics Teaching Program at the University of Kuopio (Professor of Ergonomics), 2006

VI PROFESSIONAL ACTIVITIES

Society memberships

Finnish Physiology Society 1975-2012

Finnish Society of Sports and Physical Education 1975-2012

Scandinavian Physiological Society 1996-2012

International Commission on Occupational Health 1980-2008

Finnish Ergonomics Society 1984 -

International Ergonomics Association 1975-2012

Editorial Board of the Journal Work and People, 1999-2008

International Editorial Board of Ergonomia, An International Journal of Ergonomics and Human Factors in Poland, 2003-2012

Co-Editor, Ergonomics Open Journal, 2008-2010

Positions of trust

Chairman of the Employee Association of the Finnish Institute of Occupational Health, 1978-1979

Health and safety representative of the Main Institute of the Finnish Institute of Occupational Health, 1978-1979

Chairman of the Sport Club of the Finnish institute of Occupationa Health, 1978-1979

The Main Shop Steward of AKAVA at the Finnish Institute of Occupational Health, 1991-1993

The First Employee Representative in the Board of Directors at the Finnish Institute of Occupational Health, 1991-1993

Member of the Board of the Finnish Ergonomics Society, 1995-2010

Member of the Board of the Estonian Ergonomics Society, 1999-2002

Chairman of the Group for Promoting Health and Work Ability among the Personnel of the University of Kuopio, 1998-2002

Chairman of the Wellness Group for Promoting Health, Work Ability and Wellbeing among the Personnel of the University of Kuopio, 2003-2007

VII INTERNATIONAL SCIENTIFIC MEETINGS

Nordisk konferens on samarbete rörande arbetsmiljön in trädbranscherna, Oslo, Norway, 1976

Nordisk konferens on arbeiderven og arbedsmiljo i tredbransjene, Copenhagen, Denmark, 1977 (lectured)

I Dortmund-Helsinki workshop: Techniques for measuring physiological functions in laboratory and field conditions, Dortmund, Germany, 1979 (lectured)

II Dortmund-Helsinki workshop: AET-method as a tool in occupational research, Helsinki, Finland, 1980 (lectured)

XXVII International Congress of Physiological Sciences, Budapest, Hungary, 1980 (poster)

XX International Congress on Occupational Health, Cairo, Egypt, 1981 (lectured)

31. Nordiska yrkeshygieniska mötet, Reykjavik, Iceland, 1982 (poster)

Stockholm-Helsinki workshop: Research in work physiology, Stockholm, Sweden, 1982 (lectured, twice)

American Industrial Hygiene Conference, Philadelphia, USA, 1983 (lectured)

32. Nordiska yrkeshygieniska mötet, Stockholm, Sweden, 1983 (poster)

The fourth Finnish-Soviet joint symposium on industrial hygiene, toxicology, work physiology and psychology, Kuopio, Finland, 1983 (lectured)

International Conference on Occupational Ergonomics, Toronto, Canada, 1984 (lectured)

Scandinavian symposium on protective clothing against chemicals, Copenhagen, Denmark, 1984 (lectured)

The 1985 International Safety Appliances Conference, Tokyo, Japan, 1985 (lectured)

Ninth Congress of the International Ergonomics Association, Bournemouth, England, 1985 (lectured, twice)

The Second ISRP Conference, York, England, 1985 (lectured)

1986 Safe Symposium, San Antonio, USA, 1986 (lectured)

The Sixth Finnish-Soviet Joint Symposium on Occupational Health, Rovaniemi, Finland, 1987 (lectured)

XXII International Congress on Occupational Health, Sydney, Australia, 1987 (lectured)

The 7th International Biochemistry of Exercise Conference, Quebeck London, Canada, 1988 (poster)

The Annual International Industrial Ergonomics and Safety Conference, New Orleans, USA, 1988 (lectured, twice)

The 3rd International Conference on Environmental Ergonomics, Helsinki, Finland, 1988 (lectured)

International Workshop on Mechanical Engineering in Manual Materials Handling, Tampere, Finland, 1988 (lectured)

XII World Congress on Occupational Safety and Health, Hamburg, Germany, 1990 (lectured)

23rd International Congress on Occupational Health, Montreal, Canada, 1990 (lectured)

American Industrial Hygiene Conference & Exposition, Salt lake City, USA, 1991 (lectured)

International Symposium "Shiftwork and Job Demands", Paris, France, 1991 (lectured)

11th Congress of the International Ergonomics Association, Paris, France, 1991 (lectured)

The Eighth Finnish-Soviet Joint Symposium on Occupational Health, Nauvo, Finland, 1991 (lectured)

Work in the 1990s Symposium, Helsinki, Finland, 1991 (lectured)

Nordic Seminar on Elderly Workers, Copenhagen, Denmark, 1991 (lectured)

International Scientific Symposium on Aging and Work, Haikko, Finland, 1992 (lectured)

International Conference on Computer-Aided Ergonomics and Safety '92 - CAES '92, Tampere, Finland, 1992 (session chairman)

Annual International Industrial Ergonomics and Safety Conference, Denver,SA, 1992 (lectured)

The Fifth International Conference on Environmental Ergonomics, Maastrich, The Netherlands, 1992 (poster, lectured)

Nordic Seminar on Elderly Workers, Stocholm, Sweden, 1993 (lectured)

Annual International Industrial Ergonomics and Safety Conference, Copenhagen, Denmark, 1993 (lectured)

International Ergonomics Association Word Conference on Ergonomics of Materials Handling and Information Processing at Work, Warsaw, Poland, 1993 (lectured)

24th Congress of the International Commission on Occupational Health, Nice, France, 1993 (lectured)

First International Course on Work and Age, Naantali, Finland, 1993 (lectured)

FinnAge Seminar I: Longitudinal Studies on Aging and Work, Helsinki, Finland, 1994 (lectured)

Seminar on Clothing and Safety Equipment in Forestry, Kuopio, Finland, 1994 (lectured)

12th Triennial Congress of the International Ergonomics Association, Toronto, Canada, 1994 (lectured, twice)

XVII International IAUTA Congress, Jyväskylä, Finland, 1994 (lectured)

The Paths to Productive Ageing: UOEH and IIES International Symposiums, Kitakyushu, Japan, 1994 (lectured, twice)

Tallinn-Helsinki Workshop: Assessment of stress and strain at work, Tallinn, Estonia, 1995 (lectured)

From Research to Prevention, Helsinki, Finland, 1995 (lectured, poster)

American Industrial Hygiene Conference & Exposition, Kansas City, USA, 1995 (lectured)

5th European Congress on Research in Rehabilitation, Helsinki, Finland, 1995 (lectured)

The First FEPS Congress, Maastrich, The Netherlands, 1995 (poster)

XIth Annual International Occupational Ergonomics and Safety Conference, Zurich, Switzerland, 1996 (lectured)

25th Congress of the International Commission on Occupational Health,Stockholm, Sweden, 1996 (lectured)

Work after 45? Symposium, Stockholm, Sweden, 1996 (lectured)

XIIth Annual International Occupational Ergonomics and Safety Conference, Washington DC, USA, 1997 (lectured)

13th Triennial Congress of the International Ergonomics Association, Tampere, Finland, 1997 (lectured, poster)

Women at Work Conference, Hanasaari, Finland, 1997 (lectured)

Workshop on Aging of the Workforce, Brussels, Belgium, 1998 (lectured)

International Symposium from protection to Promotion. Occupational Health and safety in Small-scale Enterprises. Helsinki, Finland, 1998 (lectured)

XIIth Annual International Occupational Ergonomics and Safety Conference, Ypsilanti, USA, 1998 (lectured, twice)

Second International ICOH Conference on Aging and Work, Elsinore, Denmark, 1998 (lectured)

Second International NIVA-Course on Cleaning and Working environment - A Comprehensive Approach to Improvements, Segeberg, Germany, 1998 (lectured, twice)

The First International Workshop on Health and Working Conditions in South East Asia "Heat Stress and Physical Workload", Bangkok, Thailand 1999 (lectured)

Symposium on Ergonomics, Tallinn, Estonia, 1999 (lectured)

The 5th World Congress on Physical Activity, Aging and Sports, Orlando, USA, 1999 (lectured)

Workshop on Ergonomics, Waterloo, Canada, 1999 (lectured)

Symposium: Risk Assessment and Preventive Strategies in Cleaning Work, Garda Lake, Italy, 1999 (lectured, twice)

International Symposium on Occupational Health for Europeans, Helsinki, Finland, 1999 (lectured)

The XIVthe Triennal Congress of the International Ergonomics Association, San Diego, USA, 2000 (lectured, poster)

The 26th International Congress on Occupational Health, Singapore, 2000 (lectured, triple)

The 21st UOEH and the 4th IIES International Symposium of Aging and Work, Kitakyushu, Japan, 2001 (lectured)

NES 2001 Nordic Ergonomics Society 33rd Annual Congress, Tampere, Finland, 2001 (lectured)

17th Asian Conference on Occupational health (ACOH 2002), Taipei, Taiwan, 2002 (lectured, twice)

27th International Congress on Occupational Health, Iguassu Falls, Brazil, 2003 (lectured)

Workshop of Paramedics, Sijsele-Damma, Belgium, 2003 (lectured, twice)

The XVth Triennal Congress of the International Ergonomics Association, Seoul, Korea, 2003 (lectured, triple)

International Conference of Aging and Work - Promotion of Work Ability, Seoul, Korea, 2003 (lectured)

International Symposium on Ergonomics and Hygiene, Lublin, Poland, 2003 (lectured)

The Closing Workshop of The EU project of Risk Assessment of Biomechanical Damage Risk in Small and Medium sized Enterprises, San Gimignano, Italy, 2004 (lectured)

The 2nd Annual Meeting of the National Bimaterial and Tissue Engineering Graduate School, Kuopio, Finland, 2004 (lectured)

70th Conference of the Human Factors and Ergonomics in Australia and 7th Conference of the Pan Pacific Council on Occupational Ergonomics, Cairns, Australia, 2004 (lectured)

The 2nd International Symposium on Work Ability: Assessment and promotion of work ability, health and well-being of ageing workers, Verona, Italy, 2004 (lectured)

The 25-year Jubilee Symposium of the Elisabeth Hospital Sijsele-Damme, Sijsele-Damme, Belgium, 2004 (lectured)

18th Asian Conference on Occupational health (ACOH 2002), Wellington, New Zealand, 2005 (lectured, twice)

NES 2005, Nordic Ergonomics Society 37th Annual Congress, Oslo, Norway, 2005 (lectured, twice)

ICOH 2006, 28th International Congress on Occupational Health, Milan, Italy, 2006 (lectured, twice)

IEA 2006, 16th World Congress on Ergonomics, Maastrich, the Netherlands, 2006 (lectured)

NES 2006, Nordic Ergonomics Society 38th Annual Congress, Hämeenlinna, Finland, 2006 (lectured)

Health and Work Conference, Birmingham, UK, 2007 (lectured)

The Eighth Pan-Pacific Conference on Occupational Ergonomics (PPCOE 2007), Bangkok, Thailand, 2007 (lectured, twice)

3rd International Symposium on Work Ability, Hanoi, Vietnam, 2007 (lectured, twice)

16th European Congress of Physical and rehabilitation Medicine, Brus, 2008, Belgium (lectured)

NES 2008, Nordic Ergonomics Society 40th Annual Congress, Reykjavik, Iceland, 2008 (lectured, twice)

The 19th Asian Conference on Occupational Health, Singapore, 2008 (lectured)

Workshop on the Prevention of Musculoskeletal Disorders in the Bangkok Suburb Area, Bangkok, Thailand, 2008 (lectured)

17th Congress of the International Ergonomics Association (IEA 2009), August 9-14, 2009, Beijing, China (lectured, twice and poster)

1st European FEES Conference on Ergonomics (ECE), 10-12 October 2010, Bruges, Belgium (lectured)

NES 2011, Nordic Ergonomics Society 43th Annual Congress, Oulu, Finland, 2011 (lectured, triple)

VIII INVITED SEMINARS

Nordic Seminar on Elderly Workers, Stockholm, Sweden, 1991

Annual International Industrial Ergonomics and Safety Conference '92, Tampere, Finland, 1992

Nordic Seminar on Elderly Workers, Stockholm, Sweden, 1993

First International Course on Work and Age, Naantali, Finland, 1993

FinnAge Seminar I: Longitudinal Studies on Aging and Work, Helsinki, Finland, 1994

From Research to Prevention, Helsinki, Finland, 1995

5th European Congress on Research in Rehabilitation, Helsinki, Finland, 1995

Women at work, Hanasaari, Finland, 1997

Workshop on Aging of the Workforce, Brussels, Belgium, 1998

XIIth Annual International Occupational Ergonomics and Safety Conference, Ypsilanti, USA, 1998

Second International Course on Cleaning and Working environment - A Comprehensive Approach to Improvements, Segeberg, Germany, 1998

The First International Workshop on Health and Working Conditions in South East Asia "Heat Stress and Physical Workload", Bangkok, Thailand, 1999

Symposium on Ergonomics, Tallinn, Estonia, 1999

Symposium: Risk Assessment and Preventive Strategies in Cleaning Work, Garda Lake, Italy, 1999

Workshop for the EU Project "Heat stress and physical workload of workers in Thailand", Brus, Belgium, 2001

Workshop of Paramedics, Sijsele-Damme, Belgium, 2003

International Symposium on Ergonomics and Hygiene, Lublin, Poland, 2003

The Closing Workshop of The EU project of Risk Assessment of Biomechanical Damage Risk in Small and Midium sized Enterprises, San Gimignano, Italy, 2004

The 2nd Annual Meeting of the National Bimaterial ans Tissue Engineering Graduate School, Kuopio, Finland, 2004

The 25-year Jubilee Symposium of the Elisabeth Hospital Sijsele-Damme, Sijsele-Damme, Belgium, 2004

18th Asian Conference on Occupational health (ACOH 2002), Wellington, New Zealand, 2005 (lectured, twice)

NES 2005, Nordic Ergonomics Society 37rd Annual Congress, Oslo, Norway, 2005 (lectured twice)

Health and Work Conference, Birmingham, UK, 2007 (lectured)

16th European Congress of Physical and rehabilitation Medicine, Brus, Belgium, 2008 (lectured)

Workshop on the Prevention of Musculoskeletal Disorders in the Bangkok Suburb Area, Bangkok, Thailand, 2008 (lectured)

1st European FEES Conference on Ergonomics (ECE), 10-12 October 2010, Bruges, Belgium (lectured)

IX TEACHING

Ergonomics, work physiology, thermal physiology, workplace health promotion

X SUPERVISE AND REVIEW OF ACADEMIC STUDIES

Quality statement for professor position

Marja Aulanko, University of Helsinki, 1999

Quality statement for docent/adjunct professor position

Ryszard Crucza, University of Kuopio, 1991
Clas-Håkan Nygård, University of Tampere, 1991
Raija Laukkanen, University of Oulu, 1998
Juha Oksa, University of Jyväskylä, 2000

Reviewer of doctoral dissertation

Erkki Kähkönen, University of Kuopio, 1992
Raija Laukkanen, University of Kuopio, 1993
Helli Toivanen, University of Kuopio, 1994
Anneli Kaukiainen, University of Tampere, 2000
Minna Päivinen, Tampere University of Technology, 2002
Leena Tamminen-Peter, University of Turku, 2005
Jarmo Sillanpää, Tampere University of Technology, 2006
Lea Saarni, University of Tampere, 2009

Opponent of doctoral dissertation

Marja Aulanko, University of Helsinki, 1987
Minna Päivinen, Tampere University of Technology, 2002
Markku Pirinen, University of Oulu, 2003
Minna Savinainen, University of Tampere, 2004

Supervisor of doctoral dissertation

Sirpa Lusa, University of Jyväskylä, 1989-1994 (PhD 1994)
Heikki Soininen, University of Kuopio, 1991-1995 (PhD 1995)
Nina Nevala-Puranen, University of Jyväskylä, 1995-1997 (PhD 1997)
Merja Perkiö-Mäkelä, University of Kuopio, 1997-2000 (PhD 2000)
Tiina Pohjonen, University of Kuopio, 1995-2001 (PhD 2001)
Elisa Mäkinen, University of Kuopio, 1998-2001 (PhD 2001)
Minna Päivinen, Tampere University of Technology, 1996-2002 (PhD 2002)
Pongjan Yoopat, University of Kuopio, 2000-2002 (PhD 2002)
Ritva Ketola, University of Kuopio, 1997-2003 (PhD 2003)
Päivi Vehmasvaara, University of Kuopio, 2001-2004 (PhD 2004)
Anne Punakallio, University of Kuopio, 1996-2004 (PhD 2004)
Tiina Ritvanen, University of Kuopio, 2001-2006 (PhD 2006)
Lars Sörensen, University of Kuopio, 1996-2008 (PhD 2008)
Irmeli Pehkonen, University of UEF, 2003-2010 (PhD 2010)
Marja Randelin (Pitkänen), UEF, 2004-2012 (PhD 2013)
Kristiina Kumpulainen, UEF, 2007-2012 (PhD 2013)
Susanna Järvelin-Pasanen, UEF, 2007-2012 (PhD 2014)

UEF = University of Eastern Finland

Supervisor, referee and/or opponent of LicSc thesis

Juha Peltonen, University of Jyväskylä, 1994
Merja Perkiö-Mäkelä, University of Jyväskylä, 1995
Minna Päivinen, Tampere University of Technology, 1998
Matti Kallio, University of Kuopio, 2000
Jalmari Heikkonen, Nordic School of Public Health, 2004

Supervisor and/or reviewer of MSc thesis

Jyrki Kiviniitty, Tampere University of Technology, 1990
Marja Aarnio, University of Kuopio, 1993
Pirkko Mäkinen, University of Kuopio, 1994
Anne Punakallio, University of Jyväskylä, 1994
Maija Kolari, University of Jyväskylä, 1994
Mika Vilkki, Tampere University of Technology, 1994
Raija Salmimies, University of Kuopio, 1995
Maija Aarniola-Rinne, University of Jyväskylä, 1995
Kristiina Juvas, University of Kuopio, 1996
Jaana Maksimainen, University of Kuopio, 1997
Jaana Laaksonen, University of Kuopio
Leila Hopsu, University of Helsinki, 1997

Merja Vikström, University of Kuopio, 1998
Kimmo Pakarinen, University of Kuopio, 1999
Kimmo Penttilä, University of Kuopio, 2000
Tarja Kantolahti, University of Kuopio, 2000
Irma Gerstenmaier, University of Kuopio, 2000
Aune Vänskä, University of Kuopio, 2000
Päivi Kinnunen, University of Kuopio, 2001
Anja Pehkonen, University of Kuopio, 2001
Pirjo Hakkarainen, University of Kuopio, 2002
Airi Hietamäki, University of Kuopio, 2002
Seija Kujala-Przelior, University of Kuopio, 2002
Marja Pitkänen, University of Kuopio, 2002
Anne Ranta, University of Kuopio, 2002
Teija Lolax, University of Kuopio, 2002
Oili Saarelainen, University of Kuopio, 2003
Sami Shemeikka, University of Kuopio, 2003
Pirjo Talvela-Blomqvist, University of Kuopio, 2003
Maritta Varis, University of Kuopio, 2003
Tuula Uurala, University of Kuopio, 2003
Sirpa Ojala, University of Kuopio, 2003
Leena Penttinen, University of Kuopio, 2003
Pauliina Juntunen, University of Kuopio, 2003
Arja Kaasinen, University of Kuopio, 2004
Sinikka Leisti, University of Kuopio, 2004
Merja Mäkitalo, University of Kuopio, 2004
Sari Tiainen, University of Kuopio, 2004
Tuija Toikka, University of Kuopio, 2004
Henna Hentilä, University of Kuopio, 2004
Eija Ovaskainen, University of Kuopio, 2004
Kati Huikuri, University of Kuopio, 2005
Aulikki Luukinen, University of Kuopio, 2005
Heli Rantsi, University of Kuopio, 2005
Virve Olli, University of Kuopio, 2005
Susanna Järvelin, University of Kuopio, 2006
Suvi Nikulainen, University of Kuopio, 2006
Sinikka Första, University of Kuopio, 2007
Johanna Koroma, University of Kuopio, 2007
Hannele Sievers, University of Kuopio, 2007
Tuula Sarin, University of Kuopio, 2007
Tuula Kemppainen, University of Kuopio, 2007
Sari Silvola, University of Kuopio, 2007
Päivi Rauramo, University of Kuopio, 2007
Susanna Kähkönen, University of Kuopio, 2008
Kaija Siitonen, University of Kuopio, 2008
Kaarina Tilli, University of Kuopio, 2008
Pinja Torssonen, University of Kuopio, 2008
Jukka Kähkönen, University of Kuopio, 2008
Maija Rauma, University of Kuopio, 2009
Mari Sarvi, University of Kuopio, 2009
Sari Keituri, University of Kuopio, 2009

Ulla Halminen-Äkräs, UEF (University of Eastern Finland), 2010
Niina Vuorenmaa, UEF, 2010
Anne Henriksson, UEF, 2011
Johanna Ekola, UEF, 2011
Anna-Mari Hakuni, UEF, 2011
Riikka Yliniitty, UEF, 2011
Tuula Sivander-Heinonen, UEF, 2012

XI REFEREE ACTIVITIES

Evaluation of programs

The Cold Work Action Program, 2003

The Risk Assessment of Biomechanical Damage Risk in Small and Medium Sized Enterprises-EU project, 2004

Referee statements

About 140 referee statements (articles, books, research proposals) 1986-2017 for

European J Appl Physiol Occup Physiol
Acta Physiologica Scandinavica
Ergonomics
Scand J Work Environ Health
Int J Ind Ergonomics
Työ ja ihminen
Ministry of Education
Finnish Fund for Labour Protection
etc.

XII OTHERS

Received external funding of 10 million euros for research studies and EU projects and Action programs in 1975-2012.

Funding partner of Myontec LtD specialized the measurements of electromyography in sports and at work utilizing wearable technology.

XIII PUBLICATIONS: SUMMARY

1. Scientific articles and reports

First author	45
Co-author	77
All	122

2. Short and proceedings papers

First author	64
Co-author	127
All	191

3. Popular articles and unpublished scientific reports

First author	129
Co-author	117
All	246

4. Abstracts

First author	49
Co-author	80
All	129

Total	688

Veikko Louhevaara

XIII PUBLICATIONS

1. Scientific articles and reports

1976-1979

Rusko J, Laine K, Louhevaara V, Ikonen K, Hakamäki J, Sauro R. Kuntokoululaisten testaustulosten analysointi ja kuntoluokkien muodostus. Jyväskylän yliopiston liikuntabiologian laitos ja Jyväskylän Uimahallin Kuntokellari, Jyväskylä 1972. Teoksessa: Vuori I (toim) Fyysisen kunnon mittaaminen. Painoprint Oy, Helsinki 1976.

Klen T, Louhevaara V. Kuitupuun kasauksen keventämisen ratkaisumahdollisuuksia harvennusmetsissä. Työterveyslaitoksen katsauksia 9, Helsinki 1976, 86 s. + liitteet.

Oja P, Louhevaara V, Korhonen O. Age and sex as determinants of the relative aerobic strain of nonmotorized mail delivery. Scand J Work Environ Health 3(1977) 225-233.

Klen T, Louhevaara V. Metsurin suojavarusteiden aiheuttama lisäkuormitus. Silva Fennica 12(1978) 151-169.

Seppälä P, Louhevaara V, Siikaranta R, Oja P. Tuotantotekniikan vaikutus työn psyykkiseen ja fyysiseen kuormittavuuteen sahateollisuudessa. Työterveyslaitoksen tutkimuksia 159, Helsinki 1979, 246 s. + liitteet.

1980

Louhevaara V, Ilmarinen J, Oja P. Comparisons of the Åstrand nomogram and the WHO extrapolation methods for estimating maximal oxygen uptake. Scand J Sport Sci 2(1980) 21-25.

Louhevaara V, Ilmarinen J, Oja P. Maksimaalisen hapenkulutuksen arviointi eri menetelmillä submaksimaalisen polkupyöräergometritestin perusteella. Stadion 17(1980) 24-27.

1981

Kalimo R, Leppänen A, Seppälä P, Louhevaara V, Koskinen P. Työn organisointi, tuotantotekniikka ja psyykkinen kuormittavuus. Tutkimus graafisessa teollisuudessa. Työterveyslaitoksen tutkimuksia 174, Helsinki 1981, 235 s. + liitteet.

1982

Oja P, Ilmarinen J, Louhevaara V. Heart rate as an estimator of oxygen consumption during manual postal delivery. Scand J Work Environ Health 8(1982) 29-36.

1983

Louhevaara V, Ilmarinen J, Nygård C-H, Pesonen I. Siivoustyön fyysinen kuormittavuus. Työterveyslaitoksen tutkimuksia 1(1983) 34-45.

Smolander J, Louhevaara V, Oja P. Liikuntavammojen esiintymistaajuus ja siihen vaikuttavia tekijöitä poliisikoulutuksessa. Suomen Liikuntalääketiede 2(1983) 126-134.

Louhevaara V. Hengityksensuojaimet ja työn fyysinen kuormittavuus. Työterveyslaitoksen tutkimuksia 1(1983) 157-169.

Smolander J, Louhevaara V, Oja P. Poliisien fyysinen suorituskyky. Liikunta ja tiede 20(1983) 128-133.

1984

Louhevaara V, Tuomi T, Korhonen O, Jaakkola J. Cardiorespiratory effects of respiratory protective devices during exercise in well-trained men. Eur J Appl Physiol Occup Physiol 52(1984) 340-345.

Ilmarinen J, Louhevaara V, Oja P. Oxygen consumption and heart rate in different modes of manual postal delivery. Ergonomics 27(1984) 331-339.

Smolander J, Louhevaara V, Tuomi T, Korhonen O, Jaakkola J. Reduction of isometric muscle endurance after wearing impermeable gas protective clothing. Eur J Appl Physiol Occup Physiol 53(1984) 76-80.

Smolander J, Louhevaara V, Tuomi T, Korhonen O, Jaakkola J. Cardiorespiratory and thermal effects of wearing gas protective clothing. Int Arch Occup Environ Health 54(1984) 261-270.

Smolander J, Louhevaara V, Oja P. Policemen's physical fitness in relation to the frequency of leisure-time physical exercise. Int Arch Occup Environ Health 54(1984) 295-302.

Louhevaara V. Physiological effects associated with the use of respiratory protective devices: A review. Scand J Work Environ Health 10(1984) 275-281.

Louhevaara V, Tuomi T, Jaakkola J, Korhonen O, Tossavainen A, Korhonen E. Hengityksensuojainten fyysinen kuormittavuus. Työterveyslaitoksen tutkimuksia 203, Helsinki 1984, 44 s.

Jaakkola J, Smolander J, Louhevaara V, Tuomi T, Korhonen E, Korhonen O, Tossavainen A. Kaasunsuojapukujen fyysinen kuormittavuus ja suojausteho. Työterveyslaitoksen tutkimuksia 208, Helsinki 1984, 50 s.

1985

Louhevaara V, Tuomi T, Smolander J, Korhonen O, Tossavainen A, Jaakkola J. Belastung und Beanspruchung bei industriellen Tätigkeiten unter Atemschutz. Arbeitsmed Sozialmed Präventivmed 20(1985) 25-31.

Louhevaara V, Smolander J, Tuomi T, Korhonen O, Jaakkola J. Effects of an SCBA on breathing pattern, gas exchange, and heart rate during exercise. J Occup Med 27(1985) 213-216.

Louhevaara V, Ilmarinen J, Oja P. Comparison of three field methods for measuring oxygen consumption. Ergonomics 28(1985) 463-470.

Louhevaara V, Tuomi T, Smolander J, Korhonen O, Tossavainen A, Jaakkola J. Cardiorespiratory strain in jobs that require respiratory protection. Int Arch Occup Environ Health 55(1985) 195-206.

Louhevaara V. Effects of respiratory protective devices on breathing pattern, gas exchange, and heart rate at different work levels. Publications of the University of Kuopio, Medicine, Original reports 7/85, 78 pp + appendix (doctoral dissertation).

Smolander J, Louhevaara V, Korhonen, O. Physiological strain in work with gas protective clothing at low ambient temperature. Am Ind Hyg Assoc J 46(1985) 720-723.

1986

Louhevaara V, Smolander J, Korhonen O, Tuomi T. Maximal working times with a self-contained breathing apparatus. Ergonomics 29(1986) 77-85.

Louhevaara V, Smolander J, Korhonen O, Tuomi T. Effects of industrial respirators on breathing pattern at different work levels. Eur J Appl Physiol Occup Physiol 55(1986) 142-146.

Louhevaara V, Smolander J, Korhonen O, Tuomi T. Effects of industrial respirators on breathing pattern, gas exhange and heart rate during exercise. Journal of the ISRP 4(1986) 1-24.

Louhevaara V. Respirator wearer's strain: A complex problem (editorial) Am J Ind Med 10(1986) 3-6.

Louhevaara V. Työntekijöiden kokeman kuormittuneisuuden yhteydet työhön ja työoloihin. Työterveyslaitoksen tutkimuksia 4(1986) 55-63.

Louhevaara V. Hengityksensuojaimen käyttäjän kuormittuneisuuden arviointiperusteet. Työterveyslaitoksen tutkimuksia 4(1986) 189-194.

Smolander J, Louhevaara V, Ahonen M. Clothing, hypotermia, and long-distance skiing. Lancet II (1986) 226-227.

1987

Ilmarinen R, Harjula R, Korhonen E, Kuoppasalmi K, Louhevaara V, Suurnäkki T, Tammela E. Lihanleikkaajan työ - kylmää ja kuormittavaa. Työ ja ihminen 1(1987) 366-387.

1988

Louhevaara V, Teräslinna P, Piirilä P, Salmio S, Ilmarinen J. Physiological responses during and after intermittent sorting of postal parcels, and recovery. Ergonomics 31(1988) 1165-1175.

Louhevaara V, Smolander J. Erityisammattien fyysiset kuormitustekijät - esimerkkinä palomies- ja poliisityö. Liikunta ja tiede 25(1988) 66-68.

Ilmarinen J, Louhevaara V, Korhonen O, Nygård C-H, Suvanto S, Hakola T, Jokinen M. Verenkiertoelimistön toimintakyvyn muutokset 51-55 -vuotiailla kunta-alan työntekijöillä. Työ ja ihminen 2(1988) 392-409.

1989

Smolander J, Louhevaara V, Hakola T, Ahonen E, Klen T. Cardiorespiratory strain during walking in snow with boots of different weights. Ergonomics 32(1989) 3-13.

1990

Louhevaara V, Sovijärvi A, Ilmarinen J, Teräslinna P. Differences in cardiorespiratory responses during and after arm crank and cycle exercise. Acta Physiol Scand 138(1990) 133-143.

Louhevaara V, Hakola T, Ollila H. Physical work and strain involved in manual sorting of postal parcels. Ergonomics 33(1990) 1115-1130.

Louhevaara V, Long AF, Owen P, Aickin C, McPhee B. Local muscle and circulatory strain in load lifting, carrying and holding tasks. Int J Ind Ergonomics 6(1990) 151-162.

1991

Rissanen S, Smolander J, Louhevaara V. Work load and physiological responses during asbestos removal work with protective clothing. Int Arch Occup Environ Health 63(1991) 241-246.

Ilmarinen J, Louhevaara V, Korhonen O, Nygård C-H, Hakola T, Suvanto S. Changes in maximal cardiorespiratory capacity among aging municipal employees. Scand J Work Environ Health 17(1991) suppl 1, 99-109.

Lusa S, Louhevaara V, Smolander J, Kinnunen K, Korhonen O, Soukainen J. Biomechanical evaluation of heavy tool-handling in two age groups of firemen (rapid communication). Ergonomics 34(1991) 1429-1432.

Louhevaara V, Leppänen A, Hakola T, Sjöblom T. Sydämen sykintätaajuus uuden konelinjan käyttöönoton ja työn hallinnan eri vaiheissa - tapausselostus paperitehtaalta. Työ ja ihminen 5(1991) 151-161.

1992

Stålhammar HR, Louhevaara V. Anthropometric, muscle strength and spinal mobility characteristics as predictors in the rating of acceptable loads in parcel sorting. Ergonomics 35(1992) 1033-1044.

Louhevaara V. Cardiorespiratory and muscle strain during manual sorting of postal parcels (review). J Occup Med, Singapore 4(1992) 9-17.

Smolander J, Louhevaara V. Effect of heat stress on muscle blood flow during dynamic handgrip exercise. Eur J Appl Physiol Occup Physiol 65(1992) 215-220.

Louhevaara V, Lindqvist-Virkamäki S, Korhonen O, Lusa S, Soukainen J. Palomiesten terveys ja työkyky I: työn fyysiset vaatimukset ja kuormittavuus. Suomen Lääkärilehti 92(1992) 2171-2174.

Lindqvist-Virkamäki S, Louhevaara V, Korhonen O, Lusa S, Soukainen J. Palomiesten terveys ja työkyky II: terveydentilan ja fyysisen työkyvyn arviointi. Suomen Lääkärilehti 92(1992) 2270-2274.

1993

Lusa S, Louhevaara V, Smolander J, Kivimäki M, Korhonen O. Physiological responses of the fire-fighting students during simulated smoke-diving in the heat. Am Ind Hyg Assoc J 54(1993) 228-231.

Rintamäki H, Hassi J, Smolander J, Louhevaara V, Rissanen S, Oksa I, Laapio H. Acclimatization in Antarctica in relation to cold exposure and outdoor physical activity. Eur J Appl Physiol Occup Physiol 67(1993) 380-384.

Louhevaara V, Smolander J. Fyysinen ylikuormitus työssä. Työolot nykyisen tutkimustiedon valossa. Työ ja ihminen 7(1993) suppl 2, 17-29.

Louhevaara V. Siivoojien työ. Työ ja ihminen 7(1993) suppl 3, 169-175.

Lusa S, Louhevaara V, Smolander J, Pohjonen T, Uusimäki H, Korhonen O. Thermal effects of fire-protective equipment during job-related exercise protocol. Safe Journal 23(1993) 36-39.

Suurnäkki T, Louhevaara V. Frisk rygg på arbetsplatsen. Nordisk Ergonomi 3(1993) 19-21.

1994

Lusa S, Louhevaara V, Kinnunen K. Are the job demands on physical work capacity equal for young and aging firefighters? J Occup Med 36(1994) 70-74.

Louhevaara V, Soukainen J, Lusa S, Tulppo M, Tuomi P, Kajaste T. Development and evaluation of a test drill for assessing physical work capacity of fire-fighters. Int J Ind Ergonomics 13(1994) 139-146.

Miettinen M, Louhevaara V. Job demands, physical fitness, work ability, and age of vehicle inspectors. Int J Ind Ergonomics 13(1994) 337-342.

Ilmarinen J, Louhevaara V. Preserving the capacity to work. Ageing International 21(1994) 34-36.

Smolander J, Louhevaara V, Ilmarinen J, Korhonen O. Kevyen liikuntaohjelman vaikutukset työ- ja toimintakykyyn keski-ikäisillä metallialan työntekijöillä. Työ ja ihminen 8(1994) 163-170.

1995

Smolander J, Louhevaara V. Ahonen E, Polari J, Klen T. The energy expenditure and clearing snow: a comparison of shovel and snow pusher. Ergonomics 38(1995) 749-753.

Louhevaara V. Assessment of physical load at work sites: A Finnish-German concept. Int J Occup Safety and Ergonomics 1(1995) 144-152.

Kolari M, Louhevaara V. Staattinen lihastyö: Fysiologiset vaikutukset ja väsymisen ehkäisy. Työ ja ihminen 9(1995) 4-15.

Louhevaara V, Ilmarinen R, Griefahn B, Kunemund C, Mäkinen H. Maximal physical work performance with European standard based fire-protective clothing system and equipment in relation to individual characteristics. Eur J Appl Physiol Occup Physiol 71(1995) 223-229.

1996

Griefahn B, Ilmarinen R, Louhevaara V, Mäkinen H, Kunemund K. Arbeitzeit und Pausen im simulierten Einsatz der Feuerwehr. Z Arb. wiss. 50(1996) 89-95.

Aminoff T, Smolander J, Korhonen O, Louhevaara V. Physical work capacity in dynamic exercise with differing muscle masses in healthy young and older men.Eur J Appl Physiol Occup Physiol 73(1996) 180-185.

Ilmarinen J, Pohjonen T, Punakallio A, Louhevaara V. Habitual physical activity, psychomotor performance and older workers. Nutrition Reviews 54;4 Pt II(1996) 44-52.

Stålhammar RH, Louhevaara V, Troup JDG. Rating of acceptable loads in manual sorting of postal parcels. Ergonomics 39(1996) 1214-1220.

Hopsu L, Louhevaara V. Osallistuva ergonomia ja liikunta osana ikääntyvien siivoojien työkykä ylläpitävää toimintaa. Gerontologia 10(1996) 242-251.

1997

Ilmarinen R, Louhevaara V, Griefahn B, Kunemund C. Thermal responses to consecutive strenuous fire-fighting and rescue tasks in the heat. In: Shapiro Y et al., eds. Environmental physiology - Recent progress and new frontiers. London, Tel Aviv, Freund Publishing House Ltd., 1997, 295-298.

Aminoff T, Smolander J, Korhonen O, Louhevaara V. Cardiorespiratory and subjective responses to prolonged arm and leg exercise in healthy young and older men. Eur J Appl Physiol Occup Physiol 75(1997) 363-368.

Louhevaara V, Ilmarinen R, Mäkinen H, Griefahn B, Kunemund K. Palomiestyössä käytettävän savusukellusvarustuksen vaikutukset verenkiertoelimistön kuormittumiseen ja työtehoon maksimaalisessa lihastyössä. Työ ja ihminen 11(1997) 115-124.

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Is the physical work load equal for ageing and young blue-collar workers?

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Abstract

The aim of this study was to quantify physical work load of blue-collar workers and to compare the work load factors between ageing (45 + years) and young workers. The subjects included 63 men (41 construction workers and 22 vehicle inspectors). The mean age of the ageing and young subjects was 52 and 33 years, respectively. The dynamic (Edholm scale and HR), static postural (OWAS method) and perceived (RPEs) work loads were assessed at work sites. Energy expenditure, HR and the proportions of poor work postures were similar when the ageing and young subjects were compared in their occupational groups. During work, RPEs varied from "very light" to "fairly hard" regardless of age. The differences in physical work load between the ageing and young construction workers and vehicle inspectors were small. The results suggest that the physical work load of blue-collar workers is not affected by age.

Relevance to industry

This study introduces some simple field methods which are relevant and often needed before planning and directing ergonomic, organisational and/or individual measures for adjusting physical work load of blue-collar workers and, particularly, ageing ones.

Keywords: Construction work; Inspection of vehicles; Dynamic load; Musculoskeletal load; Perceived load

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1. Introduction

In the post-40-year category physical fitness begins to decrease and may impair work capacity and performance particularly in physically demanding blue-collar jobs. Physical work load should be adjusted according to the work capacity of each individual worker for preventing overstrain, fatigue, disorders and injuries. In principle, physical work load should be decreased with increasing age due to the natural and evident decline of physical work capacity (Ilmarinen, 1992).

Construction work and vehicle inspection can be classified as blue-collar jobs in which large muscle masses are needed to activate for producing force with dynamic or static contractions. In Finland, the number of constructions workers in different pipe and railway installations jobs is a few thousand

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men and that of vehicle inspectors is about 700 men. Today, many of the construction workers and inspectors belong to the category of ageing (45 + years) workers. The recent measures for increasing the productivity and efficiency of work and for saving personal costs has increased the work output and work load of the construction workers and inspectors, who commonly experience their work load as too high. According to health and safety representatives the most negative factors affecting physical work load are excessive physical job demands, time pressure, cold, heat, draft and noise (Heikkinen et al., 1994; Miettinen and Louhevaara, 1994; Louhevaara et al., 1998).

The greater requirements of work output, and the effects of ageing, may considerably increase physical strain and work-related disorders in construction work and vehicle inspection type of blue-collar jobs. There is an obvious lack of field-study-based information about actual physical work load factors of ageing and young blue-collar workers.

The aim of this study was to (1) quantify physical work load of blue-collar workers in two occupations: construction work and vehicle inspection, (2) to compare the work load factors between ageing and young workers, and (3) to recommend measures for promoting the work ability and health of blue-collar workers.

2. Materials and methods

2.1. Subjects

The voluntary subjects were 41 construction workers and 22 vehicle inspectors. Both groups of the subjects included both ageing (45 + years) and young (< 45 years) men. Half of the subjects from the construction work ($n = 20$) belonged to the group of ageing workers with the mean age of 52 (range 45–58) years. The age of the young subjects ($n = 21$) averaged 34 (range 23–44) years. The subjects from the vehicle inspection included 12 ageing and 12 young men. The mean age of the ageing and young group was 51 (range 45–61) years and 32 (range 25–36) years, respectively. The mean work experience of the subjects in their present jobs was 15 years.

2.2. Methods

Dynamic, static postural and perceived work loads of the subjects were assessed in habitual daily occupational tasks at work sites. Each subject was studied during a 2–4 hr period of one randomly selected workday.

The evaluation of dynamic work load was based on the minute-by-minute observation of the frequency of work tasks and their physical activity and energy expenditure levels according to the Edholm scale (Ilmarinen et al., 1979; Suurnäkki et al., 1991) and on heart rate (HR), which was registered every minute with a Sport Tester® PM 3000 system (Leger and Thivierge, 1988; Louhevaara et al., 1990).

Static postural load was determined with an observation study using the Ovako working posture analysis system, i.e., the OWAS method (Karhu et al., 1977; Karhu et al., 1981; Louhevaara and Suurnäkki, 1992; Mattila et al., 1993). In the study on the vehicle inspection the OWAS method was supplemented with five head postures: straight, bent forward, bent sideways, bent backwards and twisted.

Overall rating of perceived exertion (RPE) on the cardiorespiratory system and the local RPEs for the back, arms and legs were regularly obtained with a scale from 6 to 20 before and after the study periods and with the intervals of 60 min (construction work) and 15 min (vehicle inspection) (Borg, 1970; Borg, 1982; Hultman et al., 1984; Louhevaara et al., 1990).

2.3. Statistics

Means, standard deviations, and ranges were used for the descriptive evaluation of the data. The differences between age groups were tested with one-way analysis of variance or t-test for means. The differences were considered statistically significant when $p < 0.05$.

3. Results

The differences were small in dynamic work load between the groups of the ageing and young

Table 1
Relative proportion of physical activity and energy expenditure levels (mean % of working hours) of the ageing and young subjects during the construction work and vehicle inspection

Category of activities	Construction ageing ($n = 20$) (%)	Young ($n = 21$) (%)	All ($n = 41$) (%)	Inspection ageing ($n = 11$) (%)	Young ($n = 11$) (%)	All ($n = 22$) (%)
1	1	0	1	0	0	0
2	12	16	14	33	37	35
3	24	16	20	51	47	49
4	3	3	3	10	12	11
5	38	42	40	4	4	4
6	14	12	13	0	0	0
7	5	7	6	0	0	0
0	3	4	4	2	0	1

	Classification of activities	Energy expenditure (kJ min)	Metabolic rate (MET^b) (%)	Metabolic power (W)
1	Lying, sitting	6	120	100
2	Sitting with light activity, Standing without movement	8	150	120
3	Standing with light activity	15	300	240
4	Walking, moving	20	400	320
5	Activity with moderate intensity	25	500	400
6	Activity with high intensity	40	800	640
7	Activity with extreme intensity	50	1000	800
0	Cannot define			

Note: Ageing versus young subjects: $p =$ NS.
[b] Multiplies of basal metabolic rate (% of MET).

subjects both in the construction work and vehicle inspection according to the results of the Edholm scale (Table 1) and HR (Table 2).

The static postural load, i.e., the proportions of poor work postures of the ageing and young subjects did not differ either in the construction work or vehicle inspection (Table 3). During the construction work the number of poor work postures was greatest for the back region. The back was bent and/or twisted for an average 47% of the working hours. In the vehicle inspection the greatest number of poor work postures was observed for the neck–arm region. The head was bent and/or twisted, an average of 42% of the working hours, and one or both arms were at or above shoulder level of 20% of the working hours.

During the construction work and vehicle inspection the RPEs varied from "very light" to "fairly hard" and from "very light" to "light", respectively. The differences between the ageing and young subjects were minor.

4. Discussion

According to present field studies, the dynamic, static postural and perceived work loads of the ageing and young blue-collar workers were similar when compared in their occupational groups: construction work and vehicle inspection. The dynamic load was high during construction work. The average working HR was 110 beats/min which requires good or at least average maximal cardiorespiratory capacity for maintaining the dynamic work load and cardiac strain in acceptable limits (Ilmarinen, 1992). The cardiorespiratory fitness of the ageing and young construction workers studied was about average according to

Table 2
Heart rate (HR) of the ageing and young subjects during the construction work and vehicle inspection

Occupational group	HR (beats/min) Mean	SD	Range
Construction (ageing, $n = 20$)	105	21	54–180
(young, $n = 21$)	113	21	58–187
Construction (all, $n = 41$)	110	21	54–187
Inspection (ageing, $n = 11$)	82	11	65–99
(young, $n = 10$)	86	10	72–104
Inspection (all, $n = 21$)	83	10	65–104

Note: Ageing versus young subjects in both occupational groups: $p =$ NS.

the age-related reference values which increases the risk for overstrain particularly among ageing workers (Louhevaara et al., 1998). Moreover, during the construction work there were occasional short-term peaks when HR reached near maximal levels. The heavy dynamic work load leading to high cardiac strain was mainly caused by manual handling of heavy loads. This type of peak load in outdoor jobs increases the risk for both cardiac failures (Heppel et al., 1991) and musculoskeletal injuries (Ilmarinen et al., 1991). The dynamic work load during vehicle inspection was low and mainly due to walking.

Based on the action categories of the OWAS method, the number of poor back postures observed during the construction work averaging 47% of the working hours may have a harmful effect on the musculoskeletal system, and measures to reduce poor work postures should be taken in the near future (Louhevaara and Suurnäkki, 1992). During vehicle inspection, the corresponding situation was observed in the neck–head region as the heads of the inspectors were bent and/or twisted an average of 42% of the working hours. Most of the poor head postures were registered during the inspection of the vehicle frame and wheels when also one or both arms were frequently over shoulder level. Inadequate visibility due to weak lighting and unadjustable technical work conditions were probably the main reasons for the high number of poor work postures of the head and arms (Miettinen and Louhevaara, 1994). The low-cost technical and training intervention, in which a participatory ergonomic approach was applied, was completed later among ageing vehicle inspectors. It proved to be feasible to reduce the number and duration of poor work postures (Louhevaara et al., 1996).

Table 3
Relative proportion of poor work postures (mean % of working hours) of the ageing and young subjects during the construction work and vehicle inspection

Poor work posture	Construction ageing ($n = 20$) %	Young ($n = 21$) %	All ($n = 41$) %	Inspection ageing ($n = 11$) %	Young ($n = 11$) %	All ($n = 22$) %
Back						
Bent forward	39	39	39	8	8	8
Twisted	3	4	4	2	2	2
Bent and twisted	4	4	4	1	2	1
Arms						
One at or above shoulder level	8	10	9	14	10	14
Both at or above shoulder level	3	4	4	6	6	6
Legs						
Standing with one leg straight	4	4	4	8	8	8
Standing with both legs bent	18	23	20	0	0	0
Standing one bent leg	1	2	2	0	0	0
Kneeling	4	2	3	1	2	2

Note: Ageing versus young subjects in both occupational groups: $p =$ NS.

The overall and local RPEs revealed no differences in perceived work load due to age. The subjects tended to rate their overall and local RPEs quite low when compared to the other "objective" results quantifying their dynamic and static postural work loads. The discrepancy, i.e., low relationships between the overall RPE, physiological responses and work output was also observed earlier in the sorters of postal parcels (Louhevaara, 1993).

A marked number of the ageing construction workers and vehicle inspectors had reduced work ability (Miettinen and Louhevaara, 1994; Louhevaara et al., 1998), as determined with the Work ability index (Tuomi et al., 1991). It is based on respondents' own opinions and is an individually and health oriented method for the quantification of work ability. The Work ability index will have a strong predictive power on work disability in the future (Ilmarinen et al., 1997). One of the main reasons for poor work ability is a nonharmonius relationship between work load factors and a worker's individual capacities and needs. Work ability decreases if the physical, psychological and social demands of the jobs cannot be coped adequately. The promotion of work ability also requires the continuous development of professional skills. The successful prevention of work disability can be achieved by the combination of various ergonomic, work organisational and individual measures supplemented with a life-long learning process of new occupational skills according to the comprehensive concept for promoting work ability (Ilmarinen et al., 1998).

5. Conclusions

The present results justify the following conclusions

1. Dynamic, static postural and perceived work loads of the ageing and young construction workers and vehicle inspectors were similar in their occupational groups, i.e., physical work load of blue-collar workers seems not to be affected by age.
2. The dynamic work load was high during construction work and unacceptable for ageing workers with average or low cardiorespiratory fitness. Occasionally dynamic work load reached near maximal levels and was caused by manual handling of heavy loads.
3. A high number of poor back postures observed during the construction work may have a harmful effect on the musculoskeletal system, and ergonomic and work organisational measures to reduce poor work postures should be taken.
4. During the vehicle inspection, the static postural load in the neck–head region was high and may have a harmful effect on the musculoskeletal system. It was feasible to alleviate postural load with an ergonomic and training intervention.
5. Physical work load should be reduced with age. Ergonomic and organisational measures, exercise and health promotion and the continuous improvement of occupational skills are needed for promoting work ability, health and wellbeing of all, and, particularly, ageing blue-collar workers.

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Age and sex as determinants of the relative aerobic strain of nonmotorized mail delivery

by PEKKA OJA, Ph.D., VEIKKO LOUHEVAARA, M.Sc., and OLLI KORHONEN, M.D.[1]

OJA, P., LOUHEVAARA, V. and KORHONEN, O. Age and sex as determinants of the relative aerobic strain of nonmotorized mail delivery. *Scand. j. work environ. & health* 3 (1977) 225—233. The relative aerobic strain (RAS) of nonmotorized mail delivery was assessed in 54 Finnish mail carriers who represented both sexes, the entire workage range and both downtown and suburban delivery districts. The mean RAS of the entire delivery time was 55 % of the maximal oxygen uptake (ml/kg · min). It was higher for women than for men, and higher for suburban than for downtown delivery. The RAS tended to increase systematically with age after the age of 50. The work strain of mail carriers of over 50 years of age, especially of older women carriers in suburban areas, was concluded to be high enough to lead to possible excessive strain on the workers.

Key words: aerobic strain, elderly workers, female workers, mail delivery.

Finnish mail carriers usually deliver the mail in urban areas on foot or by bicycle. In downtown business districts they work mainly on foot and carry the traditional shoulder bag, which holds approximately 15 kg of mail when full. In suburban districts the carriers generally use a bicycle during delivery, but they have intermittent on-foot phases when the bike cannot be ridden. A bicycle carrier normally keeps the shoulder bag on a front rack, where it is easily accessable. Additional mail is carried in bags on the back of the bike. In both types of delivery excess mail is stored in stack boxes located along the delivery route.

In addition to delivering the mail, the task of the carriers consists of sorting the mail before the delivery. Sorting requires 1 to 3 h and delivery between 1.5 and 5 h, depending on the amount of mail. The carriers receive a fixed salary with a time premium that allows them to be free as soon as the delivery has been completed.

Energy consumption values of 558 to 837 W (8—12 kcal/min) have been measured for British mailmen during on-foot delivery with a full mail bag (9). The energy consumption of cycling (2) suggests roughly equal demands for bicycle delivery. Standard work classification (5) presents work stress of this magnitude as heavy or very heavy for young healthy men. Since in Finland the mail-carrying force consists of both men and women in the entire workage range and physical work capacity is known to decrease with age and is lower in women than in men, it appears that the physiological strain relative to the workers' performance capacity might be considerably high for a large part of the carriers. Consequently, the purpose of our study was to determine the relative physiological strain of mail delivery and the extent to which it is affected by the age and sex of the carriers.

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Table 1. Selection of subjects.

Phase of selection	Men	Women	All
Selected for screening	44	49	93
Did not participate	4	1	5
Screening examination	40	48	88
Excluded	12	18	30
Medical contraindications	4	13	17
Other	8	5	13
Selected for maximal stress test	28	30	58
Did not participate	1	—	1
Completed test	26	28	54
Did not complete test	1	2	3

Table 2. Anthopometric characteristics of the subjects.

Group	n	Age (years)		Height (cm)		Weight (kg)	
		Mean	SD	Mean	SD	Mean	SD
Men							
Suburban	12	39.5	12.5	173.8	6.3	73.5	10.5
Downtown	14	42.8	11.4	175.2	8.4	72.5	11.3
Women							
Suburban	14	43.0	13.1	163.0	5.3	66.3	10.2
Downtown	14	41.5	11.8	162.4	7.1	59.9	8.4

MATERIAL AND METHODS

Ninety-three mail carriers from Helsinki and its vicinity and with work experience of a minimum of two years were invited to the screening examination (table 1). This group was selected to represent evenly both sexes, suburban and downtown delivery districts, and the age groups under 35 years, 35—50 years and over 50 years. Five of the 93 did not participate, 17 were excluded for medical reasons, and 13 were excluded randomly so that the number of subjects in the subgroups would be equal. The remaining 58 subjects were invited to a maximal stress test. Fifty-four of them completed the test successfully. These subjects were divided into 12 subgroups by age ($<$ 35, 35—50, $>$ 50 years), sex, and delivery district (downtown, suburban) for statistical treatment by the analysis of variance. The anthropometric characteristics of the subjects are shown in table 2.

Maximal oxygen uptake ($\dot{V}O_2$ max) was determined during a progressive uphill walk on a motor-driven treadmill. The test was started with a 5-min warm-up walk on a 5 % inclination at the individually adjusted speed of 4 to 5.5 km/h.

After the warm-up the treadmill grade was increased by 2.5 % every 2 min up to a maximal grade of 20 %. Thereafter the work load was increased by treadmill speed increments of 0.5 km/h every 2 min. The subjects were asked to walk to their self-determined subjective maximum. The test was discontinued prematurely whenever signs or symptoms of excessive physiological strain occurred.

During the treadmill walk, a 4-lead ECG was continuously monitored on an oscilloscope and a paper recording was made during the last 15 s of each minute. A 1- to 2-min sample of expired air was collected through a Tripple-J breathing valve into a Douglas bag at three submaximal work loads and at the maximal work load. For the calculation of oxygen consumption the volume of expired air was measured by a dry gas meter, oxygen was analyzed with a paramagnetic O_2 analyzer (Taylor Servomex OA 150) and carbon dioxide with an infrared CO_2 analyzer (Datex CD 101). The heart rate and oxygen consumption measurements were used to establish their linear relationship for each subject in the form of a first-order regression equation.

The heart rate of each subject was monitored telemetrically during the mail delivery. The subjects were carefully informed of the importance of working at their normal pace. A bipolar ECG signal was obtained with a portable heart rate meter (Medinik IC-600) and stored by a portable (Uher Cr 210) or car-mounted (Stellavox ABR) tape recorder. The person doing the monitoring followed the subject either in a van or on foot. A predetermined code for the main phases of work was stored on the magnetic tape simultaneously with the ECG signal. The tape was further processed by an automatic data analyzer, which calculated the mean heart rate per minute for each successive 15-s period and for the period preceding the change of work phase. These data were subjected to a computer analysis that determined the mean heart rates for the entire delivery time and for each work phase.

The working heart rate was used in the estimation of oxygen consumption based on the individual heart rate/oxygen consumption regression equations as determined in the stress test. The relative aerobic strain (RAS) was calculated as

$$\frac{\text{estimated work } O_2 \text{ consumption (ml/kg} \cdot \text{min)}}{\text{maximal oxygen uptake (ml/kg} \cdot \text{min)}}$$

multiplied by 100.

A fixed three-way analysis of variance with age (three levels), sex (two levels) and delivery district (two levels) as the three directions was employed in the analysis of the effects of age, sex and delivery district on selected variables.

The yield of the analysis of variance on each variable was examined further in the following manner: If there was a statistically significant ($p < 0.05$) three-way interaction, two-way interactions were examined separately on each level of the third direction. If the three-way interaction was not significant, the overall two-way interactions were considered next. If none of the three two-way interactions were significant, the main effects yielded by the overall analysis of variance were tested. If only one of the two-way interactions was significant, the two main effects that interacted were tested separately on their different levels, and the third main effect was tested as yielded by the overall analysis of variance. In the case of two significant two-way interactions, each main effect was tested separately on the different levels of each direction. When a significant overall F was obtained, the Newman—Keuls procedure (7) was utilized in the follow-up test of the means if three means were involved (comparison between the three age groups). When only two means were compared, the significance of the F value in the analysis of variance of main effect was used.

RESULTS

Some of the characteristics of the downtown and suburban delivery are presented in table 3. Only the most important work phases with respect to physiological strain have been listed. For both types of delivery the mean of the measured duration of the entire delivery was somewhat shorter than the normal delivery time that had been reported by the mail carriers. This difference reflected the fact that part of the field measurements were made during the quiet summer season. In the downtown area both delivery on level surfaces by foot and delivery while coming down stairs required slightly less than 30 % of the total time. Both delivery while climbing stairs and delivery by bicycle took about 10 % of the total time. In suburban districts delivery by foot required about half of the time and bicycle riding about 40 %.

The mean maximal values of the cardiorespiratory variables for the 12 groups are shown in table 4. The decrement of VO_2

Table 3. Some characteristics of downtown and suburban delivery (mean values).

Characteristic	Downtown delivery	Suburban delivery
Length (km)	4.4	12.1
Duration (min)	108	115
Main phases of delivery (% of total time)		
On foot on level surfaces	28	50
By bicycle	9	37
Up stairs	12	5
Down stairs	26	—

Table 4. Means and standard deviations of the maximal oxygen uptake ($\dot{V}O_2$ max), maximal heart rate (HR max) and maximal ventilation ($\dot{V}_E$ max) of the 12 groups.

Group	n	$\dot{V}O_2$max (l/min) Mean	$\dot{V}O_2$max (l/min) SD	$\dot{V}O_2$max (ml/kg · min) Mean	$\dot{V}O_2$max (ml/kg · min) SD	HRmax (beats/min) Mean	HRmax (beats/min) SD	$\dot{V}_E$max (l/min) Mean	$\dot{V}_E$max (l/min) SD
Men									
< 35 years									
Downtown	5	2.80	0.42	38.9	4.1	191.6	5.2	82.0	11.0
Suburban	4	3.09	0.19	44.8	4.3	193.2	11.9	92.4	10.2
35—50 years									
Downtown	3	2.77	0.68	38.4	2.7	176.7	1.5	97.1	5.8
Suburban	4	2.99	0.41	40.1	2.8	189.5	5.4	74.6	15.3
> 50 years									
Downtown	5	2.36	0.37	32.1	4.5	176.0	11.8	61.5	10.2
Suburban	4	2.32	0.38	31.3	7.6	156.7	13.0	17.4	11.1
Women									
< 35 years									
Downtown	5	1.91	0.09	33.0	2.9	189.6	6.0	55.1	7.5
Suburban	5	1.96	0.29	33.7	1.5	184.6	10.3	56.1	18.4
35—50 years									
Downtown	5	2.00	0.36	33.3	2.2	182.4	4.6	52.9	10.5
Suburban	4	2.12	0.21	31.7	3.5	180.2	10.0	63.9	12.7
> 50 years									
Downtown	4	184	0.22	30.3	1.9	168.2	7.8	59.3	13.7
Suburban	3	1.80	0.06	26.8	2.9	162.3	2.9	48.5	4.6

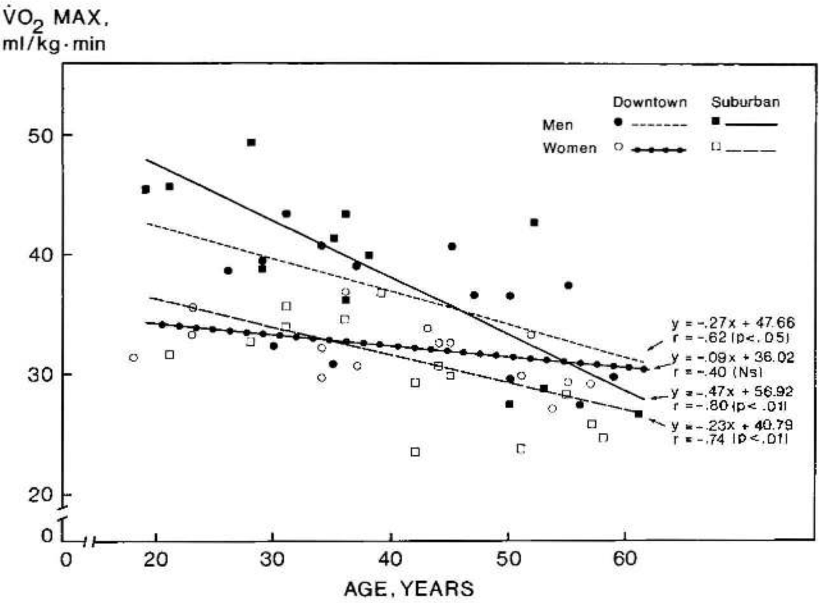

Fig. 1. Decrement in the maximal aerobic power ($\dot{V}O_2$ max, ml/kg · min) of Finnish mail carriers with age. The linear regression lines are shown for both sexes of downtown and suburban carriers.

max with age is illustrated by the linear regression lines in fig. 1. All the correlation coefficients were statistically significant at the p level of < 0.05 with the exception of the coefficient of the female downtown carriers.

The analysis of variance revealed a statistically significant overall F for $\dot{V}O_2$ max

Table 5. Means and standard deviations of the maximal oxygen uptake ($\dot{V}O_2$ max) of the different age, sex and delivery groups.

Group	n	$\dot{V}O_2$max					
		(l/min)			(ml/kg · min)		
		Mean	SD	p (F)[a]	Mean	SD	p (F)[a]
Age				< 0.01			< 0.001
< 35 years	19	2.40	5.82		37.2	5.6	
35 — 50 years	16	2.42	5.79		35.6	4.4	
> 50 years	16	2.12	3.83		30.5	4.7	
Sex				< 0.001			< 0.001 [b]
Men	25	2.71	0.47		37.4	6.3	
Women	26	1.95	0.24		31.9	3.2	
Type of delivery				NS			NS
Downtown	27	2.26	0.51		34.2	4.3	
Suburban	24	2.39	0.56		35.0	6.9	

[a] P values based on the overall F test in the analysis of variance.

[b] Nonuniform effect on the two types of delivery.

Table 6. Means and standard deviations of the heart rate (HR) and estimated oxygen consumption ($\dot{V}O_2$) of the entire delivery time of the different age, sex and delivery groups.

Group	n	HR (beats/min)			$\dot{V}O_2$ (ml/kg · min)		
		Mean	SD	p(F)[a]	Mean	SD	p(F)[a]
Age				NS			NS
< 35 years	19	123.9	16.4		19.9	4.9	
35 — 50 years	17	122.4	15.1		18.4	5.0	
> 50 years	18	112.8	15.1		16.5	4.2	
Sex				NS			NS
Men	26	117.1	15.4		18.6	5.5	
Women	27	122.1	16.5		18.0	4.1	
Type of delivery				< 0.05			< 0.05
Downtown	28	115.5	15.6		16.7	4.4	
Suburban	25	124.3	15.6		20.1	4.7	

[a] P values based on the overall F tests in the analysis of variance.

for age and sex but a nonsignificant F for the type of delivery (table 5). The analysis showed a two-way interaction between sex and type of delivery for the $\dot{V}O_2$ max ml/kg · min values and indicated that the effect of sex was not uniform among downtown and suburban carriers. The follow-up test between the means of the three age groups yielded significant differences between age groups > 50 and < 35 and between > 50 and 35—50.

The mean heart rate and the estimated oxygen consumption for the entire delivery time (table 6) was lower in the oldest age group than in the two other age groups, but the difference was not significant. The means of the men and women did not differ from each other in either variable, but were lower in downtown than in suburban delivery ($p(F) < 0.05$).

The means and standard deviations of the RAS of the entire delivery time, the longest phase of work, and the most straining phase of work are shown in table 7. The analysis of variance indicated nonsignificant differences between the age groups, but significantly more strain for women than for men, and more strain for suburban delivery than for downtown delivery. These two RAS differences were

Table 7. Relative aerobic strain of the entire delivery time, longest phase of work and the most straining phase of work for the different age, sex and delivery groups.

Group	n	Entire delivery			Longest phase			Most straining phase		
		Mean	SD	p(F)[a]	Mean	SD	p(F)[a]	Mean	SD	p(F)[a]
Age				NS			NS			NS
< 35 years	19	54.0	12.4		51.6	13.4		68.4	10.7	
35 — 50 years	16	51.3	13.3		52.0	12.9		63.8	14.8	
> 50 years	16	55.4	14.8		54.1	15.0		68.4	17.5	
Sex				< 0.05			< 0.05			< 0.05[b]
Men	25	49.5	12.4		48.7	11.8		62.9	15.6	
Women	26	57.4	13.3		56.3	14.3		70.9	11.8	
Type of delivery				< 0.05			< 0.01			NS
Downtown	27	49.5	13.1		47.9	12.3		66.3	14.2	
Suburban	24	58.2	12.3		57.8	13.2		67.7	14.6	

[a] P values based on the overall F test in the analysis of variance.
[b] Nonuniform effect on the two types of delivery.

consistent for the entire length of delivery and for the longest single phase of delivery. The results for the most straining phase included a significant three-way interaction. Subsequent testing indicated a nonuniform effect of sex on the two types of delivery.

DISCUSSION

Theoretical considerations suggest that, when the energy demand of a given work remains constant, the relative physiological strain increases with age and is higher in women than in men due to the differences in work capacity. This study was undertaken to examine whether this hypothesis holds for mail carriers in an occupational situation.

The generally known trends of maximal aerobic power for age and sex were demonstrated well with our data (fig. 2). The decrement in $\dot{V}O_2$ max of 0.4 ml/kg · min per year for men agrees rather well with annual changes reported for North American and Scandinavian untrained men in cross-sectional studies (8). The corresponding yearly decrement of 0.2 ml/kg · min for women was somewhat less than the trend illustrated by the regression line constructed for untrained women from the data compiled by Drinkwater (6).

The mail carriers' work capacity was close to that of Swedish building construction workers (1) but lower than the work capacity of Norwegian lumberjacks (3). When the work strain in mail delivery is considered, it is rather surprising that the work capacity of mail carriers does not differ from the so-called untrained population. This phenomenon may reflect the strong effect of selection which operates among people who voluntarily come to work capacity testing, as is most often the case with so-called untrained people.

The estimated energy consumption of mail delivery was independent of age and sex but higher in suburban than in downtown delivery (table 6). The observed difference between the delivery types was somewhat unexpected, since demanding stairclimbing is generally thought to characterize downtown delivery. However, in our sample, stairclimbing was found to represent only a little more than 10 % of the total delivery time in downtown delivery and almost the same amount (approx. 5 %) was found in suburban delivery. On the other hand, bicycle riding, which required almost half of the suburban delivery time, was found to be the most demanding phase of the work, together with stairclimbing.

When the observed differences in the aerobic power of men and women is considered on one hand and the equal energy demand of the job on the other, a difference in the relative strain of work should be expected between men and women. The results of the RAS measurements verified this assumption. A similar effect was expected for age, but the analysis of variance based on the means of the three age groups did not reveal it. We examined the possible effect of age more closely by performing a linear multiple regression analysis with RAS as the dependent variable and sex (coded as 0 = female, 1 = male), delivery type (coded as 0 = downtown, 1 = suburban), and age as the independent variables for age groups > 35, > 40, > 45, > 50. Age had the highest partial correlation coefficient in all age groups. The correlation coefficient between age and RAS was 0.62 ($p < 0.05$) for the age group of > 50 years (fig. 3). This correlation was not significant when the lower age limit was decreased to 45, 40 and 35 years, and thus a dependence between RAS and age was indicated only after the age of 50.

The mean RAS of mail delivery was found to be 55 % of the maximal aerobic power of the carriers. This level is higher than the work strain of 37 % of Norwegian coastal fisherman (10) and that of 40 % of Swedish building construction workers (1). However, the values are not directly comparable because of the short duration of mail delivery. According to the formula for maximal allowable caloric expenditure for different durations of work devised by Bink et al. (4), the mean measured relative strain exceeded this limit in all age groups of women carriers and notably (by up to 30 %) among suburban women carriers.

From the occupational health and safety point of view the main results of our study were the higher work strain among women than men and the increasing strain with age after the age of 50. These differences were obtained in a work situation in which the carriers are essentially free to set their own work pace. Thus it appears that self-control may not be sufficient to protect some groups of workers from straining themselves beyond an acceptable limit. One can speculate that the standards of the delivery performance may be set by the

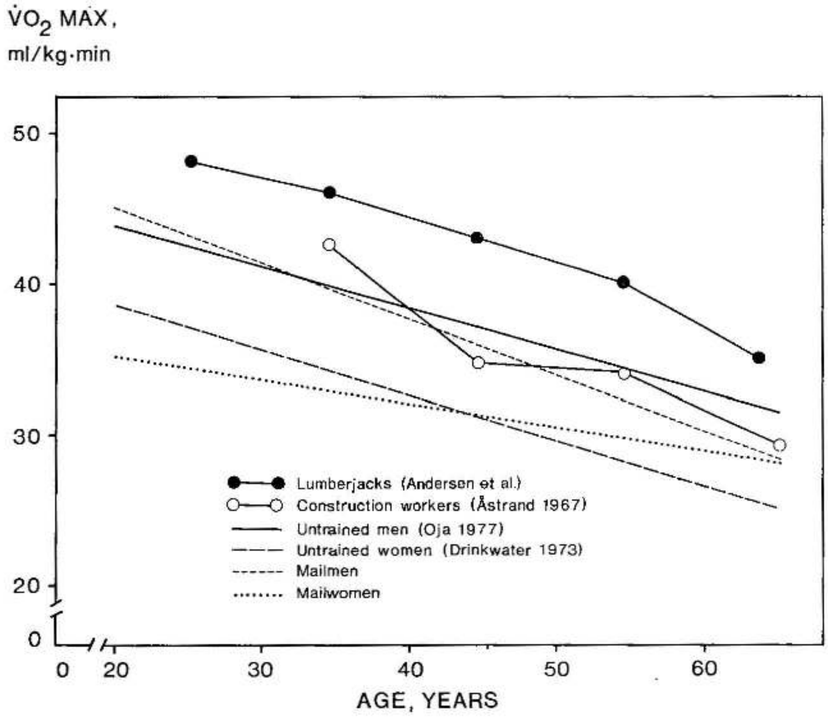

Fig. 2. Comparison of maximal aerobic power ($\dot{V}O_2$ max, ml/kg · min) of Finnish mail carriers with that of Norwegian lumberjacks, Swedish construction workers and untrained people.

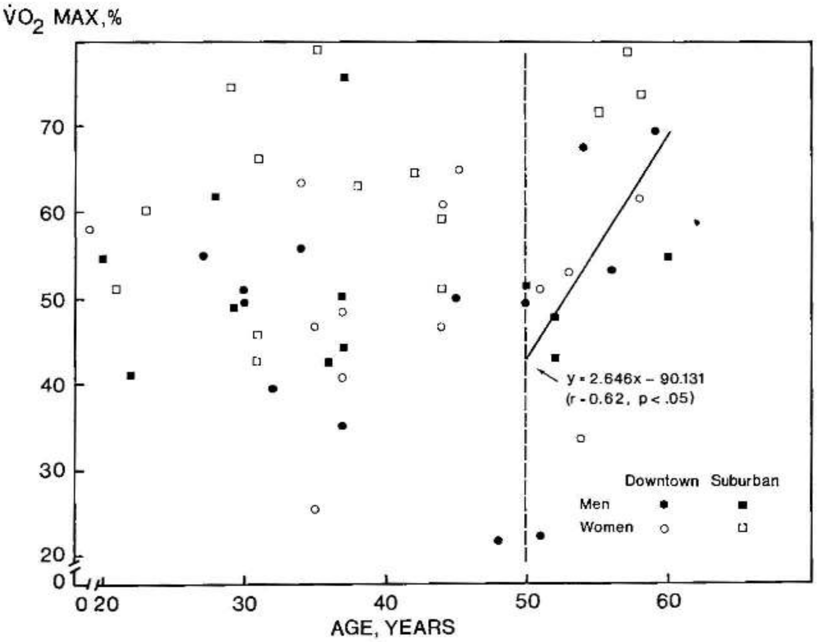

Fig. 3. Plot of relative aerobic strain ($\dot{V}O_2$ max, %) and age for Finnish mail carriers. The linear regression line is shown for carriers older than 50 years age.

young and fit mailmen and this pressure, together with the time bonus, causes the older and less fit women and older mailmen, in this case, to strain themselves more than they would otherwise.

In summary, we found that the RAS of mail delivery was higher in women than in men and higher in suburban delivery than in downtown delivery. The relative strain of work tended to increase systematically with age after the age of 50. The measured relative strain of work consistently exceeded the maximal allowable limit among all suburban women carriers, especially among those older than 50 years of age.

On the basis of our results, we conclude that the aerobic strain of mail delivery is high enough to warrant control measures for all mail carriers older than 50 years of age, especially for older women carriers in suburban areas.

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ORIGINAL ARTICLE

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Cardiorespiratory responses to fatiguing dynamic and isometric hand-grip exercise

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Abstract In occupational work, continuous repetitive and isometric actions performed with the upper extremity primarily cause local muscle strain and musculoskeletal disorders. They may also have some adverse effects on the cardiorespiratory system, particularly, through the elevation of blood pressure. The aim of the present study was to compare peak cardiorespiratory responses to fatiguing dynamic and isometric hand-grip exercise. The subjects were 21 untrained healthy men aged 24–45 years. The dynamic hand-grip exercise (DHGE) was performed using the left hand-grip muscles at the 57 (SD 4)% level of each individual's maximal voluntary contraction (MVC) with a frequency of 51 (SD 4) grips $\cdot$ min^{-1}. The isometric hand-grip exercise (IHGE) was done using the right hand at 46 (SD 3)% of the MVC. The endurance time, ventilatory gas exchange, heart rate (HR) and blood pressure were measured during both kinds of exercise. The mean endurance times for DHGE and IHGE were different, 170 (SD 62) and 99 (SD 27) s, respectively ($P < 0.001$). During DHGE the mean peak values of the breathing frequency [20 (SD 6) breaths $\cdot$ min^{-1}] and tidal volume [0.89 (SD 0.34) l] differed significantly ($P < 0.01$) from peak values obtained during IHGE [15 (SD 5) breaths $\cdot$ min^{-1}, and 1.14 (SD 0.32) l, respectively]. The corresponding peak oxygen consumptions, pulmonary ventilations, HR and systolic blood pressures did not differ, and were 0.51 (SD 0.06) and 0.46 (SD 0.11) l $\cdot$ min^{-1}, 17.1 (SD 3.0) and 16.7 (SD 4.7) l $\cdot$ min^{-1}, 103 (SD 18) and 102 (SD 17) beats $\cdot$ min^{-1}, and 156 (SD 17) and 161 (SD 17) mmHg, respectively. The endurance times of both DHGE and IHGE were short (< 240 s). The results indicate that the peak responses for the ventilatory gas exchange, HR and blood pressure were similar during fatiguing DHGE and IHGE, whereas the breathing patterns differed significantly between the two types of exercise. The present findings emphasize the importance of following ergonomic design principles in occupational settings which aim to reduce the output of force, particularly in tasks requiring isometric and/or one-sided repetitive muscle actions.

Key words Physiological strain · Muscle mass · Hand-grip · Dynamic exercise · Isometric exercise

Introduction

Repetitive and isometric types of muscular actions using the upper extremity have been shown to be common in industry, in the office and in many service jobs (Kilbom 1994a; Louhevaara et al. 1998). Repetitive and isometric actions have been found to be often associated with the use of hand tools (Kadefors et al. 1993) and data processing equipment (HLEG 1997, Nakasenko et al. 1982). Continuous repetitive and isometric actions have been found primarily to cause local muscle strain and musculoskeletal disorders (Bergqvist et al. 1995; Hales et al. 1994; Kadefors et al. 1993; Kilbom 1994b; Rempel et al. 1992) but they may also have some adverse effects on the cardiorespiratory system, particularly, through the elevation of blood pressure (Veiersted 1997).

Comparisons of the cardiorespiratory responses to repetitive and isometric actions has mostly been based on dynamic exercise of large muscle groups and isometric actions with small muscle groups when, for instance, two-legged cycling or walking on a treadmill have been compared with an isometric hand-grip action (e.g. Lind and McNicol 1967). During dynamic exercise, relatively large increases in oxygen consumption

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($\dot{V}O_2$), heart rate (HR), cardiac output, and systolic blood pressure with minor changes in diastolic pressure can be observed. In contrast, an isometric action has been shown to produce marked increases in the systolic and diastolic blood pressure with modest increases in $\dot{V}O_2$, HR and cardiac output (Lind and McNicol 1967).

Only a few studies have compared cardiorespiratory responses to dynamic and isometric actions performed with muscle groups of similar size (Blomqvist et al. 1981; Lewis et al. 1983, 1985). In these studies, a gradual transition of the cardiorespiratory responses from "dynamic" to "isometric" has been observed with decreasing size of active muscle mass (Blomqvist et al. 1981). Thus, both Blomqvist et al. (1981) and Lewis et al. (1985) have suggested that the amount of the active muscle mass is a more marked determinant of cardiorespiratory responses than the type of muscle action. This phenomenon may be important when physiological strain, taken as a whole, is considered in occupational work including repetitive and isometric actions by the upper extremity which especially affect blood pressure and HR. Therefore, it was considered necessary to carry out a study to confirm and provide more details on the observations that have been reported by Blomqvist et al. (1981) and Lewis et al. (1985).

The aim of the present study was to compare the peak cardiorespiratory responses to fatiguing dynamic and isometric hand-grip exercise.

Methods

Subjects

The subjects were 21 untrained healthy men who worked as parcel-handlers in the Post Office. The mean age, height, body mass and body fat (Durnin and Rahaman 1967) were 33 (SD 6) years, 178 (SD 7) cm, 78 (SD 13) kg and 18 (SD 5)%, respectively. The study procedures were accepted by the Ethics Committee of the Finnish Institute of Occupational Health. Each subject signed a statement of informed consent.

Protocol

The subjects were measured twice with a mean interval of 9 days in the exercise laboratory at an ambient temperature of 22–24 °C and a relative humidity of 30%–40%. The subjects wore shorts during the measurements. During the occasion of the first test subjects were given a medical examination supplemented with the recording of an electrocardiogram and the measurement of blood pressure (BP) at rest. During both occasions the isometric maximal voluntary action, i.e. contraction (MVC) of the right and left hand-grip muscles was measured. The MVC was measured with the subject in a sitting position and the active arm extended to the side at a 10° angle to the vertical. The subject was instructed to produce a steady maximal grip for 2–3 s. The measurement was repeated after a 1-min rest. The higher force level attained was considered to be the MVC.

About 20 min after the MVC tests the dynamic hand-grip exercise (DHGE) was performed with the left hand at a target level of 50% of MVC with a target frequency of 50 grips $\cdot$ min^{-1}. About 15 min after DHGE the isometric hand-grip exercise (IHGE) was done with the right hand at the same 50% target level of MVC. Both DGHE and IHGE were carried out in the same body position as the MVC measurements. The DHGE and IHGE were terminated when the subject was not able to produce force at the predetermined level and given frequency of grips or to maintain the predetermined isometric force level. The researcher carefully monitored each test performance and terminated it after one warning if the force or frequency level did not meet the criterion. During the second occasion the measurements were repeated.

Measurements

The hand-grip forces were measured with a dynamometer which included a water-filled rubber tube with a pressure transducer (Honeywell Microswitch-division 142P30G, USA) connected to an indicator and power supply (constructed at the Finnish Institute of Occupational Health). The pressure transducer had a built-in amplifier. Paper recordings of the measurements were taken with a chart recorder (Yokogawa 3057, Japan; Smolander et al. 1984). The 50% levels of the individual's MVC and the frequency of the grips were continuously monitored on the paper of the recorder, which was placed in front of the subject at eye level.

Before both DHGE and IHGE the subject rested in a sitting position for 4 min and his baseline cardiorespiratory responses were recorded. After the termination of DHGE and IHGE the recovery was followed for 4 min. At rest, during DHGE and IHGE, and during the recovery, respiratory frequency, tidal volume, pulmonary ventilation, $\dot{V}O_2$, production of carbon dioxide and respiratory exchange ratio were continuously measured and automatically printed every minute by a microprocessor-controlled respiratory gas exchange analyser (Morgan Exercise Test System. P.K. Morgan Ltd, UK). The measurement unit consisted of a flowmeter, a paramagnetic oxygen analyser (Morgan 500d), and an infrared carbon dioxide analyser (Morgan 800d). A low-resistance breathing valve (Modified Koegel Y-valve) with a mouthpiece and a nose clip was used continuously during the measurements. Before each measurement session the flowmeter was calibrated by four inspiratory strokes with a 1-l pump, and the gas analysers with two mixtures of gases of known oxygen and carbon dioxide concentrations. The values for the respiratory gas exchange were recorded every minute. The HR was continuously recorded with a telemetric Sport Tester PE 3000 Cardiac Monitor (Polar Electro, Finland). The results of HR were printed out with means for 15-s intervals. The systolic and diastolic BP were assessed using the conventional auscultatory technique, the cuff being located on the right arm during DHGE and on the left arm during IHGE. The BP was measured every minute. The mean time for attaining occlusion with a sufficient cuff pressure was about 15 s. The length of the BP measurement was about 30 s.

Analysis of the data

Peak cardiorespiratory responses of both DHGE and IHGE were determined. The data obtained during the 4th min of the rest and recovery periods were used as the rest and recovery values. Between the first and second test occasion, there were no statistically significant differences in the endurance times and peak cardiorespiratory responses of DHGE and IHGE according to the Student's *t*-test for paired observations. Therefore, their mean values were used in the analysis of the data, which were first treated for conventional descriptive statistics. The significance of differences in the peak cardiorespiratory responses was evaluated using Student's *t*-test for paired observations applying standard procedures. The differences were considered significant when $P < 0.05$.

Results

The mean MVC were 102 (SD 22) kPa and 100 (SD 19) kPa for the right and left hand-grip muscles, respectively. During DHGE the actual force level was 57 (SD 4)% MVC with a frequency of 51 (SD 4) grips · min^{-1}. For IHGE the corresponding level of force was 46 (SD 3)% MVC ($P < 0.001$). The mean endurance times for DHGE and IHGE were 170 (SD 62) and 99 (SD 27) s, respectively ($P < 0.001$).

During DHGE the mean peak values of the breathing frequency [20 (SD 6) breaths · min^{-1}] and tidal volume [0.89 (SD 0.34) l] differed significantly ($P < 0.01$) from peak values obtained during IHGE [15 (SD 5) breaths · min^{-1}], and [1.14 (SD 0.32) l], respectively. The corresponding peak $\dot{V}O_2$, pulmonary ventilation, HR and the systolic BP did not differ significantly, and were 0.51 (SD 0.06) and 0.46 (SD 0.11) l · min^{-1}, 17.1 (SD 3.0) and 16.7 (SD 4.7) l · min^{-1}, 103 (SD 18) and 102 (SD 17) beats · min^{-1}, and 156 (SD 17) and 161 (SD 17) mmHg, respectively. At rest and during recovery no significant differences were observed in any of the variables between the DHGE and IHGE tests (Table 1).

Discussion

Breathing pattern and pulmonary ventilation

The ventilatory response to dynamic muscle exercise has been found to be a function of increases in both tidal volume and breathing frequency until the ventilatory threshold is reached (Hey et al. 1966), whereas contradictory data have been reported for the ventilatory response to IHGE. Fontana et al. (1993) have reported an increase in both respiratory frequency and tidal volume, whereas Muza et al. (1983) have found no significant changes in respiratory frequency during IHGE.

In the present study, the breathing pattern based on the peak values of the breathing frequency and tidal volume was different between the fatiguing DHGE and IHGE, leading to similar peak values for pulmonary ventilation, however. During IHGE the peak pulmonary ventilation was almost solely attained by the larger tidal volume which was, on average, 32% higher than the mean baseline value. During DHGE both the peak breathing frequency and tidal volume were higher than the baseline values. The results of this study support the previous findings by Muza et al. (1983), which were also obtained during intense IHGE. The breathing pattern observed during IHGE may have been be related to breathholding (Valsalva manoeuvre) which is associated with the output level of force, and has often been observed during intense isometric exercise (Rodahl 1989).

Ventilatory gas exchange, HR and BP

In this study, values of peak pulmonary ventilation, $\dot{V}O_2$, HR and BP were similar during fatiguing DHGE and IHGE. The increase in HR and BP during IHGE may have been affected by the breathholding of the subjects, as has been suggested by Rodahl (1989). On the other hand, the peak HR and BP values during DHGE were at the same levels as during IHGE which might be explained by almost a doubling of endurance time of DHGE. The mean peak BP values for both DHGE (156 mmHg) and IHGE (161 mmHg) can be classified as high because they were 84% and 87%, respectively, of the values of these subjects that have been measured at maximum during cycling (Louhevaara et al. 1990).

Table 1 Mean peak oxygen consumptions ($\dot{V}O_2$), respiratory exchange ratios (*R*), pulmonary ventilations ($\dot{V}_E$), respiratory frequencies (*f*), tidal volumes ($\dot{V}_T$), heart rates (*HR*), systolic blood pressures (*BP_s*) and diastolic blood pressures (*BP_d*) at rest, during the dynamic (*DHGE*) and isometric (*IHGE*) hand-grip exercise, and during the recovery

		Rest		Exercise		Recovery	
		DHGE	IHGE	DHGE	IHGE	DHGE	IHGE
$\dot{V}O_2$ (l · min^{-1})	Mean	0.32	0.31	0.51	0.46	0.31	0.30
	SD	0.07	0.06	0.06	0.11	0.08	0.06
R	Mean	0.85	0.90	0.95	0.99	0.92	0.91
	SD	0.12	0.13	0.15	0.20	0.12	0.13
$\dot{V}_E$ (l · min^{-1})	Mean	10.2	10.6	17.1	16.7	11.8	10.7
	SD	2.1	2.3	3.0	4.7	3.5	2.4
f (breaths · min^{-1})	Mean	14	14	20	15**	14	14
	SD	5	4	6	5	5	5
$\dot{V}_T$ (l)	Mean	0.75	0.78	0.89	1.14**	0.87	0.78
	SD	0.12	0.21	0.34	0.32	0.34	0.22
HR (beats · min^{-1})	Mean	75	80	103	102	78	75
	SD	15	14	18	17	16	14
BP_s (mmHg)	Mean	123	122	156	161	124	124
	SD	12	14	17	17	12	13
BP_d (mmHg)	Mean	80	78	107	111	81	80
	SD	8	10	12	13	9	11

**$P < 0.01$ between peak values for the *DHGE* and *IHGE*

The mean $\dot{V}O_2$, pulmonary ventilation, HR and BP values of DHGE and IHGE agree with the findings that have been presented by Blomqvist et al. (1981) and Lewis et al. (1985), and confirm their primary conclusion, without including the breathing pattern, that the type of muscle action (dynamic compared to isometric) is not the major determinant of the cardiorespiratory responses to exercise using a small muscle mass. The comparison of BP between DHGE and IHGE may be affected by the use of the left hand for DHGE and the right hand for IHGE although the baseline values were similar.

Endurance time

The present results for endurance times disagree with the previous findings of Lewis et al. (1985) who have reported the similar mean endurance times for the fatiguing DHGE and IHGE (362 compared to 354 s, respectively). The discrepancy between these studies could be explained by differences in the relative force level or the frequency of grips per minute. Lewis et al. (1985) have used a slower frequency of grips (33–40 $\cdot$ min^{-1}) and a lower level of both dynamic force (108 N) and relative isometric force (24% MVC) compared to the mean values in the present study [51 grips $\cdot$ min^{-1} at 57% MVC (about 350 N) and 46% MVC, respectively]. A higher relative intensity has been demonstrated to result in a considerable decrease in the endurance time both during DHGE and IHGE (Monod and Sherrer 1957; Rohmert 1960).

Practical implications of the present findings emphasize the importance of following ergonomic design principles in occupational settings which have the aim of reducing the output of force, particularly in tasks requiring isometric and/or one-sided repetitive muscle actions with small muscle masses. The reduction of repetitive actions with small muscle groups seems to be as necessary as that of isometric actions because the dynamics of the repetitive type of actions does not remove the elevation of BP and HR. This should be considered especially in relation to workers having cardiovascular risk factors or illnesses.

Conclusions

During fatiguing DHGE performed at a frequency of 51 grips $\cdot$ min^{-1} at 57% MVC and during fatiguing IHGE at 46% MVC the endurance times were short ($<$ 240 s). The peak responses for the ventilatory gas exchange, HR and BP were similar during DHGE and IHGE, whereas the breathing patterns differed significantly between the two types of exercise. The present findings emphasize the importance of following ergonomic design principles in occupational settings which aim to reduce the output of force particularly in tasks requiring isometric and/or one-sided repetitive muscle actions with small muscle masses.

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Cardiorespiratory strain in jobs that require respiratory protection

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Summary. Twenty-one workers in the construction, foundry, shipyard, and metal industries, and nine firemen were studied in jobs that require the regular use of various industrial respirators. The subjects' heart rates (HR) were continuously recorded during 1 to 2 workshifts or during special tasks. Their oxygen consumption ($\dot{V}_{O_2}$) and ventilation rates were measured during main work phases. The subjects' $\dot{V}_{O_{2max}}$ were determined by a submaximal bicycle-ergometer test. In construction and industrial jobs, when a filtering device or an air-line apparatus was worn, the subjects' mean HR-values ranged from 66 to 132 beats min^{-1}, which is equivalent to a relative aerobic strain of 12 to 57% $\dot{V}_{O_{2max}}$. In smog-diving and repair and rescue tasks with self-contained breathing apparatus and protective clothing, the corresponding mean values were 142 to 160 beats min^{-1} and 54–74% $\dot{V}_{O_2}$, respectively. The field results were compared with those measured in the laboratory with the same type of respirator. The suitability of different respirators in practical work situations was then evaluated, as were the physical qualifications required of the wearer.

Key words: Industrial respirators – Field conditions – Heart rate – Oxygen consumption – Ventilation rate

Introduction

Industrial respirators are used to protect the wearer against contaminated atmospheres. Respirators must be worn if primary preventive controls involving technical and organizational arrangements at work prove to be insufficient.

Industrial respirators are usually classified with regard to their technical features and effectiveness into three major categories: filtering (air-purifying) devices, air-line (supplied-air) apparatus, and self-contained breathing apparatus (Raven et al. 1979). Filtering devices contain dust and/or gas filters. Air-

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Comparison of three field methods for measuring oxygen consumption

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Keywords: Oxygen consumption; Field methods; Douglas Bag; Oxylog; Kofranyi–Michaelis gas meter.

The Oxylog (OX) and the Kofranyi–Michaelis (KM) field methods for measuring oxygen consumption ($\dot{V}O_2$) were compared with the conventional Douglas Bag (DB) technique in standardized walking and lifting work in the laboratory. Subjects comprised six men. According to the mean differences in $\dot{V}O_2$ the OX underestimated (4·1% and 6·4%) and the KM overestimated (3·8% and 0·8%) $\dot{V}O_2$ in walking and lifting work, respectively. The linear regression equations between the DB and the OX as well as between the DB and the KM revealed a good agreement ($r = 0{\cdot}91$–$0{\cdot}99$) of the $\dot{V}O_2$ values. The OX and the KM are accurate for reliable $\dot{V}O_2$ measurements under field conditions. Some practical improvements for the OX use, based on several field studies, are recommended.

1. Introduction

Oxygen consumption ($\dot{V}O_2$) is a basic variable in work physiology. Under field conditions the Douglas Bag technique is the conventional method. The Kofranyi–Michaelis gas meter has also been widely used for measuring $\dot{V}O_2$. However, both methods are rather laborious and have many limitations in practice (Andersen *et al.* 1978).

Recently a new portable instrument, the Oxylog (OX) (P. K. Morgan Ltd, Chatham, Kent), has been introduced to measure and show directly $\dot{V}O_2$ and ventilation volume. The OX (Humphrey and Wolff 1977, Ballal and Macdonald 1982, Harrison *et al.* 1982) consists of a half face mask fitted with a turbine flow meter on the inspiratory side, and an expiratory hose connected to an analyser. The OX measures the volume of inspired air, the partial pressure of oxygen with two polarographic oxygen sensors for inspired and expired air, and air temperature. The OX's digital display indicates in litres the total ventilation volume and the minute $\dot{V}O_2$, or the total $\dot{V}O_2$, and the minute ventilation volume. An output is available to record the variables measured. Calculated values for $\dot{V}O_2$ within a range of 0·25–3·00 l min^{-1} are correct for a respiratory exchange ratio (R) of 1·00 and a relative humidity (RH) of 50%.

The purpose of the present study was to compare the OX, and the Kofranyi–Michaelis (KM) gas meter to the conventional Douglas Bag (DB) technique for measuring $\dot{V}O_2$ during dynamic work (walking) and during combined static and dynamic work (lifting) under standardized laboratory conditions.

2. Methods

Six male subjects aged 27–41 years volunteered to participate in the study. Their mean (±S.D.) weights and heights were 77·2 (±8·1) kg and 178·5 (±6·9) cm, respectively. The subjects walked on a treadmill and performed lifting work on two separate days in the laboratory. The range of the room temperature was 23–26°C and that of the relative humidity was 30–50%.

The walking consisted of three sequential walks at a constant speed of 5 km hour^{-1}. Each walk lasted on the average 19 min. The mean (± S.D.) grades of the three walks were 3 (±2), 8 (±3) and 13 (±6)%, respectively. The lifting comprised three sequential tasks. Each task lasted on the average 15 min. Lifting frequencies used in the three tasks were 4, 8 and 12 lifts min^{-1}, respectively. A box of 7 kg of dimensions 33 cm × 22 cm × 20 cm was lifted from a 6 cm platform to a 60 cm high desk. An assistant put the box down and timed the lifting frequency with a stop-watch. The subjects were instructed to use leg-lifts and to keep their backs in an upright position.

During the measurement the subjects wore a mouthpiece and a noseclip or a face mask. The DB, the OX and the KM gas meter were stationary or carried by an assistant. The sampling times were the longest with the DB (2 min) and the KM (6 min) at light work levels (grade $\leqslant 5\%$ or 4 lifts min^{-1}) with low ventilation volumes. The sampling time (4–5 min) was independent of the work level for the OX. Measurements were made with the OX until at least three steady $\dot{V}O_2$ readings were obtained.

Measurements of $\dot{V}O_2$ at each work level was started 3–4 min after the beginning of the work at steady-state conditions, as judged by the subject's heart rate. This was calculated from an ECG recording (Mingograf 34) obtained during the last 15 s of each minute. The order of the comparative measurements with the three methods was fixed so that the first and the last measurement of each work level was always made with the DB. Between these measurements reading were alternatively taken with the OX and KM from one work level to another.

With the DB the expired air was collected through a Triple J breathing valve (Barlett *et al.* 1972) into plastic bags. The sampling time was 1–2 min. The volume of expired air was measured by a calibrated dry gas meter. With the KM a sample of 0·6% of expired air through a Single J breathing valve (Bartlett *et al.* 1972) was collected automatically in a small rubber bag. The collection time was 3–6 min. The volume of expired air was read from the KM's own dry ventilometer. The collected air samples of the DB and KM were immediately analysed with a polarographic oxygen analyser (Beckman OM 14) and an infrared carbon dioxide analyser (Datex CD 101).

To calculate the differences in $\dot{V}O_2$ the result obtained with the OX or the KM was always compared to the nearest DB value in the collection sequence. Mean differences and linear regression equations of the compared measurements were calculated. The statistical significance of the mean differences and the correlation coefficients was tested with two-tailed *t*-tests.

3. Results

3.1. *The DB versus the OX*

The difference between the mean $\dot{V}O_2$ measured in walking with the DB (1730 ml min^{-1}) and with the OX (1660 ml min^{-1}) was −4·1% ($p < 0{\cdot}01$). The corresponding difference in lifting was −6·4% (ns) calculated from the means 1240 ml min^{-1} with the DB and 1150 ml min^{-1} with the OX. The correlation coefficients between the DB and the OX measurements in walking and lifting (figure 1) were 0·99 and 0·91, respectively (table 1). At different $\dot{V}O_2$ levels the magnitude of the mean underestimations by the OX varied unsystematically from 30 ml min^{-1} to 120 ml min^{-1} (table 2). In five comparisons from the total of 31 the underestimation exceeded 200 ml min^{-1} (table 4).

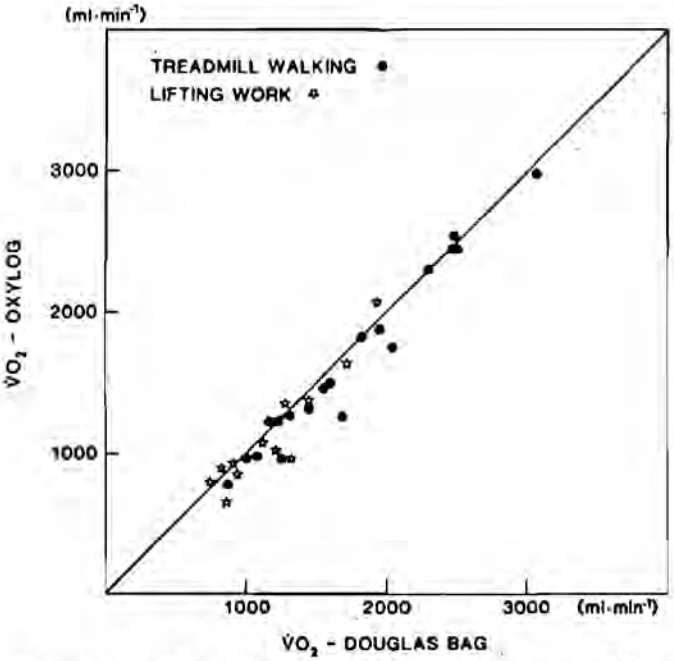

Figure 1. Comparison of the values of the oxygen consumption ($\dot{V}O_2$) obtained with the Douglas Bag and the Oxylog.

Table 1. Number of comparisons (n), intercepts (a), slopes (b) and correlation coefficients (r) based on the regression equations; and the means of X and Y and the mean difference (± S.D.) between X and Y in the $\dot{V}O_2$. All values have been calculated as millilitres per minute except the relative difference between the means (%).

Comparison	Work mode	n	a	b	r	$\bar{X}$(DB)	$\bar{Y}$	Difference $\bar{x}$	S.D.	Percentage
X(DB) versus Y(OX)	Walking	18	−120	1·03	0·99***	1730	1660	−70	100	−4·1**
	Lifting	13	−40	0·96	0·91***	1240	1150	−90	170	−6·4
X(DB) versus Y(KM)	Walking	17	−30	1·02	0·98***	1690	1750	+60	110	+3·8*
	Lifting	12	−50	1·05	0·95***	1320	1330	+10	120	+0·8

* $p<0{\cdot}05$, ** $p<0{\cdot}01$, *** $p<0{\cdot}001$.

Table 2. The mean differences in the $\dot{V}O_2$ between the Douglas Bag (DB) and the Oxylog (OX) at different $\dot{V}O_2$ levels. Number of comparisons (n).

Walking (ml min⁻¹)	n	Difference, DB versus OX (ml min⁻¹)	Difference, DB versus OX (%)	Lifting (ml min⁻¹)	n	Difference, DB versus OX (ml min⁻¹)	Difference, DB versus OX (%)
<1250	5	−100	−8·7	<1000	5	−30	−3·3
1250–2000	8	−40	−2·7	1000–1500	5	−120	−9·0
>2000	5	−80	−3·6	>1500	3	−120	−7·4

3.2. *The DB versus the KM*

The mean $\dot{V}O_2$ measured with the KM in walking (1750 ml min^{-1}) and in lifting (1330 ml min^{-1}) was 3·8% ($p < 0·05$) and 0·8% (ns) higher than the corresponding means of the DB. In walking the correlation coefficient between the methods was 0·98 and in lifting 0·95 (table 1 and figure 2). In walking at different $\dot{V}O_2$ levels the mean overestimations by the KM were between 30 and 90 ml min^{-1}. In lifting the range of the mean differences varied from −20 ml min^{-1} to +70 ml min^{-1} (table 3). The overestimations obtained with the KM were over 200 ml min^{-1} in three, from a total of 29 comparisons (table 4).

3.3. *The first Douglas Bag (DB1) versus the second Douglas Bag (DB2) measurement*

The mean differences in $\dot{V}O_2$ between the DB1 and the DB2 reference measurements were in walking 0·6% and in lifting 0·0%. The correlation coefficients between the DB1 and the DB2 were 0·99 and 0·97, respectively. These values indicate that a good steady-state condition for $\dot{V}O_2$ was attained at each work level; and that the reproducibility of the DB measurements was high.

3.4. *Practical experiences with the OX under field conditions*

At the Institute of Occupational Health (Helsinki, Finland) three OX's have been used for the past 3 years. Field studies with the OX have been made in the graphic industry, the delivery of dairy products, sled pulling, municipal occupations, meat cutting and the metal industry. Different work phases of 98 subjects have been measured using continuous measuring periods of the maximum possible lengths. The sampling times have varied from 15 to 75 min. Usually one to five samples per workshift for each subject have been obtained with the OX. During the studies with the OX two

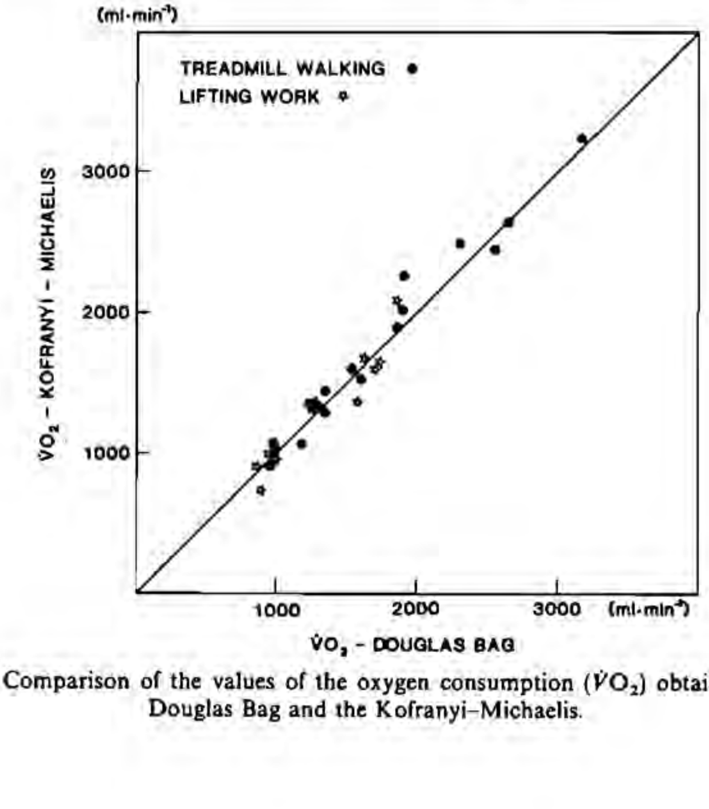

Figure 2. Comparison of the values of the oxygen consumption ($\dot{V}O_2$) obtained with the Douglas Bag and the Kofranyi–Michaelis.

Table 3. The mean differences in the $\dot{V}O_2$ between the Douglas Bag (DB) and the Kofranyi–Michaelis (KM) at different $\dot{V}O_2$ levels. Number of comparisons (n).

Walking (ml min^{-1})	n	Difference, DB versus KM (ml min^{-1})	Difference, DB versus KM (%)	Lifting (ml min^{-1})	n	Difference, DB versus KM (ml min^{-1})	Difference, DB versus KM (%)
<1250	5	+30	2·5	<1000	4	−10	−1·4
1250–2000	8	+90	+5·5	1000–1500	4	+70	+5·5
>2000	4	+50	+1·9	>1500	4	−20	−1·6

Table 4. The number of the largest differences between the Douglas Bag (DB) and the Oxylog (OX) and between the Douglas Bag (DB) and the Kofranyi–Michaelis (KM). Number of comparisons (n).

	DB versus OX		DB versus KM	
Difference (ml min^{-1})	Walking ($n=18$)	Lifting ($n=13$)	Walking ($n=17$)	Lifting ($n=12$)
> −200	2	3	0	0
> −100	2	1	1	2
> +100	0	1	4	1
> +200	0	0	2	1

air hoses broke, one plug connecting the wire of the flow meter to the analyser had to be renovated. Oxygen sensors were changed at least once a year. The original face mask and a waist belt have been substituted by a half face mask (Kemira Silner 12) and light nylon harness designed by ourselves. It has also proved difficult to read the small digital displays positioned in an inconvenient place on top of the OX, and now we have constructed larger displays which can be placed on one side of the OX. No automatic data recording systems have been used in our studies.

4. Discussion

According to the mean values of both work modes, the OX underestimated, and the KM overestimated $\dot{V}O_2$ as compared with the DB technique. The absolute and relative differences in the mean $\dot{V}O_2$ values obtained with the OX or the KM were not dependent on the work level.

The linear regression equations revealed a very good agreement between the DB, OX and KM methods in all comparisons. With the OX underestimations over 200 ml min^{-1} (13%) were more frequent than corresponding overestimations with the KM (five versus three).

The observed underestimation in the $\dot{V}O_2$ measured in this study with the OX could be due to errors in ventilation volumes ($\dot{V}I$), in respiratory exchange ratio (R) and in the relative humidity (RH). The OX underestimated the ventilation volume at the average of 6 l min^{-1} ($p < 0.001$) in walking and 3 l min^{-1} (ns) in lifting as compared with the DB volumes. The percentages of the underestimations were 13 and 9%, respectively. Low ventilation volumes may be caused by the poor design of the face mask for the OX resulting in an inadequate seal between the face and the mask. On the other hand with the DB the large dead space of the Triple J breathing valve (300 ml) may have increased the ventilation volume (Barlett *et al.* 1972).

The average R ($\pm$S.D.) in the DB measurements was for walking and lifting 0·90 ($\pm$0·10). Two R values under 0·70 and four over 1·05 were rejected because some technical error in gas analyses was suspected. According to the correction table supplied by the manufacturer (P. K. Morgan, Catalogue no. 070) the 0·90 value of the R produces an underestimation of 1·8% in the $\dot{V}O_2$. Also, during a few measurements the RH in the laboratory was under 50% which may slightly lower the ventilation volume ($<0{\cdot}5\%$) and through that one $\dot{V}O_2$ obtained with the OX (P. K. Morgan, Catalogue no. 070).

If the correction table for R and the correction figure for the RH had been used, the observed mean differences in the value of $\dot{V}O_2$ would have been about 2% smaller. The corrections were not made because when the OX is used in real work situations the true R values are not available, and the influence of the RH is negligible. If the individual's energy expenditure should be calculated on the basis of $\dot{V}O_2$ measured by the OX the application of the Weir formula (Weir 1949), described by Ballal and Macdonald (1982), can be used.

The results of the present study concerning $\dot{V}O_2$ measured with the OX agree well with two recent evaluations of the OX. Ballal and Macdonald (1982) found a very good agreement between parallel measurements with the OX and the DB based on the mean values and the linear regression equation. Harrison *et al.* (1982) reported significant mean underestimations by the OX (4 and 6%) as compared with the 'standard' method in their two experiments. The dependence between the methods was very high as seen by the regression equations. A similar technical fault was noticed by Ballal and Macdonald (1982) and Harrison *et al.* (1982), this was that sometimes the $\dot{V}O_2$ reading of the first minute with the OX was too low and/or delayed.

The KM slightly overestimated $\dot{V}O_2$ for both work modes although the average ventilation volume ($\dot{V}E$) of the KM in walking was 9 l min^{-1}, i.e. 19% ($p<0{\cdot}001$) and in lifting 2 l min^{-1}, i.e. 6% ($p<0{\cdot}001$) lower than with the DB. The difference in $\dot{V}E$ is probably due to the combined expiratory breathing resistance of the Single J valve (Bartlett *et al.* 1972) and the KM's ventilometer, particularly at higher flow rates. The reference values of the DB were measured with the triple J valve which has a lower breathing resistance but a larger dead space than the single J valve. The dissimilarity of the valves may have an affect on the differences between the ventilation volumes of the DB and KM. Low ventilations without marked changes in $\dot{V}O_2$ indicate a relative hypoventilation with oxygen (Gee *et al.* 1968, Hermansen *et al.* 1972) during the KM measurements. The hypoventilation in the KM was more pronounced at higher ventilation volumes, supporting the possible effects of the breathing resistance. The observed differences in the ventilation volumes were larger than the error limits of the KM's ventilometer calculated by Consolazio (1971). He used a large manual respiration pump and the calculated error limits varied from $\pm$0·5 l min^{-1} to $\pm$1·3 l min^{-1} at a p level $<0{\cdot}05$.

In actual work situation subjects must also carry, besides a mouthpiece and a noseclip or a mask, the extra weight of the instrument with belts or harness. The conventional DB system weighs 2–3 kg. The weight of the analyser of the OX with a leather case and a waist belt is 2·6 kg. The KM gas meter weighs 3·2 kg. So the possible influence of the extra weight carried on $\dot{V}O_2$ (Borghols *et al.* 1978) is almost the same with all three methods.

In conclusion it can be stated that the OX as well as the KM gas meter showed very good agreement with the DB technique, in spite of the slight underestimations with the OX, and the slight overestimations with the KM in the compared $\dot{V}O_2$ means. The OX and the KM are accurate for reliable $\dot{V}O_2$ measurements under field conditions. Experience gained during several field studies has shown that the OX is very well suited to field measurements, but some practical improvements concerning the mask, the waist belt and the digital displays are necessary.

L'Oxylog (OX) et les techniques de Kofranyi–Michaelis (KM) pour la détermination de la consommation d'oxygène ($\dot{V}O_2$) ont été comparés à la classique méthode du sac de Douglas (DB) lors d'exercices de marche et de soulèvement effectués en laboratoire. Six hommes ont servi de sujets. L'OX sous-estimait de 4,1 et 6,4% et le KM sur-estimait de 3,8 et 0,8% respectivement pour la marche et le soulèvement, les différences moyennes de la $\dot{V}O_2$. Les équations de la régression linéaire entre DB et OX, ainsi que celles entre DB et KM rélèvent un bon accord ($r=0{,}91$–$0{,}99$) entre les valeurs de la $\dot{V}O_2$. L'OX et le KM s'avèrent suffisamment précis pour effectuer des mesures fidèles de la $\dot{V}O_2$ en situation de travail réel. Un certain nombre d'améliorations dans l'utilisation du OX dans des situations réelles sont proposées.

Die Felduntersuchungsmeßmethoden zur Bestimmung des Sauerstoffverbrauchs ($\dot{V}O_2$) Oxylog (OX) and Kofranyi–Michaelis (KM) werden bei stansardisierter Geh- und Hebearbeit im Laboratorium verglichen. 6 männliche Versuchspersonen wurden eingesetzt. $\dot{V}O_2$ wurde bei der Methode OX zu niedrig gemessen (4,1% und 6,4%) und bei der KM Methode zu hoch (3,8% und 0,8%) beim Gehen und Heben. Die lineare Regression zwischen DB und OX sowie zwischen DB und KM zeigte eine gute Übereinstimmung der gemessenen $\dot{V}O_2$ Größen ($r=0{,}91$–$0{\cdot}99$). OX und KM sind für reliable $\dot{V}O_2$ Messungen unter Feldbedingungen genau genug. Für die Verwendung der OX wurde einige praktische Verbesserungen aufgrund verschiedener durchgeführter Felduntersuchungen vorgeschlagen.

酸素摂取量（$\dot{V}_{O_2}$）測定のための Oxylog（OX）及び Kofranyi-Michaelis（KM）のフィールド測定法と，実験室での標準歩行と持上げ作業による伝統的なダグラスバッグ（DB）法との比較を行った。被験者は男性6名である。$\dot{V}_{O_2}$ の差の平均によれば，歩行時と持上げ作業時の $\dot{V}_{O_2}$ の値は OX 法ではそれぞれ4.1%と6.4%低く見積り，KM 法では3.8%と0.8%だけ高く見積った。DB 法と KM 法の間の関係と同様に DB 法と OX 法との間の線形回帰方程式も $\dot{V}_{O_2}$ 値の良い一致を示した（$r=0.91-0.99$）。OX 法と KM 法は正確で，フィールド条件下で信頼できる $\dot{V}_{O_2}$ の測定法となる。いくつかのフィールド研究に基づく，OX 法使用のための実際的な改善について提案を行う。

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Development and evaluation of a test drill for assessing physical work capacity of fire-fighters

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Abstract

A submaximal job-related test drill was developed for assessing physical work capacity of fire-fighters at worksites. The drill with the fixed maximal working time of 14.5 min consists of five common smoke-diving (entry into a smoke-filled space) tasks done with full personal protective equipment. Cardiac strain of the drill and its dependence on the maximal oxygen consumption (VO_2max) and age were studied with 59 experienced male fire-fighters aged 27–54 years. Their VO_2max ranged from 29.7 to 67.0 ml/min/kg for cycling. Heart rate (HR) in the tasks of the drill was 91–184 beats/min corresponding to cardiac strain of 49–99% of the maximal HR. The estimated mean VO_2 of the drill was 26 ml/min/kg and 2.1 l/min (56% VO_2max). Cardiac strain was significantly related to VO_2max ($r = -0.50$, $p < 0.001$) but insignificantly to age. The test drill efficiently rated fire-fighters according to their physical work capacity, and showed to be a valid and feasible method for the use in fire stations.

Relevance to industry

In demanding fire-fighting and rescue operations, poor physical work capacity of a fire-fighter decreases efficiency of work and increases health and safety hazards for each involved in the operations. A submaximal job-related test drill was developed for the worksite assessment of a fire-fighter's physical work capacity. In this study, the physiological features of the drill were evaluated with experienced firemen. The test drill showed to be valid and feasible for rating physical work capacity of fire-fighters in fire stations.

Key words: Fire-fighting; Field test; Validity; Feasibility; Heart rate; Oxygen consumption; Physical work capacity

1. Introduction

In fire-fighting and rescue work, smoke-diving (entry into a smoke-filled space) tasks with protective clothing and a self-contained breathing apparatus (SCBA) are performed a few times a year by every professional fire-fighter regardless of age (Lusa et al., 1993a). Smoke-diving sets high demands on work capacity, particularly on the cardiorespiratory system as oxygen consumption (VO_2) and heart rate (HR) have been observed to average 2–3 l/min and 140–150 beats/min, respectively (Lemon and Hermiston, 1977; Louhevaara et al., 1985; Lusa et al., 1993b).

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Several reports agree that smoke-diving tasks require a healthy fire-fighter having a maximal oxygen consumption (VO_2max) of at least 3 l/min. Also regular fitness tests are recommended to ensure the sufficiency of VO_2max for work (Davis et al., 1982; Kilbom, 1980; Louhevaara, 1986).

The determination of VO_2max in laboratory settings requires professional staff and expensive equipment, and is time-consuming. In the statutory occupational health services, there are very limited prerequisites for such measurements, and no generally accepted guidelines are available on the follow-up of the work capacity of the fire-fighters. In actual situations, the selection of the fire-fighters for physically demanding tasks is done by a fire chief responsible for his crew. In order to improve safety at work and to assist fire chiefs, there was a need for practical methods to rate physical work capacity of the operative fire-fighters. Therefore, a simple job-related test drill was developed for the worksite assessment of fire-fighters' physical work capacity for smoke-diving tasks.

The aim of this study was to evaluate cardiac strain imposed by the test drill, and to relate strain to VO_2max and age.

2. Material and methods

2.1. Subjects

The subjects were 59 male fire-fighters aged 27–54 years from the Fire and Rescue Department of the Oulu City. Their VO_2max ranged from 29.7 to 67.0 ml/min/kg (Table 1). The work experience of the subjects at their present job was 4–28 years.

Table 1
Physical characteristics of the subjects ($N = 59$) and their maximal oxygen consumption (VO_2max) and maximal heart rate (HRmax) during cycle exercise

	Mean	Range
Age (years)	39	27–54
Height (cm)	177	160–196
Weight (kg)	83	63–122
VO_2max		
(l/min)	3.82	2.51–5.20
(ml/min/kg)	46.8	29.7–67.0
HRmax (beats/min)	184	140–207

2.2. The test drill

The test drill was developed within this study. The submaximal test drill consists of five common tasks associated with smoke-diving. They are done wearing full personal protective equipment against fire and contaminated atmosphere. These include long underwear, socks, a commando-type cap, a helmet, fire protective suit, rubber safety boots, safety gloves, a tool belt, and an SCBA with one air container on the back (total weight of equipment: 25 kg). While performing the drill, the full-face mask of the SCBA is worn and breathing air is taken from the container.

The tasks and their order in the drill are the following:

(1) Walking without and with two rolls of hose
First a fire-fighter walks on the level for 100 m without extra load, and thereafter for another 100 m with two rolls of hose in his hands. One roll weights 16.6 kg. The length and diameter of the hose are 25 m and 76 mm, respectively.

(2) Stair climbing and ascending
A fire-fighter climbs and ascends for 20 m without extra carriage within the task. The optimal height of a stair step is 18–22 cm. In this study the subjects continuously climbed up and down for 12 times nine steps (half of a floor). The height of one step was 18.5 cm.

(3) Hammering the truck tire
A fire-fighter has a hammer. Its head weighs six kilograms. The length of the handle is 90 cm with the diameter of 32 mm. Hitting with the hammer a fire-fighter moves a truck tire (total diameter 103 cm, diameter of tire 25 cm) without a wheel on the cement floor for three meters. The weight of the tire is 47 kg and it is lying flat on the floor during hammering.

(4) Going over and under bars
The length of the track is eight meters and there are three light bars at the distance of

two meters. The height of the bars from the floor is 60 cm. Their breadth is two meters. A fire-fighter goes under the first bar, over the second, and again under the third one, turns and goes back in a similar way. This performance is repeated three times.

(5) Hose rolling
A fire-fighter walks and rolls the hose in his hands. While rolling, the other end of the extended hose is stationary on the floor. The weight, length and diameter of the hose are 5.9 kg, 25 m, and 39 mm, respectively.

There is a fixed maximal working time of 14.5 min for the drill. The fixed times for the tasks are four, three and a half, two, three, and two minutes, respectively (Table 2). After the drill, the recovery is followed for five minutes while a fire-fighter is in a sitting position without the SCBA. The tasks are performed at habitual work rate and style without competing. If the task is done faster than allowed by the given time, the rest of the work time is used for recovery in a standing position before starting the next task or ending the drill. The start and the end points of the tasks are located within 10 m in order to minimize walking between the tasks.

For monitoring and classifying physical strain, it is recommended to measure HR continuously in the drill with a portable cardiometer or at least during the end (15–30 s) of the last minute of each task by palpation. The classification of cardiac strain (percentage of maximal HR, %HRmax) can be done using HRs obtained in the tasks of the drill and applying the age-related formula for HRmax: 220 − age (Mitchell et al., 1958). If the individual HRmax is known, it must be used for the calculations of strain. Without the measurements of HR the pass or non-pass of the drill is the only objective indication of the performance. A fire-fighter's physical work capacity is considered too low for smoke-diving if he is not able to pass the drill within the fixed maximal time of 14.5 min.

2.3. Measurements for assessing cardiac strain

In the worksite experiments of this study, HR was recorded every 5 s throughout the drill by a portable telemetric cardiometer (Sport Tester PE 3000, Polar Electro Oy, Finland). In the laboratory, after the medical screening and basic anthropometric assessments, VO_2max and HRmax were directly measured on an electronic cycle-ergometer (Tunturi EL-400, Tunturi Oy, Finland). In the test, the first load was 50 W and it was increased by 25 W every second minute until exhaustion. Maximal effort was defined as the plateau of VO_2 or exceeding the level of over 1.0 in the respiratory exchange ratio.

While pedalling the ergometer, expired air was directed through a low resistance breathing valve and tubing to an ergospirometer (Medikro 202, Medikro Co., Finland), which determined pulmonary ventilation, VO_2, the production of carbon dioxide and the respiratory exchange ratio every 30 s. Before each test the gas analyzers were calibrated with a gas mixture with known concentrations of oxygen and carbon dioxide. HR for cycling was recorded every 15 s with the Sport Tester PE 3000 and an electrocardiogram was continuously monitored with an oscilloscope (OLLI 431D, Kone Oy, Finland).

Table 2
Heart rate (HR) and cardiac strain (percent of maximal heart rate, %HRmax) in tasks of the drill

Task	Time (min)	HR (beats/min)		%HRmax (%)	
		Mean	Range	Mean	Range
Walking and carrying	4	122	91–166	66	49–87
Stair climbing	3.5	135	98–174	73	53–92
Hammering	2	150	112–184	82	63–96
Over and under bars	3	158	116–184	86	73–99
Hose rolling	2	149	100–182	81	61–99
All	14.5	140	102–175	76	59–93

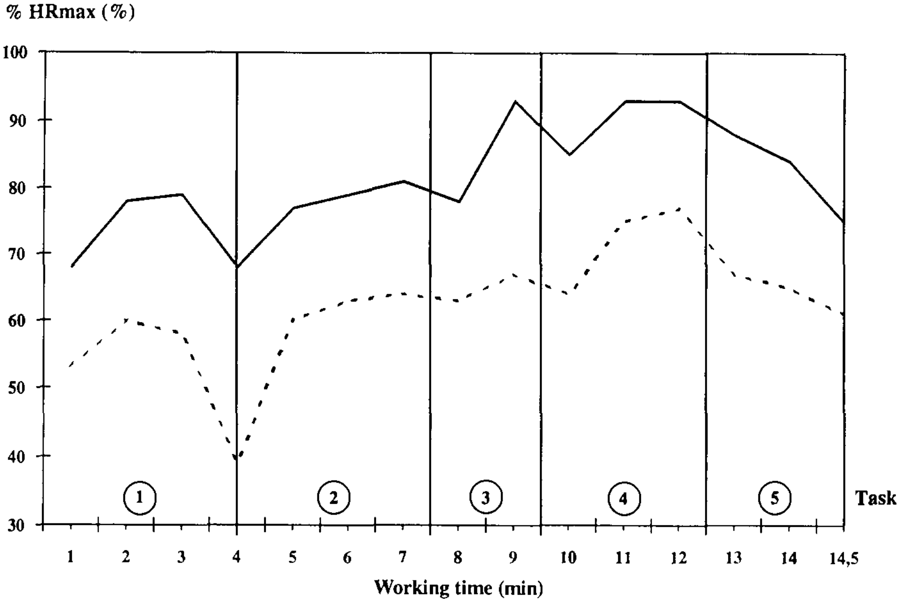

Fig. 1. The solid curve through the tasks of the test drill indicates cardiac strain (%HRmax) of a subject with a low maximal oxygen consumption ($VO_2max = 31.6$ ml/min/kg). The broken curve shows that for a subject with a high maximal oxygen consumption ($VO_2max = 63.1$ ml/min/kg).

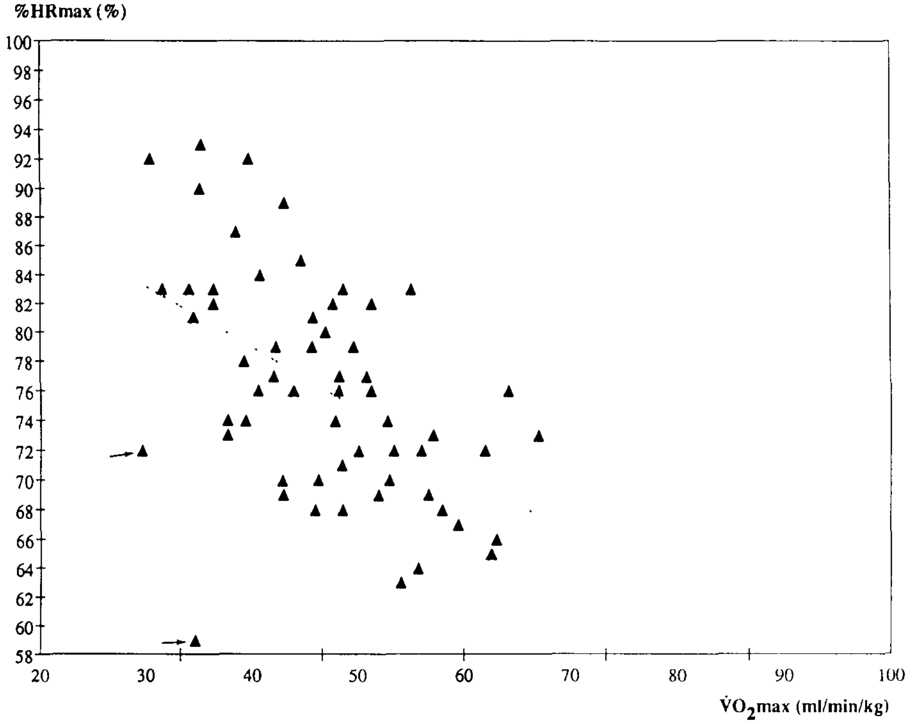

Fig. 2. The individual plotting and linear regression equation between maximal oxygen consumption (VO_2max) per body weight for cycling and cardiac strain (%HRmax) of the test drill. The regression equation for %HRmax was $-0.42 * VO_2max + 95.80$ ($r = -0.50$, $p < 0.001$). Two "outliers" included in the equation are marked with an arrow.

Table 3
Maximal oxygen consumption (VO_2max) and maximal heart rate (HRmax) for cycling as well as heart rate (HR) and cardiac strain (%HRmax) of the drill in different age groups. The values are means (range)

	Age (years)			
	27–29 ($N = 5$)	30–39 ($N = 25$)	40–49 ($N = 25$)	50–54 ($N = 4$)
VO_2max				
(l/min)	4.46 (3.93–5.20)	4.02 (3.21–4.79)	3.54 (2.70–4.67)	3.46 (2.51–4.51)
(ml/min/kg)	50.9 (38.5–64.2)	50.0 (29.7–67.0)	43.1 (31.6–63.1)	44.3 (36.4–55.7)
HRmax (beats/min)	195 (190–199)	186 (159–204)	181 (140–207)	184 (172–191)
HR (beats/min)	153 (140–165)	136 (104–163)	142 (102–175)	143 (119–159)
%HRmax (%)	79 (72–87)	73 (63–92)	78 (59–93)	78 (64–83)

2.4. Statistical analysis

Means and ranges were used as parameters to describe physiological responses in the tasks of the drill and in different age groups. In the drill, cardiac strain (%HRmax of the drill) for each subject was calculated by relating HR of the drill to HRmax for cycling. The dependence of %HRmax of the drill on VO_2max for cycling and age were examined with linear regression equa-

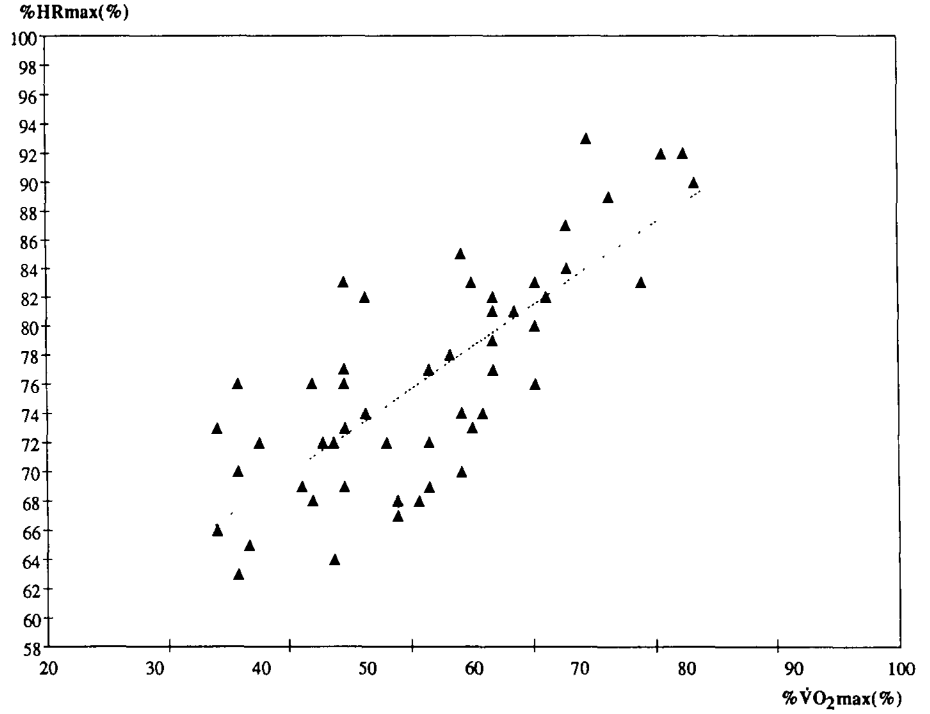

Fig. 3. The relationship between cardiac strain (%HRmax) of the test drill and the relative aerobic strain (%VO_2max) for cycling in different levels of exertion. The regression equation for %HRmax was 0.50 * %VO_2max + 48.39 ($r = 0.78$, $p < 0.001$).

tions. The individual mean HR of the drill was related to equal HR for cycling to establish the relationship between %HRmax of the drill and VO_2 for cycling as well as relative aerobic strain (%VO_2max) for cycling. The estimated individual %VO_2max values of the drill were used for the classification of cardiac strain. The determination of the relationships between the variables was based on regression analyses including the SAS Statistical Package. The results were considered statistically significant when $p < 0.05$.

3. Results

In the tasks of the drill, the range of HR was 91-184 beats/min with a corresponding cardiac strain of 49-99% HRmax. The highest strain was observed in the task "Going over and under bars" (73-99% HRmax) (Table 2 and Fig. 1).

There was a large individual variation in VO_2max and HRmax for cycling as well HR and %HRmax of the drill in different age groups (Table 3).

Cardiac strain (%HRmax) of the drill depended significantly ($r = -0.50$, $p < 0.001$) on VO_2max per body weight for cycling (Fig. 2). A significant relationship was not found ($r = 0.22$, p = NS) between age and %HRmax of the drill.

The relationship between %VO_2max for cycling and %HRmax of the drill was significant ($r = 0.78$, $p < 0.001$). At the mean cardiac strain level of the drill (76% HRmax) the VO_2 for cycling was 26 ml/min/kg and 2.1 l/min (56% VO_2max). The levels of 85 and 95% HRmax of the drill were estimated to correspond to about 75 and 90% VO_2max for cycling, respectively (Fig. 3).

4. Discussion

4.1. Cardiac strain of the drill in relation to VO_2max and individual characteristics

The test drill efficiently sorted out the subjects according to their VO_2max. The drill was quite easily passed by the subjects having a VO_2max over 40 ml/min/kg for cycling. A very large individual variation was found in the cardiac strain (%HRmax) of the drill. The regression equation between VO_2max per body weight and %HRmax even included two "outliers" i.e., subjects who had both a very low VO_2max for cycling (poor cardiorespiratory capacity) and low %HRmax of the drill. This suggests that a skilful performance may to some extent compensate an impaired VO_2max, and the pass of the drill is possible. %HRmax of the drill correlated significantly to VO_2max but not to age, although VO_2max, on average, decreased with age. This can be affected by a large individual variation of VO_2max being more dependent on physical training than age.

In the worksite experiments, one tall fire-fighter with a considerable overweight was not able to pass the drill within the fixed maximal time of 14.5 min. This was due to his exceptionally high consumption of air (pulmonary ventilation), which emptied the air container. Furthermore, a few older fire-fighters refused to participate in the study because they had some doubts about passing the drill. The results of six fire-fighters who passed the drill were not included in the study because they regularly used medication inhibiting HR.

Eight subjects with a VO_2max smaller than 36 ml/min/kg passed the drill with near maximal levels of cardiac strain. The results of this study agree with the previous recommendations that VO_2max for smoke-diving tasks should be at least 3.0 l/min and/or 36 ml/min/kg (e.g. Davis et al., 1982; Louhevaara and Lusa, 1993). Moreover, VO_2max should be assessed during muscle exertion, which imitates actual work tasks. In the laboratory, the valid and reliable result can be yielded when VO_2max is measured during uphill walking on a treadmill using a specific protocol including the wear of full personal protective equipment for smoke-diving (Lusa et al., 1993c).

4.2. Rating of cardiac strain of the drill

The submaximality of the drill is an important feature preventing health and safety hazards associated with all performance tests. At the cardiac strain levels of 75-84, 85-94, and 95-100%

HRmax of the drill, the estimated relative aerobic strain can be classified as high (50–74% VO_2max), very high (75–89% VO_2max) and extremely high (90–100% VO_2max), respectively. With high cardiac strain a fire-fighter can continuously work for over 60 min. At the very high and extremely high levels of strain, the maximal times for continuous work are 20–30 min and 1–10 min, respectively (Louhevaara et al., 1986).

In practical interpretation and use of the test results, either the non-pass of the drill within a fixed time of 14.5 min or cardiac strain level of 90–100% HRmax are strong indicators of low physical work capacity. It may reduce efficiency and safety in actual smoke-diving tasks.

4.3. VO_2max and HRmax in relation to age

The mean VO_2max of the subjects of this study systematically decreased in older age groups. In each group individual variation was large and the number of subjects was small in the youngest and oldest age group. When compared to the age-related classifications of Shvartz and Reibold (1990), the absolute VO_2max of the subjects averaged "very good" or "excellent" in different age groups. Correspondingly, the means of VO_2max per body weight were "good" or "very good". This shows the selection of the fit and well-motivated subjects for this type of studies.

HRmax of the subjects also decreased due to age. The results favour more the function of HRmax = 205 − (0.5 * age) for the prediction of the age-related HRmax than that of HRmax = 220 − age (Mitchell et al., 1958; Arstila et al., 1984). The differences were more pronounced in the age groups of 40–49 and 50–54 years. For the health and safety of the aging fire-fighters, however, lower HRmax table values ie. the function of HRmax = 220 − age can be recommended for practical use.

4.4. Feasibility of the drill

The subjects were asked to evaluate the feasibility and usefulness of the drill. Over two-thirds of the subjects (71%) considered that the drill was a better method for assessing physical work capacity than a cycle-ergometer test. The results of the drill were evaluated to motivate for physical training by 91% of the subjects. Almost everyone (90%) thought that the results can be utilized in the occupational health services.

The drill is a test method but it may also be used for rehabilitation, for example, after a long sick leave. First the drill can be carried out slower or without the SCBA.

In conclusion, the developed and evaluated job-related test drill showed to be valid and feasible for the worksite assessments of fire-fighters' physical work capacity for smoke-diving tasks.

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Differences in cardiorespiratory responses during and after arm crank and cycle exercise

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LOUHEVAARA, V., SOVIJÄRVI, A., ILMARINEN, J. & TERÄSLINNA, P. 1990. Differences in cardiorespiratory responses during and after arm crank and cycle exercise. *Acta Physiol Scand* 138, 133–143. Received 1 September 1988, accepted 22 September 1989. ISSN 0001–6772. Department of Physiology, Institute of Occupational Health, Finland, Laboratory of Clinical Physiology, Helsinki Central University Hospital, Finland, and Department of Physical Education and Recreation, University of Kentucky, USA.

The differences in cardiorespiratory responses were examined during and after intermittent progressive maximal arm-crank and cycle exercise. Arm-crank exercise was performed in a standing position using no torso restraints to maximize the amount of active skeletal muscle mass. Recovery was followed for 16 min. In the tests a variety of ventilatory gas exchange variables, heart rate, the blood pressure, and the arm venous blood lactate concentration were measured in 21 untrained healthy men aged 24–45 years. At equal submaximal external workloads for arm cranking and cycling (50 and 100 W) the respiratory frequency, tidal volume, pulmonary ventilation, oxygen uptake, carbon dioxide output, the respiratory exchange ratio, heart rate, the arm venous blood lactate concentration, and the ventilatory equivalent for oxygen were higher ($P < 0.001$) during arm cranking than cycling. The maximal workload for arm cranking was 44% lower than that for cycling (155 ± 37 *vs* 277 ± 39 W, $P < 0.001$) associated with significantly ($P < 0.001$) lower maximal tidal volume (−20%), oxygen uptake (−22%), carbon dioxide output (−28%), systolic blood pressure (−17%) and oxygen pulse (−22%) but a higher ventilatory equivalent for carbon dioxide (+22%) and arm venous blood lactate concentration (+37%). However, these responses after arm-crank and cycle exercises behaved almost similarly during recovery. The high cardiorespiratory stress induced by arm work should be taken into account when the work stress and work–rest regimens in actual manual tasks are assessed, and when arm work is used for clinical testing, and in physiotherapy particularly for patients with heart or pulmonary diseases.

Key words: arm cranking, arm venous blood lactate, blood pressure, cycling, heart rate, recovery, ventilatory gas exchange.

Many agricultural, forest and manual material handling tasks as well as sport activities require substantial use of upper body muscle groups (Vrijens *et al.* 1975, Sen *et al.* 1983, Ilmarinen 1984, Kukkonen-Harjula & Rauramaa 1984). In occupational and exercise studies, it is thus sometimes necessary to assess the work capacity of the upper body (Falkel *et al.* 1986, Louhevaara *et al.* 1988). In clinical physiology and in physiotherapy arm work is also applied for disabled individuals having difficulties in using their legs for exercising (Hjeltnes 1977, Lazarus *et al.* 1981).

Evaluation of the capacity and function of the upper body is almost solely based on the recording of cardiorespiratory responses to arm-crank exercise in a sitting position (see, for example, Sawka 1986). Most investigators have

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reported higher aerobic, anaerobic and heart rate responses to arm cranking than to cycling at equal submaximal power outputs, but lower peak responses and maximal power output (e.g. Christensen 1932, Åstrand *et al.* 1965, Bevegård *et al.* 1966, Vokac *et al.* 1975). In spite of increased scientific interest in the physiology of upper body exercise (Sawka 1986), no data are available about cardiorespiratory responses both during and after arm-crank exercise while standing and using no torso restraints. Furthermore, the previous data have often been obtained from physically trained, young subjects (Secher *et al.* 1974, Vrijens *et al.* 1975, Bergh *et al.* 1976, Davis *et al.* 1976), whereas the problems in work and clinical physiology and in physiotherapy usually involve untrained individuals at different ages.

It was hypothesized that the differences in cardiorespiratory responses during and after arm cranking and cycling become smaller when arm cranking is carried out in a standing position without torso restraints, i.e. when it is attempted to maximize the amount of active skeletal muscle mass during arm cranking. This test mode for arm cranking was selected because the aim of this study was to highlight the differences in conventional stress testing administered by leg exercise and performance testing simulating actual work tasks with upper body muscle groups (Louhevaara *et al.* 1988).

Consequently, the purpose of the present study was to determine the differences in ventilatory gas exchange, heart rate, the systolic blood pressure, and the arm venous blood concentration between arm cranking while standing without torso restraints and cycling in untrained healthy men at submaximal and maximal exercise levels and during recovery. This knowledge is important when physical stress is studied in manual work tasks, when the arm work is used for clinical testing, rehabilitation, and training, and to attain a better understanding of control mechanisms being involved in cardiorespiratory responses to the arm-crank exercise.

MATERIALS AND METHODS

Twenty-one untrained healthy men, aged 24–45 years, volunteered for the study. Their physical characteristics are given in Table 1. The study procedure followed the Helsinki declaration, and was accepted by the Ethical Committee of the Institute of Occupational Health. Each subject signed a statement of informed consent.

Table 1. Subjects' physical characteristics and forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1)

	$n = 21$	
	Mean	SD
Age (years)	33·3	5·9
Height (cm)	178.4	7.2
Weight (kg)	78.3	12.7
Body fat (%)	18.4	5·3
FVC (l)	5.84	0.84
FVC (% of predicted)*	104.8	11.6
FEV_1 (l)	4·93	0.67
FEV_1 (% of predicted)*	111.8	13·3

* According to Berglund *et al.* (1963).

The cycle and arm-crank exercise tests were carried out in the laboratory, with an ambient temperature of 22–24 °C and a relative humidity of 30–40%. The cycle test was followed by the arm-crank test, and they were administered on separate occasions, with an interval of 2–7 days. For one subject, the interval between the tests was 30 days. Between the cycle and arm-crank tests half of the subjects performed a work test (Louhevaara *et al.* 1988) while the rest of them accomplished it after the arm-crank test. The subjects wore shorts and sneakers during the tests.

The subjects' initial measurements comprised a determination of their anthropometric characteristics including the assessment of the body fat (Durnin & Rahaman 1967), dynamic spirometry with a water spirometer introduced by Bernstein, and a clinical examination performed by a physician and supplemented with the recording of an electrocardiogram (ECG). Before the exercise tests a plastic needle for repeated venous blood sampling was inserted in a superficial cubital vein in the forearm. The first external workload was 50 W in the cycle test and 25 W in the arm-crank test. The load was increased by 50 W or 25 W respectively, every fourth minute. At each submaximal workload, the pedalling or cranking was interrupted for 30 s after a 3-min exercise while the blood pressure was measured and a sample of arm venous blood was taken. Thereafter the pedalling and cranking were continued at the preceding exercise level to the end of the 4-min period. The blood pressure was measured and the blood samples were also collected before and after the exercise, with the subjects in a sitting position. During recovery the blood pressure was measured immediately, and thereafter every second minute after the end of the exercise, while the blood samples were taken immediately and during the minutes of 1, 4, 8, 12 and 16 after the exercise.

During arm cranking the subjects stood without torso restraints, and no attempts were made to limit the possible use of back and leg muscles. The pedalling and cranking rate was maintained at 50 r.p.m. The subjects were asked to continue exercising until exhaustion. During the last minute of exercise the resistance force of friction was kept constant, and the subjects were asked to increase the external workload (the power output) to maximum by speeding up the revolution rate as much as possible. After the exercising ended, the responses continued to be recorded for 16 min.

Calibrated, mechanically braked cycle ergometers (Monark, Monark A/S, Sweden) were used in both tests. The ergometer for the arm-crank exercise was modified from the cycle ergometer (Bohannon 1986). The crank shaft was at a constant height of 0.83 m. The pedalling and cranking rates were paced by a metronome, and registered by an inductive revolution meter connected to a printer (Printina, Misuratory Electronici, Italy).

During the tests the respiratory frequency, tidal volume, pulmonary ventilation, oxygen uptake, carbon dioxide output and the respiratory exchange ratio were continuously measured and automatically printed by a microprocessor-controlled respiratory gas exchange analyser (Morgan Exercise Test System, P. K. Morgan Ltd, UK). The measurement unit consisted of a flowmeter, a paramagnetic oxygen analyser (Morgan 500d), and an infrared carbon dioxide analyser (Morgan 800d). A low-resistance breathing valve (modified Koegel Y-valve) with a mouthpiece and a nose clip were used continuously during the entire test periods. Before every test the flowmeter was calibrated by four inspiratory strokes with a 1-litre pump, the gas analysers with two mixtures of gases of known oxygen and carbon dioxide concentrations.

The initial ECG at rest was recorded with the standard 12 leads. In the tests four CH leads were used. The ECG was monitored continuously during the entire test period on an oscilloscope, and paper recordings were obtained during the last 15 s of each minute with a three-channel ECG recorder (Mingoraf 34, Siemens-Elema, FRG). The heart rate was obtained manually from 15 successive QRS intervals of the ECG recordings. The systolic blood pressure was measured with the conventional auscultatory technique, and the cuff was located on the left arm.

The arm venous blood samples of 2.0 ml were collected through the needle into disposable syringes. The tip of the needle was inserted into approximately the middle part of the right forearm. Two separate blood samples of 25 μl were taken from the syringe for the enzymatical determination of the blood lactate concentration, using the flow injection method described by Karlsson *et al.* (1983). The mean value of the duplicates was accepted if the values differed by less than 4% (Smolander *et al.*1986). The arm venous blood samples were used for the determinations of the blood lactate concentrations due to further analysis of the responses profile of the acid–base balance in arm venous blood (Teräslinna & Louhevaara 1988).

The gross efficiency of work was calculated as the ratio of power output to aerobic metabolic (oxygen uptake) input (Powers *et al.* 1984).

The data were treated for conventional descriptive statistics. The significance of the differences was evaluated with the Student's *t*-test for paired observations.

RESULTS

At the two submaximal stages of arm-crank and cycle exercise tests when external workloads were equal (50 and 100 W), the respiratory frequency, tidal volume, pulmonary ventilation, oxygen uptake, carbon dioxide output, heart rate and the arm venous blood lactate concentration as well as the respiratory exchange ratio and the ventilatory equivalent for oxygen were significantly higher ($P < 0.001$) during arm cranking than during cycling (Figs. 1–4). At a load of 50 W, the gross mechanical efficiency was 11% during arm cranking and 16% during cycling; the difference was significant ($P < 0.001$). When the load was 100 W, the efficiencies were 15% and 20% ($P < 0.001$) respectively.

At the maximal exercise level, most parameters reflecting the power output of the work remained significantly lower during arm cranking than during cycling. The maximal external workload was 44% (155 ± 37 *vs* 277 ± 39 W, $P < 0.001$), tidal volume 20% (2.42 ± 0.30 *vs* 3.01 ± 0.53 l, $P < 0.001$), pulmonary ventilation 11% (90.4 ± 13.6 *vs* 102.0 ± 14.3 l min^{-1}, $P < 0.01$), oxygen uptake 22% (2.52 ± 0.32 *vs* 3.24 ± 0.44 l min^{-1}, $P < 0.001$), carbon dioxide output 28% (2.72 ± 0.32 *vs* 3.76 ± 0.35 l min^{-1}, $P < 0.01$), the respiratory exchange ratio 7% (1.09 ± 0.08 *vs* 1.17 ± 0.10, $P < 0.01$) and oxygen pulse 22% (14.2 ± 1.9 *vs* 18.1 ± 2.8 ml beat^{-1}, $P < 0.001$) lower during arm cranking (Figs. 1–4). On the other hand, during maximal arm cranking, the parameters reflecting anaerobic metabolism were significantly higher than during maximal cycling. The respiratory frequency was 7% (37.6 ± 5.8 *vs* 35.0 ± 5.9 breaths min^{-1}, $P < 0.05$), the arm venous blood lactate concentration 37%

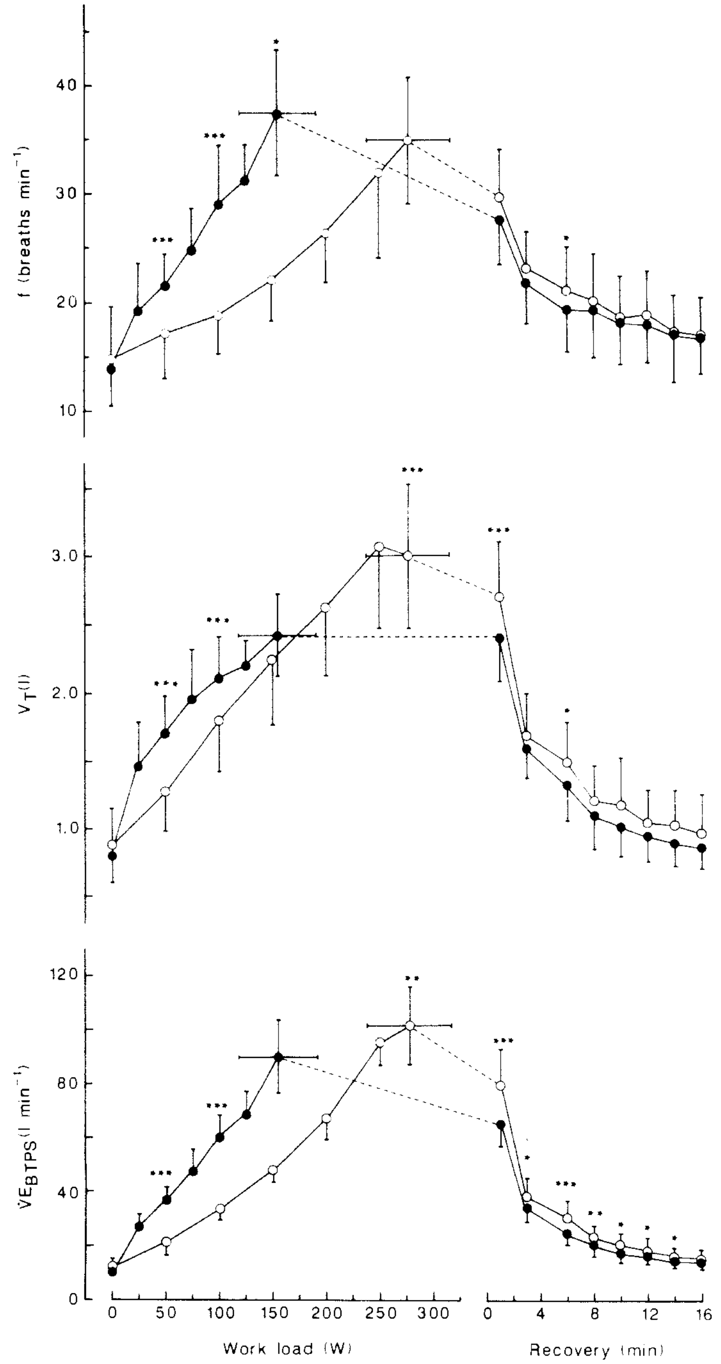

Fig. 1. Respiratory frequency (*f*), tidal volume (V_T) and pulmonary ventilation ($\dot{V}_{E,\,BTPS}$) in a sitting position, at submaximal exercise levels, at the maximum and during the recovery period for arm-crank (●–●) and cycle (○–○) tests. The values given are the means ± SD. At the load of 125 W for arm cranking and 250 W for cycling $n = 4$ and $n = 3$ respectively. Levels of statistical significance are expressed as $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

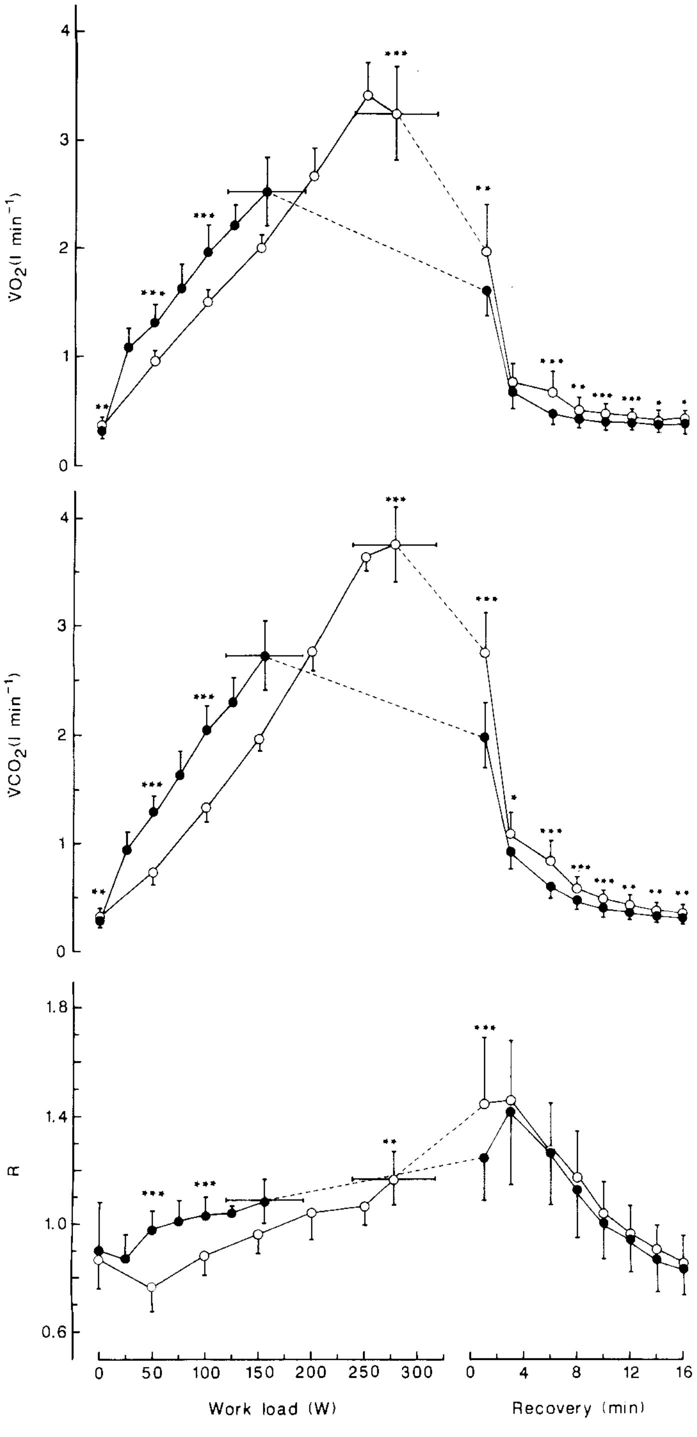

Fig. 2. Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$) and the respiratory exchange ratio (R) in a sitting position, at submaximal exercise levels, at the maximum and during the recovery period for arm-crank (●–●) and cycle (○–○) tests. See also the legend to Fig. 1.

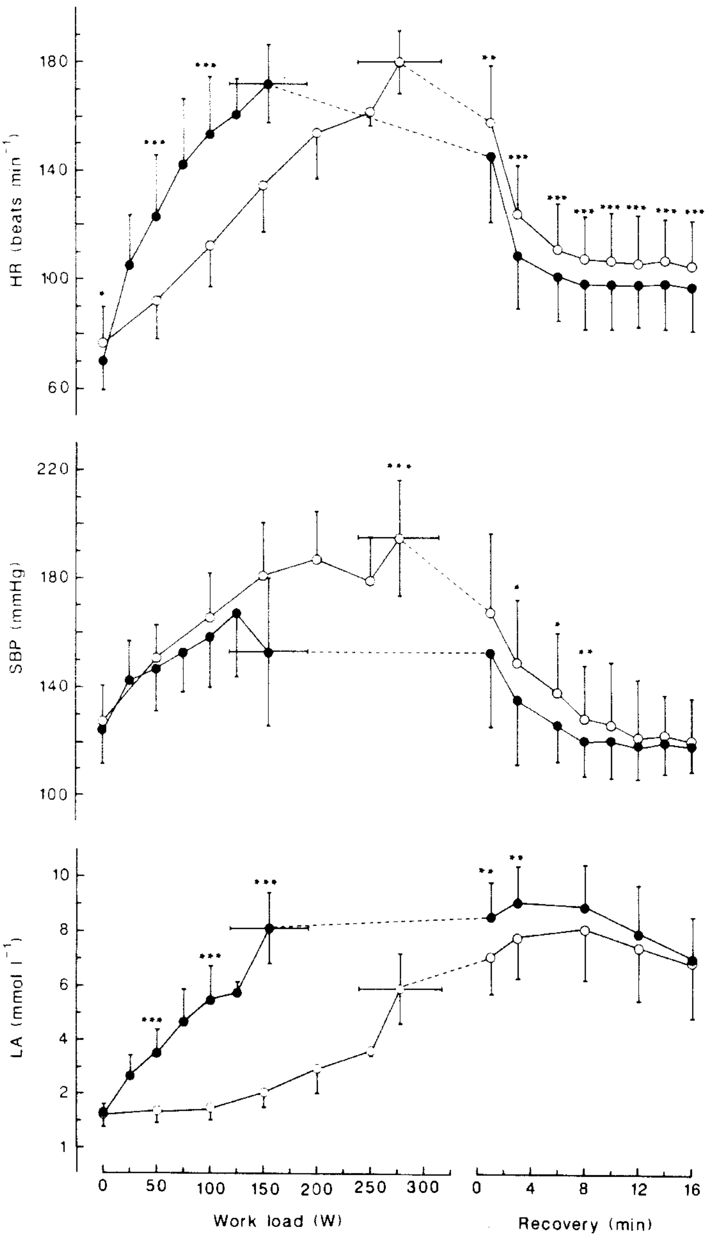

Fig. 3. Heart rate (HR), the systolic blood pressure (SBP) and the arm venous blood lactate concentration (LA) in a sitting position, at submaximal exercise levels, at the maximum and during the recovery period for arm-crank (●–●) and cycle (○–○) tests. See also the legend to Fig. 1.

(8.1 ± 1.3 *vs* 5.9 ± 1.3 mmol l^{-1}, $P < 0.001$), the ventilatory equivalent for oxygen 14% (36.1 ± 4.7 *vs* 31.8 ± 5.6 l l^{-1}, $P < 0.05$) and that for carbon dioxide 22% (33.3 ± 3.7 *vs* 27.2 ± 3.7 l l^{-1}, $P < 0.001$) higher during maximal arm cranking. There was no significant difference in the maximal heart rate while the systolic blood pressure was 17% (153 ± 27 *vs* 185 ± 22 mmHg, $P < 0.001$) lower during maximal arm cranking.

At the maximal power output, the gross efficiency was 18% during arm cranking and 25% during cycling ($P < 0.001$). At maximum

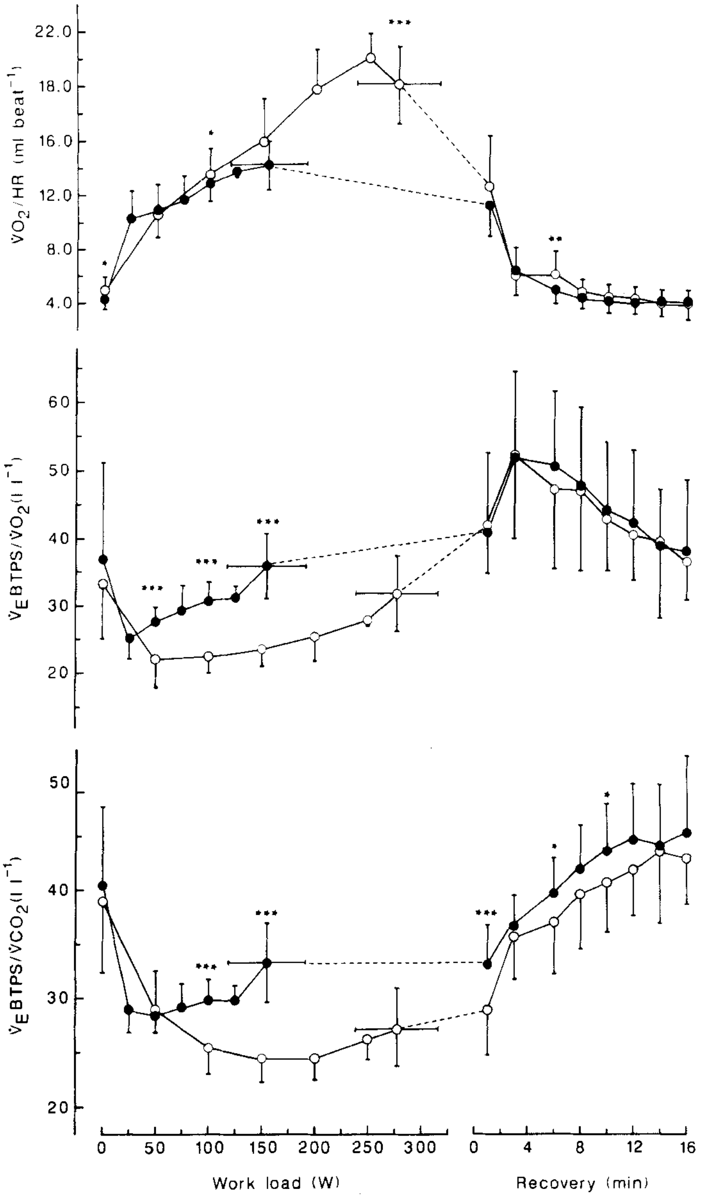

Fig. 4. Oxygen pulse ($\dot{V}O_2$/HR), the ventilatory equivalent for oxygen ($\dot{V}_{E,BTPS}/\dot{V}O_2$) and for carbon dioxide ($\dot{V}_{E,BTPS}/\dot{V}CO_2$) in a sitting position, at submaximal exercise levels, at the maximum and during the recovery period for arm-crank (●–●) and cycle (○–○) tests. See also the legend to Fig. 1.

the resistance force of friction and the revolution rate were 26 ± 3 N and 60 ± 11 r.p.m. for arm cranking and 49 ± 6 N and 57 ± 10 r.p.m. for cycling.

After 2 min of recovery in both arm cranking and cycling, no significant differences were found in respiratory frequency, tidal volume, the respiratory exchange ratio, oxygen pulse and the ventilatory equivalent for oxygen and carbon dioxide (Figs. 1–4). After a recovery of 16 min, oxygen uptake was 12% (0.38 ± 0.09 *vs* 0.43 ± 0.07 l min^{-1}, $P < 0.05$), carbon dioxide output 14% (0.31 ± 0.06 *vs* 0.36 ± 0.07 l min^{-1}, $P < 0.01$) and heart rate 8% (97 ± 16 *vs* 105 ± 16 beats min^{-1}, $P < 0.001$) lower after arm cranking than cycling. At the end of the recovery period, for both the cycle and the arm-crank test, the respiratory frequency, pulmonary ventilation, oxygen uptake, heart rate, the arm venous blood lactate and the ventilatory equivalent for carbon dioxide were significantly ($P < 0.5$–0.001) higher than the baseline values measured before the tests with the subject in a sitting position. The arm venous blood lactate level remained about fivefold higher and heart rate about 30 beats min^{-1} higher (Figs. 1–4).

DISCUSSION

Differences in body postures, the use of torso restraints, the different crank shaft heights and training status of the subjects involved in arm cranking may cause variations when the physiological responses to arm cranking are compared to those of cycling (Secher *et al.* 1974, Vrijens *et al.* 1975, Bergh *et al.* 1976). Arm-crank exercise has usually been carried out with the subjects in a sitting position with no torso restraints (Sawka 1986). In the present experiments, the arm-crank exercise was performed in a standing position without artificial torso restraints and attempts to limit the possible use of back and leg muscles while cranking. The exercise was designed to increase the amount of active skeletal muscle mass as much as possible. Furthermore, the use of efficient torso restraints may restrict blood flow and respiration (Louhevaara *et al.* 1985). On the other hand, torso restraints may reduce the amount of internal work, i.e. mainly isometric muscle work to stabilize posture and the rotational movement of upper body. Hence, the reduction of the amount of internal work may even increase the mechanical efficiency of arm cranking (Davies & Sargeant 1974, Pendergast *et al.* 1979).

At equal loads of 50 W and 100 W, arm cranking provoked minute ventilation almost twice as high as cycling. Higher ventilation was elicited by significant increases both in respiratory frequency and tidal volume, whereas Bevegård *et al.* (1966) found slightly higher values for respiratory frequency and/or tidal volume. Significantly higher submaximal responses during arm cranking when compared with cycling were also observed in oxygen uptake, carbon dioxide output, heart rate and the arm venous blood lactate concentration, the result being substantial increases in the respiratory exchange ratio as well as the ventilatory equivalents for oxygen and carbon dioxide. However, the systolic blood pressure and oxygen pulse tended to remain smaller during arm cranking than during cycling. These findings did not agree with the hypothesis of this study, and indicated that arm cranking in a standing position also had high cardiorespiratory responses at low external workloads as earlier reported, for example by Bevegård *et al.* (1966), Davies & Sargeant (1974), Vokac *et al.* (1975) and Nag (1984). Previous results on the systolic blood pressure during submaximal arm cranking have been obtained with different techniques and are somewhat controversial (e.g. Åstrand *et al.* 1965, Bevegård *et al.* 1966, Balady *et al.* 1986). The results of this study support the recent observations of Balady *et al.* (1986) when they reported slightly lower cuff arm systolic blood pressure for arm cranking than cycling at equal submaximal workloads up to 120 W.

Maximal workload during arm cranking was, on average, only 56% of that attained during maximal cycling, this outcome being associated with an 11% lower value for pulmonary ventilation and a 22% lower value for oxygen uptake. Tidal volume during maximal arm cranking remained low, restricting maximal pulmonary ventilation, which was only partly compensated for by a significantly higher maximal respiratory frequency, previously observed also by Davies & Sargeant (1974). According to the results of several investigations reviewed by Sawka (1986), the mean peak value of pulmonary ventilation has been 19% and that of oxygen uptake 27% lower during arm cranking in a sitting position than during cycling. The unexpectedly low systolic blood pressure measured immediately after the maximal arm cranking has not been reported earlier and remains unexplained. The comparison of the maximal results did not support well the hypothesis of this study.

In the present study, the arm venous blood lactate concentration at maximal exercise was significantly higher during arm cranking than during cycling. However, the results summarized by Sawka (1986) showed, on average, blood lactate values 12% lower during maximal arm cranking than during cycling. There are many possible reasons for the difference. The subjects' training status (Bergh *et al.* 1976), the place of blood sampling (Pimental *et al.* 1984) and the use of an intermittent test procedure may affect the peak blood lactate concentrations. The subjects in the present study were well motivated but physically untrained and not very familiar with cycling or arm cranking. In both tests the arm venous blood samples were taken from the same location – the superficial vein of the middle part of the right forearm – and immediately after each workload when the subjects rested. The arm venous blood samples during arm cranking represented blood directly draining the active muscles, but during cycling the blood sampling was distal to the most active muscles. The place of sampling is probably the main reason for both the higher blood lactate concentrations during arm cranking and quite low concentrations determined during cycling. Furthermore, the isometric work of arm muscles also observed in cycle exercise (Luhtanen *et al.* 1987) may have reduced peripheral blood flow and the mixing of venous blood.

The present results of gross mechanical efficiency for arm cranking (11–18%) and cycling (16–25%) at submaximal and maximal loads agree with the previous calculations (Sawka *et al.* 1983, Nag 1984, Powers *et al.* 1984, Luhtanen *et al.* 1987). Hence the internal workload in addition to considerable anaerobic work during arm cranking must be high. At the maximal load, the efficiency for arm cranking in the standing position was high, most probably reflecting the benefit induced by the increase the dynamic component of exercise due to the relatively high cranking (60 ± 11 r.p.m.) rate attained by the subjects during the last test minute (Sawka *et al.* 1983).

During submaximal arm cranking, as compared to cycling, increased internal work and the smaller active skeletal muscle mass involved during arm cranking have been thought to accelerate considerably the local accumulation of muscle metabolites because of the limited skeletal muscle blood flow (Åstrand *et al.* 1965, Secher *et al.* 1974, Reybrouck *et al.* 1975, Sawka *et al.* 1982). These substances increase minute ventilation and thus also carbon dioxide output (Åstrand 1960). Respiration may also be stimulated by the high sympathetic and proprioceptive drive associated with the arm-crank exercise (Bevegård *et al.* 1966, Vokac *et al.* 1975). The high heart rates occurring during submaximal arm cranking may also be due to a strong sympathetic stimulus, mainly caused by the extra isometric work of the upper body and the limited increase of stroke volume (Åstrand *et al.* 1965, Bevegård *et al.* 1966, Davies & Sargeant 1974, Clausen 1976). The additional isometric work required by arm cranking increases intramuscular and thorax pressures (Åstrand *et al.* 1965). Furthermore, during arm cranking perfusion pressure into the active muscle groups may be lower than during cycling (Eiken 1987). High thoracic pressure can impair venous return and preload of the heart, resulting in a decreased stroke volume during arm cranking (Bevegård *et al.* 1966, Davies & Sargeant 1974, Reybrouck *et al.* 1975).

During maximal arm cranking, the small active skeletal muscle mass, the restricted skeletal muscle blood flow and reduced cardiac output via insufficient stroke volume are the most probable reasons for the decreases in oxygen uptake, carbon dioxide output and pulmonary ventilation as well as in the attainable external workload, these being highly dependent on individual physical training status (Reybrouck *et al.* 1975, Bergh *et al.* 1976, Clausen 1976).

The recovery after maximal cycle and arm-crank exercise was followed for 16 min to consider differences in rest periods needed after arm and leg work. The differences in the ventilatory gas exchange were small, this being in agreement with the hypothesis of this study. The somewhat higher recovery values for some gas exchange parameters observed after cycling are probably due to the higher active skeletal muscle mass, inducing a greater external work and metabolic load. The arm venous blood lactate concentrations after arm cranking and cycling were equal in the latter half of the recovery period, and varied from 8.9 to 6.8 mmol l^{-1}, and about fivefold in comparison to the baseline values. The removal of lactate exceeded its release into circulation after the maximal exercise when the recovery period had progressed for 5–10 mins, as recently discussed, by, for example, Åstrand *et al.* (1986). The recovery of heart rate was significantly faster after maximal arm cranking than after cycling, possibly because of the difference in stroke volumes employed by arm cranking and cycling. However, after the 16-min recovery following arm cranking and cycling, heart rates were still substantially (about 30 beats min^{-1}) *higher than* the baseline values before the tests, and primarily attributed to the elevated body temperature. Probably this also affected the slow recovery of the respiratory frequency.

According to the present study, the power output of the normal male subjects during arm cranking while standing without torso restraints was markedly lower than during cycling at equal metabolic stress levels, and the recovery after arm cranking was not substantially faster than after cycling. In physically heavy work tasks, the use of upper body muscle groups should be avoided due to the resulting inefficiency and the rapid development of symptoms of local and general systemic overstrain and fatigue. When arm work is needed, the work stress and work–rest regimens should be adjusted according to the actual physiological strain, which can be indicated, for example, by simple measurements of heart rate (Vokac *et al.* 1975, Louhevaara *et al.* 1986). Furthermore, the high cardiorespiratory stress induced by arm work should be taken into account in clinical stress testing for diagnostic purposes, and when physiotherapy is planned for and guidelines for physical activity are given to disabled individuals and particularly to patients with heart or pulmonary diseases.

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LOCAL MUSCLE AND CIRCULATORY STRAIN IN LOAD LIFTING, CARRYING AND HOLDING TASKS

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ABSTRACT

In order to quantify local muscle and circulatory strain in manual materials handling, continuous parcel lifting, carrying and holding tasks were simulated in the laboratory. In the tasks the parcel weighed 4 kg, and the set maximum work time was 30 min. The subjects were six female (age 26–41 years) and six male (age 32–41 years) volunteers. The maximum work time and the local ratings of perceived exertion (RPE) showed that strain on the back became intolerable after holding for 7.6 ± 4.5 min. According to the EMG amplitude distribution probability function (related to muscle force, %MVC) in each task, strain for at least two of the studied muscles (brachioradialis, upper trapezius, erector spinae (L3 level), and semitendinosus) was too high at the static (over 5 %MVC) and/or median (over 14 %MVC) contraction levels. Heart rate, blood pressure and the overall RPE indicated that average circulatory strain in the tasks was low. Strain was significantly higher during lifting than holding, and the difference was accentuated if a subject used the leg lift technique. There were only few differences in local and circulatory strain due to sex. To prevent the development of excessive local muscle strain in these types of tasks the work pattern should be indivudally adjustable, and include sufficient rest pauses.

RELEVANCE TO INDUSTRY

The study showed advantages and limitations of some reliable and practical methods which can be used to quantify local and circulatory strain in actual work situations. The results can be utilized for work design and for the consideration of work-rest regimens in manual materials handling tasks.

KEYWORDS

Lifting, carrying, holding, muscle strain, circulatory strain.

INTRODUCTION

Lifting, carrying and holding of loads constitute ordinary components of manual materials handling such as in postal, nursing, warehouse and airport transport work (Peacock, 1980; Rutenfranz et al., 1980; Ljungberg et al., 1989).

In order to quantify local muscle and circulatory strain during typical load lifting, carrying and holding work, such tasks were simulated in the laboratory using recent field data on manual sorting of postal parcels (Louhevaara et al., 1989). That study showed that the mean (±SD) number

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of parcels manually sorted by means of lifting and carrying was 1173 ± 630 during the work shift of 391 ± 46 min. The parcels weighed, on average, 4 kg. The sorters walked 4.7 ± 2.3 km with and without the load.

During work a sorter's cardiorespiratory and musculoskeletal strain was evaluated to stay within acceptable limits. This was due to the intermittent work process associated with adequate rest pauses, and the fact that all sorters studied were healthy men. Furthermore, in the workplaces it was impossible to assess musculoskeletal strain by more sophisticated methods than the observation of work output and work postures (Karhu et al., 1977; Louhevaara et al., 1989), and subjective ratings (Borg, 1970; Stalhammar et al., 1989).

Musculoskeletal strain may be quantified by electromyography (EMG) or by biomechanical methods. Probably the recordings of EMG with surface electrodes provide the most accurate and feasible method to evaluate local muscle strain and fatigue in occupational work situations. The EMG amplitude indicates the amount of local muscle strain, and both amplitude increase and a change in the EMG spectrum towards lower frequencies have been used to determine local muscle fatigue (Chaffin, 1973; Jonsson, 1982; Westgaard, 1988).

It was assumed that in many materials handling tasks, comparable to sorting of postal parcels, work practices are continuous rather than intermittent, and are also performed by female workers. Therefore, the present study was conducted to investigate local muscle and circulatory strain of male and female subjects while performing continuous manual materials handling tasks.

TABLE 1
Physical characteristics of the subjects and their static force during maximal voluntary contraction (MVC) in the elbow flexion, shoulder raising, trunk extension and leg flexion tests

Subject	age (years)	Height (cm)	Weight (kg)	MVC (N)			
				Elbow	Shoulder	Trunk	Leg
Female ($n = 6$)							
Mean	31.2	166.7	57.5	117	460	648	216
SD	6.1	5.4	5.6	12	67	93	28
Male ($n = 6$)							
Mean	34.2	177.3	76.6	212	757	793	305
SD	6.7	6.0	15.3	50	217	167	73

The purpose of this laboratory study was (a) to measure and evaluate local muscle and circulatory strain in simulated continuous load lifting, carrying and holding tasks with average healthy female and male subjects, and (b) to consider the feasibility of the measurements and subjective ratings used in the simulations for the assessment of strain, particularly on the back, in the workplaces.

MATERIAL AND METHODS

Subjects

The subjects comprised six female (age 26–41 years) and six male (age 23–41 years) volunteers (Table 1). They were healthy but eight of them have had musculoskeletal disorders in the shoulder or back region during the last 12 months. The subjects' daily work mainly consisted of sedentary, office type of activities. The subjects were informed about the procedures and possible discomforts involved in the study. Each subject signed a statement of informed consent.

Procedures

The tasks simulated in the laboratory were load lifting, carrying and holding. They were performed on separate days. Lifting and carrying were implemented in random order, and followed by the load holding task. The load used in each task was a parcel (41 × 31 × 16 cm) weighing 4.0 kg and having a cardboard cover.

The preparations of the subject lasted for 1–1½ h at the beginning of each experiment. During the preparations force–EMG calibrations were performed, and the subject's anthropometric characteristics and musculoskeletal disorders were assessed with the Nordic questionnaire (Kuorinka et al., 1987). After the preparations the subject rested in a sitting position for five minutes. Thereafter, she/he was subjected to the standardized pre-tests. First, the subject stood without the load for one minute in a habitual upright position. Second, she/he stood with the load for one minute. The load was held with both hands, and the elbow angle was about 120°.

The load lifting task was simulated using a metallic frame with a set of shelves (Ergonomix, Australia). For the task the lower shelf was 40 cm and the upper shelf 140 cm above the floor level. The load was lifted up and down between the shelves six times min^{-1}, i.e., maximum time allowed for each lift was five seconds. The style of lifting was free, allowing the use of back or leg lift techniques.

The load carrying task was performed on a treadmill (Pro-Trak, Australia). The walking speed was 0.7 m s^{-1} (2.5 km h^{-1}) on the level. The load was held similarly as in the pre test while standing with the load.

The load holding task was carried out while the upper body was bent forward. The angle of the back was 30° from vertical. The load was held with both hands, arms being straight downwards. In the task the back angle was controlled and the movements of the hip region were prevented with the pelvic stabilization assembly of the Trunk Exercise System of Kin-Com (USA).

The lifting, carrying, and holding tasks were terminated if the subject exceeded the set maximum work time of 30 min or she/he felt excessive fatigue or other strain symptoms. After the tasks the 1-min tests, i.e., standing without the load and with the load, were repeated.

The experiments were carried out in the air-conditioned laboratory at an ambient temperature of 22–24°C, and a relative humidity of 50–70%. The subjects wore shorts and t-shirts.

Measurements and equipment

In the pre and post tests and in the tasks the Root Mean Square (RMS) EMG signal amplitude was recorded on the right side of the body for the brachioradialis, upper trapezius, erector spinae (L3 level), and semitendinosus muscles.

A pair of surface electrodes (1-cm silver chloride disk) were attached over the belly of each muscle group along the fiber. Before attaching, the skin were dry-shaved, rubbed until red with a sponge moistened with methylated spirit, and carefully scratched with a sand paper. The electrodes were filled with conductive gel. On the skin the distance between the electrodes in each pair was 2 cm. The electrode impedance was measured and a value less than 15 kΩ was taken as acceptable for each electrode pair. The ground lead was attached on the shoulder using an electrocardiogram (ECG) electrode.

The RMS EMG signal amplitude was obtained with the Physiometer PHY-400A device (Norway). The Physiometer was a battery operated microcomputer with a ten channel A/D converter. The data was stored and displayed by a computer (Evervision MN-200, U.S.A.). The sampling rate of the EMG inputs was 400 Hz. The RMS value of each EMG input was sampled at 10 Hz. The raw EMG signal of each channel could be monitored with an oscilloscope (Tektronix 2210, U.K.). Physiometer was also used for the recording of the back angles during extension and flexion of the upper body.

ECG was continuously monitored during the experiments with the Rigel Cardiac Monitor 302 (U.K.). Heart rate (HR) was manually recorded during the last 15-s of each minute.

The systolic and diastolic blood pressure was measured in a sitting position on the left arm with a conventional auscultatory technique. The blood pressure was determined at the end of the rest period and immediately after each task.

Overall rating of perceived exertion (RPE) and the local RPE for arms, back, and legs were graded using a scale from 6 to 20 (Borg, 1970; Hultman et al., 1984; Genaidy et al., 1989). The ratings were asked at the end of the rest period, and at the end of pre and post tests. In the lifting and carrying tasks the ratings were registered every second minute, and in the load holding task every minute.

Force–EMG calibration

Static force during maximal voluntary contraction (MVC) and the simultaneous EMG amplitude as well as baseline amplitudes were measured with the Kin-Com and Physiometer, respectively, for each muscle group studied at the beginning of the experiments. In the last experiment the calibration procedure was extended to include also submaximal force–EMG levels of about 50%, 35%, 20%, and 10% of MVC. Maximal force and EMG amplitude was determined during three contractions for each muscle group. Submaximal levels were measured twice. The time interval between the contractions was at least 30 s. The duration of maximal and submaximal contractions was 5–7 s.

The force–EMG calibration curves for the brachioradialis muscle were obtained during the static flexion of the elbow joint at the angle of 120°. During test contractions the subject was in a sitting position, and the lower arm was prone. It was stabilized with the cuff assembly of the Kin-Com. The force–EMG curve for the upper trapezius muscle was determined in a shoulder raising test. The subject was placed in an upright sitting position using two belts to avoid sideways movements of the upper body. The contractions were done against the paddle head connected to the force lever of the Kin-Com. The force–EMG relationship for the erector spinae muscle was measured during the extension of the upper body. The subject was in an upright standing position. The hip was kept immobile with the pelvic stabilization assembly of the Kin-Com. The force–EMG for the semitendinosus muscle was determined during the flexion of the lower leg at the knee angle of 160°. In the test the subject was lying prone. The leg was stabilized with the cuff assembly of the Kin-Com.

Data analyses and statistics

Simple regression equations were calculated to determine the relationship between muscle force and EMG amplitude. For each muscle the relationship was linear. For the brachioradialis muscle the correlation coefficients were 0.89–0.97 and for the upper trapezius muscle 0.86–0.99. The corresponding values for the erector spinae and semitendinosus muscles were 0.94–0.99 and 0.85–0.99, respectively.

The median values of EMG amplitude for the time periods of one to two minutes were used when comparing pre and post tests, and the first and last work minutes in the tasks.

In order to evaluate local muscle strain the EMG amplitude distribution probability function was established for each muscle and task in the manner described by Jonsson (1976). The amplitude distribution probability function describes the distribution of different levels of contraction. Each point on the distribution function curve indicates the probability that the level of contraction will be lower or equal to the force level in question. A probability of 0.1 ($P = 0.1$) is defined as the static (low) contraction level, a probability of 0.5 ($P = 0.5$) as the median contraction level, and a probability of 0.9 ($P = 0.9$) as the peak contraction level (Bjorksten and Jonsson, 1977; Hagberg, 1981; Jonsson, 1982).

Otherwise, the results were evaluated with the conventional descriptive statistics. The results were tested with a three-way analysis of variance with repeated measures. Post hoc comparisons were performed with the Duncan's multiple range test. The differences were considered statistically significant when $p < 0.05$.

RESULTS

Work time

While holding the load the maximum work time was 7.6 ± 4.5 min. All subjects completed load lifting but carrying was interrupted at the 23rd minute by two female subjects.

Local muscle strain

Local muscle strain based on the EMG amplitude (related to muscle force, %MVC) for the brachioradialis muscle was higher ($p < 0.001$) for the female than for the male subjects in the tasks. At the static contraction level strain was higher ($p < 0.001$) during carrying than during lifting and holding. There was a higher strain ($p < 0.001$) during lifting and carrying than during holding at the median contraction level. Strain for each task differed ($p < 0.001$) at the peak contraction level, being the greatest during lifting. During carrying strain at the static contraction level was 8 ± 4 %MVC for the female subjects. While lifting and carrying their strain at the median contraction level was 15 ± 4 and 14 ± 7 %MVC, respectively (Fig. 1).

Local strain for the upper trapezius muscle did not differ (NS) due to sex. At the static contraction level strain was higher ($p < 0.001$) during carrying (9 ± 8 %MVC) than during lifting and holding. At the median contraction level a higher strain ($p < 0.001$) was observed for lifting (19 ± 12 %MVC) than for holding. At the peak contraction level strain for the upper trapezius muscle was higher ($p < 0.001$) during lifting than during carrying and holding (Fig. 2).

In the tasks local strain for the erector spinae muscle was equal (NS) for the female and male subjects. At the static contraction level strain differed ($p < 0.001$) in each task, being the greatest during holding (16 ± 10 %MVC). At the median contraction level strain averaged from 19 to 25 %MVC (NS) in the tasks. At the peak contraction level strain for the erector spinae muscle was

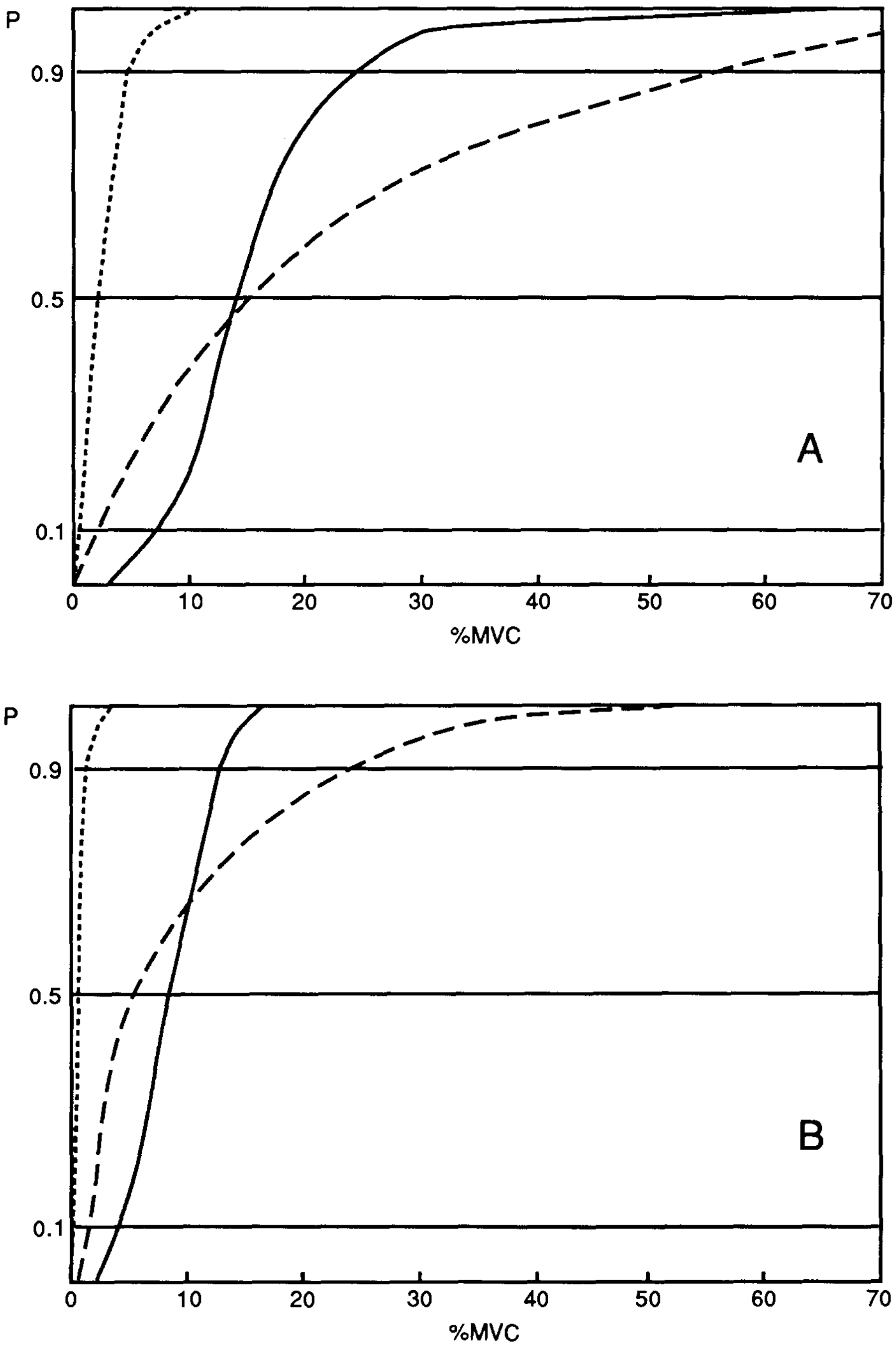

Fig. 1. The amplitude distribution probability function of the brachioradialis muscle (%MVC) during lifting (— — —), carrying (———), and holding (· · ·). The values given are the means for six female (A) and six male (B) subjects.

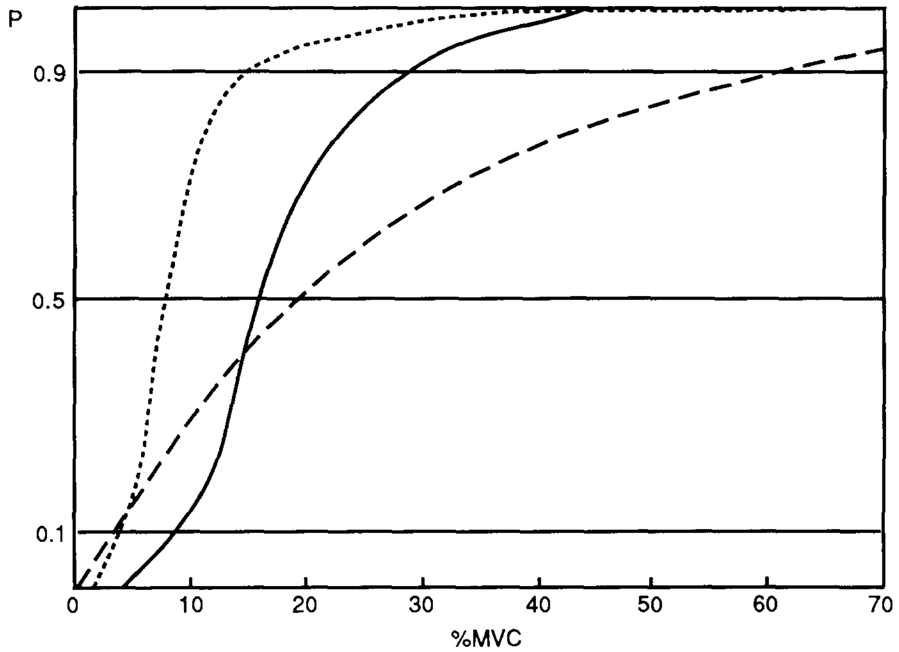

Fig. 2. The amplitude distribution probability function of the upper trapezius muscle (%MVC) during lifting (— — —), carrying (———), and holding (· · ·). The values given are the means for 12 subjects.

higher ($p < 0.001$) during lifting than during holding (Fig. 3).

Local strain for the semitendinosus muscle was higher ($p < 0.05$) for the male than for the female subjects in the tasks. At the static contraction level strain was higher ($p < 0.001$) during holding (males 9 ± 5 %MVC) than during lifting and carrying. There was observed similar strain (NS) at

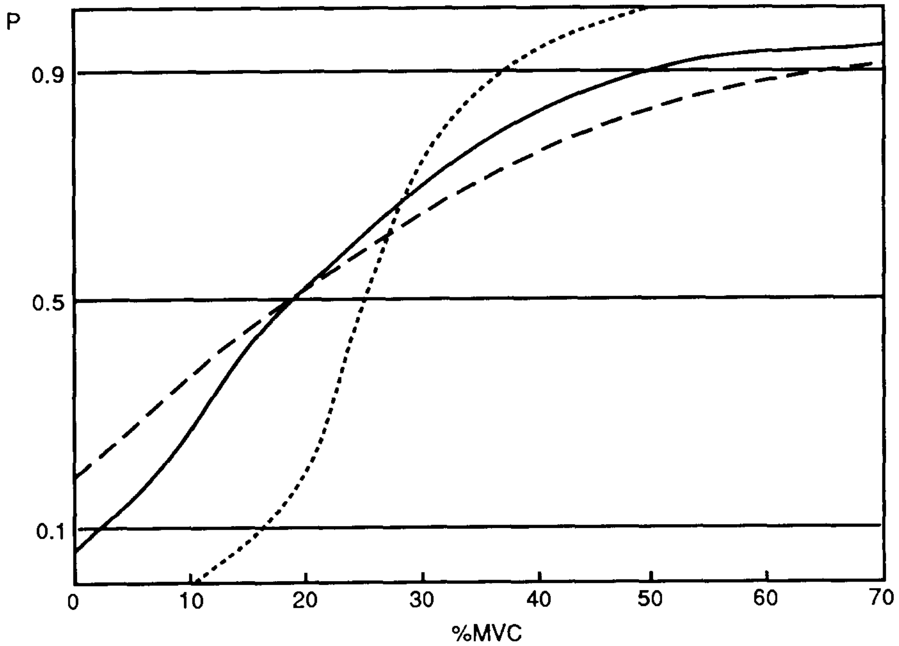

Fig. 3. The amplitude distribution probability function of the erector spinae muscle (%MVC) during lifting (— — —), carrying (———), and holding (· · ·). The values given are the means for 12 subjects.

the median contraction level in the tasks. At the peak contraction level strain for the semitendinosus muscle was higher ($p < 0.001$) during carrying than holding (Fig. 4).

Local muscle strain, i.e., the median EMG amplitude for the brachioradialis muscle increased ($p < 0.001$) during carrying but did not differ (NS) when the pre tests without and with the load

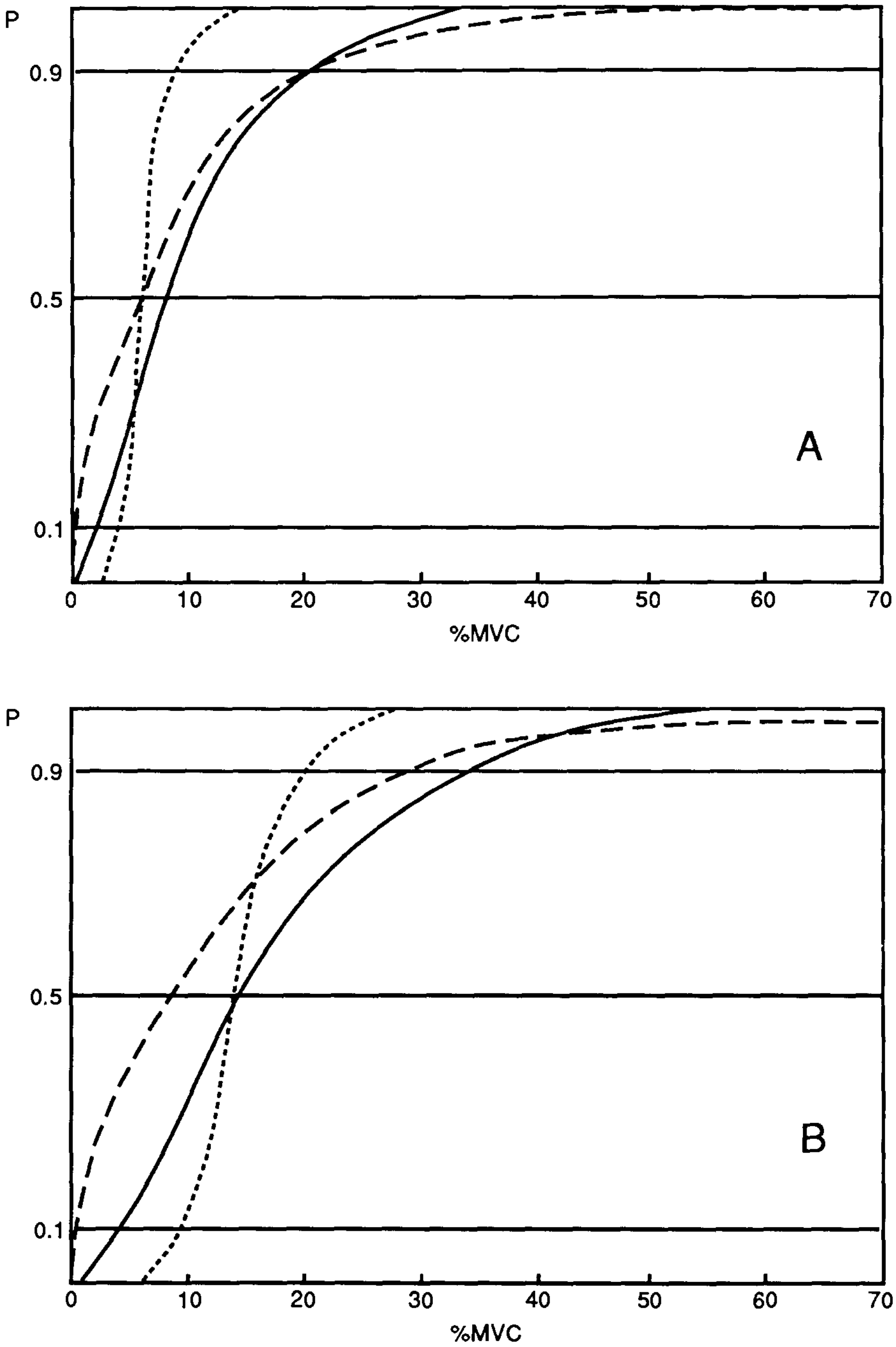

Fig. 4. The amplitude distribution probability function of the semitendinosus muscle (%MVC) during lifting (— — —), carrying (———), and holding (· · ·). The values given are the means for six female (A) and six male (B) subjects.

TABLE 2

Local ratings of perceived exertion for arms (RPEarms), for back (RPEback), and for legs (RPElegs) in the load lifting, carrying and holding tasks, for the female and male subjects, and in the different test and task phases

Group variable	RPEarms			RPEback			RPElegs		
	Mean	SD	p	Mean	SD	p	Mean	SD	p
Task			NS			< 0.001[b]			NS
Lifting	9	2		8	2	A[a]	8	3	
Carrying	8	3		8	2	A	8	2	
Holding	8	2		10	4	B	8	3	
Sex			NS			NS			NS
Female	8	3		8	3		8	2	
Male	8	2		9	3		8	3	
Phase			< 0.001			< 0.001			< 0.001
Pre w/o load	6	1	A[a]	6	1	A[a]	7	1	A[a]
Pre with load	8	2	BC	7	1	A	7	1	A
First task min	8	2	C	8	3	B	8	2	B
Last task min	10	4	D	12	5	C	10	4	C
Post w/o load	7	1	C	9	2	B	8	2	B
Post with load	9	2	B	8	2	B	8	2	B

[a] Means with the same letter are not significantly different.

[b] Nonuniform effect on the test and task phases.

were compared to the corresponding post tests. Local strain of the upper trapezius, erector spinae and semitendinosus muscles did not increase (NS) during the tasks, and no differences (NS) were found between the pre and post tests.

The RPE for back was higher ($p < 0.001$) during holding than during lifting and carrying. The RPE for arms, back and legs increased ($p < 0.001$) during the tasks. The local RPEs were higher ($p < 0.001$) in the post than pre tests with the exception of the RPE for arms with the load (NS). The local RPEs did not differ (NS) due to sex (Table 2).

The back angles during extension and flexion ranged from -8 to $9°$ during carrying when calculated from the "zero" posture while standing in an upright position. The corresponding values were -17 and $126°$ during lifting.

Circulatory strain

HR was 89 ± 16 beats min^{-1} for lifting and 79 ± 12 beats min^{-1} for holding ($p < 0.01$). At the end of lifting HRs of 123–127 beats min^{-1} were observed for the male subjects who used the leg lift technique. HR and the overall RPE increased ($p < 0.001$) during lifting, carrying and holding, and both responses were higher ($p < 0.001$) in the post than in the pre tests (Table 3).

Before and after the tasks the systolic and diastolic blood pressures were equal (NS). The values were lower ($p < 0.05$) for the female than for the male subjects (110 ± 8 vs. 118 ± 9 mmHg and 67 ± 8 vs. 76 ± 9 mmHg, respectively).

TABLE 3

Heart rate and the overall rating of perceived exertion (RPEoverall) in the load lifting, carrying and holding tasks, for the female and male subjects, and in the different test and task phases.

Group variable	Heart rate (beats min^{-1})			RPEoverall		
	Mean	SD	p	Mean	SD	p
Task			< 0.01			NS
Lifting	89	16	A[a]	8	2	
Carrying	84	9	AB	8	2	
Holding	79	12	B	8	3	
Sex			NS			NS
Female	86	13		8	3	
Male	83	14		7	2	
Phase			< 0.001			< 0.001
Pre w/o load	80	11	A[a]	6	1	A[a]
Pre with load	80	11	A	7	1	A
First task min	85	13	B	7	2	B
Last task min	93	15	C	10	3	C
Post w/o load	84	13	B	8	2	B
Post with load	84	13	B	8	2	B

[a] Means with the same letter are not significantly different.

DISCUSSION

Work time

In each continuous task the load was a 4-kg parcel, and the maximum work time was limited to 30 min. Both female and male subjects completed the lifting task with the frequency of 12 times min^{-1}. This result agrees with the study of Genaidy and Asfour (1989). Their young male subjects were able to maintain the lifting frequency-load combination (10 times min^{-1}; 5 kg) for 141 ± 93 min.

All subjects with the exception of two females completed load carrying. Recently Genaidy et al. (1989) reported that during intermittent carrying with a heavy load (20 kg over 4 m distance 8 times min^{-1}) the endurance time was 42 ± 19 min. Their subjects were young men being inexperienced in the tasks of manual materials handling.

Each subject interrupted the load holding task, and the mean maximum work time was 7.6 min. Similar results were reported by Kivi et al. (1988). They assessed the endurance times and physiological responses to the commonest poor static work tasks observed in the construction sites. In the tasks that required holding of a tool and supporting of a subject's own body weight, the maximum work times were 4.3–9.5 min.

Local muscle strain

In earlier EMG studies on occupational activities, local strain based on the amplitude and related to muscle force (%MVC) has frequently been obtained from the upper trapezius muscle (e.g., Jonsson, 1982; Christensen, 1986; Hagberg and Sundelin, 1986; De Groot, 1987). In the present load lifting, carrying and holding tasks strain for the upper trapezius muscle was, on average, 3–9 %MVC at the static contraction level, 8–19 %MVC at the median contraction level, and 15–62 %MVC at the peak contraction level. These results were similar to those of the above mentioned studies at the static and median contraction levels but somewhat higher at the peak contraction level.

During lifting, carrying and holding the range of strain for the brachioradialis, erector spinae and semitendinosus muscles was larger at each contraction level (static 0–16 %MVC, median 1–19 %MVC, and peak 1–66 %MVC) than that of the upper trapezius muscle. The previous vocational EMG results on these arm, back and leg muscles are scarce, and usually the EMG amplitude was not calibrated against muscle force (Kumar and Davis, 1983; Jonsson et al., 1983).

Based on the EMG amplitude distribution probability function and expressed as %MVC, the following upper strain limits for different levels of contraction has been recommended for a work period of one hour or more (up to an 8-h work shift): 2–5 %MVC for the static level, 10–14 %MVC for the median level, and 50–70 %MVC for the peak level (Bjorksten and Jonsson, 1977; Jonsson, 1982). In the lifting task the median limit of 14 %MVC was exceeded for the brachioradialis (female subjects), upper trapezius and erector spinae muscles, and local strain of the muscles could be classified as too high at this contraction level. During carrying, strain for the brachioradialis (female subjects) and upper trapezius muscles was too high at the static contraction level (over 5 %MVC) and too high for all investigated muscles at the median contraction level with the exception of the brachioradialis muscle for the male subjects and the semitendinosus muscle for the female subjects. During holding the upper strain limits at the static and median contraction level (5 and 14 %MVC, respectively) were exceeded for the erector spinae and semitendinosus (male subjects) muscles.

Strain for the brachioradialis muscle was about two fold higher at the end of carrying than that during the first minute of carrying both for the female and male subjects. This was probably a sign of local muscle fatigue caused by the continuous static supporting of the 4-kg parcel.

During lifting and carrying strain for the brachioradialis muscle for the female subjects was significantly higher than that for the male subjects at the different contraction levels. It is likely that this was affected by the 45% lower maximum force of the female subjects in their elbow flexors when compared to that of the male subjects (117 ± 12 vs. 212 ± 50 N). On the other hand, the differences in strain for the semitendinosus muscle between the female and male subjects were converse in each task. This might be due to a considerable difference in body weight (females 57.5 ± 5.6 kg vs. males 76.6 ± 15.3 kg) and the female subjects being leaner. Their body mass index was, on average, 20.6 kg m^{-2} compared with 24.4 kg m^{-2} for the male subjects. These factors may have overwhelmed the advantage given by the stronger leg muscles of the male subjects. Their maximum static force in the flexion of the lower leg was 305 ± 73 N compared with 216 ± 28 N for the female subjects.

After the tasks the restitution of the EMG amplitude was rapid and no significant differences were found in any of the pre and post tests. The recovery of the EMG spectrum has also been observed to be rapid after a fatiguing muscle exercise (Kuorinka, 1988). Thus the physiological recovery of muscle seems to be substantially slower than the restitution of the EMG signal.

In the lifting task the local RPE values were low and the subjects did not complain of any specific strain symptoms at the end of lifting. During carrying exertion for arms was constantly graded as "hard" at the end of the task. Two female subjects interrupted carrying due to excessive local pain symptoms on the elbow or shoulder region. During holding the RPE for back were graded by all subjects from "hard" to "very very hard". Usually after holding for a few minutes the local strain symptoms on the lower or upper back became painful and soon intolerable. Kivi et al. (1988) also reported that work time in poor static work tasks was limited by very local pain symptoms.

The local RPE values during lifting, carrying and holding increased significantly over the period of work, and were significantly higher in the post than in the pre tests. The local RPEs showed no differences in strain between the female and male subjects. Thus, the local RPEs did not follow EMG patterns of strain.

Circulatory strain

The mean HR, blood pressure and overall RPE levels during and after lifting, carrying and holding were low. The individual variation of HR was very large particularly for the male subjects. At the end of lifting it was 70–127 beats min^{-1} 71–102 beats min^{-1} for carrying and 68–105 beats min^{-1} for holding. The same subject had the lowest HR during lifting and carrying but the highest HR during holding. He was very well motivated and probably both static muscle work and local pain symptoms stimulated his HR during load holding.

Three male subjects used a very orthodox leg lift techique, and their HRs were the highest at the end of lifting. Recently Genaidy and Asfour (1989) reported similarly that the leg lift technique is more stressful physiologically than the free-style and back lift techniques.

The changes in the blood pressure were minor due to the present tasks, and the observed differences due to sex were probably affected by the differences in body weight and fat. Kivi et al. (1988) found an increase of 26 ± 12 mmHg in the systolic blood pressure when their subjects worked in poor static tasks for as long as possible.

Circulatory strain for the female and male subjects was about the same. The standardized external work loads of the tasks should have been relatively higher for the female subjects due to their lower muscle strength and aerobic capacity. These disadvantages were probably compensated by smaller amounts of internal work. Each task required moving and/or supporting a subject's own body mass which was substantially lower for the female subjects.

Feasibility of the methods in the workplace

In the simulated work situations the Physiometer proved to be very usable for the assessments of EMG amplitude and back angles. The recording of one subject's back angles during lifting was not successful because her lift technique included very rapid and jerky movements of the upper body. In actual work tasks the EMG recordings with the Physiometer are feasible, particularly, if the cord connecting the Physiometer to a computer can be eliminated by a portable data logger or telemetric system. However, the site preparation for the electrodes and force–EMG calibration are very exacting and time consuming procedures. The measurement of muscle force at worksites requires simple tests with portable equipment. Usually also both skin preparation and force measurements cause some discomfort to the subject, and require the full co-operation of the subject.

HR and blood pressure are easy to measure in the workplace. However, the relevance of blood pressure determined with a conventional auscultatory technique is questionable because it cannot be done during work.

In the current simulations both overall and local RPEs gave valuable information. Some language problems may exist with immigrant subjects.

From the current methods the EMG, particularly when related to muscle force, was time consuming and labour-intensive. This type of EMG measurements are not feasible for comprehensive field studies or for wide epidemiological studies. The development of reliable and simple job analysis methods to quantify local muscle strain is very necessary as previously stated by Punnett and Keyserling (1987).

CONCLUSIONS

The following conclusions can be reached:

1. Local muscle strain while holding a 4-kg parcel in a bent forward posture became intolerable after a work period of a few minutes. In the continuous load lifting, carrying and holding tasks strain for at least two of the studied muscles (brachioradialis, upper trapezius, erector spinae (L3 level), and semidendinosus) was too high at the static (over 5%MVC) and/or median (over 14%MVC) contraction level.
2. Average circulatory strain in the load lifting, carrying and holding tasks was low and about the same for the female and male subjects. Strain was significantly higher during lifting than holding, and the difference was accentuated if a subject used the leg lift technique.
3. To prevent the development of excessive local strain in these types of manual materials handling tasks the work pattern should be individually adjustable, and include sufficient rest pauses.
4. The EMG measurements were time consuming and labour-intensive. The development of reliable and simple job analysis methods to quantify local muscle strain is very necessary for comprehensive field studies.

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ORIGINAL ARTICLE

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Maximal physical work performance with European standard based fire-protective clothing system and equipment in relation to individual characteristics

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Abstract Every fire fighter needs to wear fire-protective clothing and a self-contained breathing apparatus (SCBA) several times a year while carrying out various fire-fighting and rescue operations in hazardous work environments. The aim of the present study was to quantify the effects of a multilayer turnout suit designed to fulfil European standard EN 469 used over standardized (Nordic) clothing and with SCBA (total mass 25.9 kg) on maximal physical work performance, and to evaluate the relationship between individual characteristics and power output with the fire-protective clothing system and SCBA. The subjects were 12 healthy firemen aged 26–46 years. The range of their body mass, body fat and maximal oxygen consumption was 69–101 kg, 10–20% and 2.70–5.86 $\mathrm{l \cdot min^{-1}}$, respectively. The maximal tests without (control) and with the fire-protective clothing system and SCBA were carried out on a treadmill in a thermoneutral environment. When compared to the control test, the decrease in the maximal power output in terms of maximal working time and walking speed averaged 25% ($P < 0.001$) varying from 18% to 34% with the fire-protective clothing system and SCBA. At maximum, no significant differences were found in pulmonary ventilation, absolute oxygen consumption, the respiratory exchange ratio, heart rate, systolic blood pressure, the rate-pressure product, mechanical efficiency, and the rating of perceived exertion between the tests with and without the fire-protective clothing system and SCBA. The reduction of the power output was related to the extra mass of the fire protective clothing and SCBA. In this study, robust build and parameters associated with good anaerobic capacity were the most powerful individual characteristics contributing to the smallest drop in the power output with the fire-protective clothing system and SCBA. All possible means to decrease the mass of both the fire-protective clothing system and SCBA for maintaining the sufficient power output in physically demanding fire-fighting and rescue tasks need to be considered.

Key words Work physiology · Fire fighting · Personal protective equipment · Cardiorespiratory work capacity · Anthropometrics · Power output

Introduction

In the recent study of Lusa et al. (1994) it was reported that every fire fighter in the age range of 22–54 years is required to wear fire-protective clothing and a self-contained breathing apparatus (SCBA) several times a year while carrying out various fire-fighting and rescue operations such as smoke-diving (entry into a smoke-filled room), clearing debris and roof work in hazardous work environments.

In a thermoneutral environment, it has been found that the use of SCBA with or without fire-protective clothing increased cardiorespiratory and thermal strain significantly at submaximal work levels (Louhevaara et al. 1985; Smolander et al. 1991; Ilmarinen and Mäkinen 1992; Mäkinen et al. 1995), and decreased maximal work performance, on average, by 20% in terms of the working time to exhaustion and the maximal work pace (Raven et al; 1977; Manning and Griggs 1983). In the study of Louhevaara et al. (1985) decreased maximal physical work performance with the SCBA has been shown to be associated with a deviant

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breathing pattern, incomplete respiratory gas exchange, and reduced absolute maximal oxygen consumption. During short-term strenuous work, thermal strain produced internally by locomotive and breathing muscles did not greatly hamper physical work performance. It mainly seemed to depend on a fire fighter's individual capacity to carry the extra mass of fire protective clothing and SCBA, which weighed 24 kg in the study of Lusa et al. (1993). However, under long-term heat exposure, maximal physical work performance has been reported to be impaired by thick and heavy clothing materials with high insulating properties, with a vapour barrier when the clothing limited adequate body cooling through evaporation (White and Hodus 1987; Ilmarinen et al. 1993, 1994; Mäkinen et al. 1995). Furthermore, it has been shown that a poor design and fit of fire-protective clothing or the shoulder harness of SCBA may decrease the mechanical efficiency of moving and breathing as well as cause discomfort during both submaximal and maximal work (Louhevaara et al. 1985).

A multilayer turnout suit designed to fulfil the European standard (EN 469) has been reported to provide good protection against fire, thermal radiation and chemicals, but is heavy (mass up to 3 kg) and usually has a moisture barrier, which makes the suit tight and prevents body cooling (Nunneley 1989). No quantitative data are available about the possible adverse effects of this type of suit used over standardized (Nordic) clothing and with SCBA on physical performance and physiological responses during maximal dynamic work.

Consequently, one aim of the present study was to quantify the effects of the European standard based turnout suit worn over standardized (Nordic) clothing and with SCBA on power output and on cardiorespiratory responses during maximal uphill walking on a treadmill in a thermoneutral environment. The other aim was to evaluate individual characteristics as predictors for the differences in maximal power output due to the use of the fire-protective clothing system and SCBA.

Methods

Subjects

Nine professional and experienced fire fighters from Germany and three from Finland aged from 26 to 46 years volunteered for the study (Table 1).They were physically active and most of them performed endurance type of training at least twice a week. The study was conducted according to the principles of the Declaration of Helsinki (1976), which lays down the ethics of human experimentation, and with the approval of the Ethics Committee of the Institut für Arbeitsphysiologie at the Universität Dortmund. Each subject signed an informed consent before the tests, which the Ethics Committee considered suitable for healthy volunteers, on condition that a maximal test with shorts and sneakers should always be done before the maximal test with the fire-protective clothing system and SCBA.

Table 1 The subjects' age, height, body mass and fat, and maximal oxygen consumption ($\dot{V}O_{2max}$) on the treadmill

	$n = 12$ Mean	Range
Age (years)	32	26–46
Height (cm)	180	174–187
Body mass (kg)	85.6	69.1–101.0
Body fat[a] (%)	14	10–20
$\dot{V}O_{2max}$[b]		
($l \cdot min^{-1}$)	4.02	2.70–5.86
($ml \cdot min^{-1} \cdot kg^{-1}$)	46.9	33.4–73.3

[a] According to Durnin and Rahaman (1967)

[b] Assessed wearing shorts and sneakers

Procedure

Before the maximal tests a clinical health examination was performed on the subjects by a physician and supplemented with etiological screening and recording of blood pressure and an electrocardiogram (ECG) at rest. The maximal exercise tests were carried out without (control test) and with the fire-protective clothing system and SCBA. There was at least 1 day of rest between the tests. The subjects performed the maximal tests, continuously medically supervised by two physicians, by walking on an electronically driven calibrated treadmill. After a 5-min warm-up period on the level, the gradient of the treadmill was increased every 2nd min by 2° up to a gradient of 10°. The walking speed was 1.3 $m \cdot s^{-1}$ (4.5 $km \cdot h^{-1}$). Thereafter, the gradient of 10° was maintained and the walking speed was increased every 2nd min by 0.3 $m \cdot s^{-1}$ (0.5 $km \cdot h^{-1}$) to the point where the subjects were not able or willing to continue the test. During the subsequent recovery period, the subjects walked slowly on the level for 6 min. All tests were conducted in a climatic chamber under carefully controlled environmental conditions. The air temperature was maintained at 18 °C with a constant relative humidity of 50%, and a constant air velocity of 0.3 $m \cdot s^{-1}$.

The fire-protective clothing and equipment

The two-piece multilayer turnout suit designed to fulfil the European standard (EN 469; 1994) was brand-new. The suit was worn over standardized clothing – typical in the Nordic countries – consisting of cotton underwear with long sleeves and legs, a polyester fleece sweat shirt and trousers. In addition, the subjects wore leather safety boots without a liner, leather gloves, a woollen underhood, helmet, and a tool belt. They carried SCBA of Dräger with one air container on the back. The full-face mask of SCBA was not worn but carried along. The total mass of the fire-protective clothing system and SCBA averaged 25.9 kg, and had a thermal insulation (I_{cl}) of 1.85 clo measured with a thermal mannequin of the Helsinki University of Technology (Laboratory of HVAK). The specifications for the fire-protective clothing system and SCBA are given in Table 2.

Physiological measurements

For the determination of maximal pulmonary ventilation, oxygen consumption ($\dot{V}O_2$), the production of carbon dioxide and the respiratory exchange ratio two consecutive expiratory air samples of at least 15 s were collected into 150-l Douglas bags before the interruption of each test. During the collection of the samples, the subjects used a nose clip and a mouth piece attached to a low-resistance single-J breathing-valve. Immediately after the tests, the

Table 2 Specifications of the fire-protective clothing system (two-piece multilayer turnout suit, Nordic type of middle and under clothing), safety equipment and self-contained breathing apparatus (*SCBA*)

Fire-protective clothing system and the SCBA[a]	Material	Mass (g)
Turnout suit:		
– Jacket		1 600
– Trousers		1 146
Outer layer	Aramid (Nomex III)	
Middle layer	Aramid wadding	
Lining	Aramid fabric	
Paddings	In shoulders and knees aramid wadding	
Rib fabric	Knitted aramid	
Hood	Fasten	
Sweat shirt and trousers	Flame retartant polyester fleece	787 732
Gym pants and underwear with long sleeves and long legs	Cotton	41 328
Socks	Woollen	116
Safety boots	Leather, without liner	2 090
Gloves	Leather with moisture barrier and with insulation and inner lining	334
Underhood	Woollen	94
Helmet and tool belt	Metal and leather	3 244
SCBA	Dräger with a steel air container	15 429
Total mass		25 941

[a] Thermal insulation of 1.85 clo measured with the thermal mannequin without the helmet which was unsuitable for the head of the mannequin

volume of the samples was measured, and analysed for oxygen and carbon dioxide, with a Servomex O_2 and an UNOR CO_2 analyser respectively calibrated with a Wösthoff gasmixpump before each test session against known gas mixtures. A 7-lead ECG and heart rate (HR) were continuously monitored and printed by a Hellige-ECG recorder during the last minute of every exercise level of the test. At the end of each exercise level, blood pressure was measured with the conventional auscultation method of Riva-Rocci, and the rating of perceived exertion (RPE) on the cardiorespiratory system was assessed using a scale from 6 to 20 (Borg 1970).

Statistics

The significance of the differences between the tests without (control) and with the fire-protective clothing system and SCBA were tested using Student's *t*-test for paired observations. Correlations were calculated using Pearson's correlation test. The individual characteristics as the predictors for the differences in the maximal power output with the fire-protective clothing system and SCBA were evaluated with stepwise linear multiple regression analyses. The differences were considered significant when $P < 0.05$.

Results

Maximal power output

The mean mass of the fire-protective clothing system and SCBA (25.9 kg) was 30% of the average body mass of the subjects. When compared to the control test, the wearing of the fire-protective clothing system and SCBA decreased the maximal exercising time to exhaustion, on average, by 27% ($P < 0.001$), and the maximal walking speed at a gradient of 10° by 22% ($P < 0.001$). Individually, the decreases ranged from 12% to 34% for the maximal working time and walking speed (Table 3), which correlated significantly ($r = 0.70$, $P < 0.05$).

Maximal physiological responses

At maximum, there were no significant differences in pulmonary ventilation, absolute $\dot{V}O_2$, the respiratory exchange ratio, HR, systolic blood pressure, the rate-pressure product, mechanical efficiency of walking, and RPE between the tests with and without the fire- protective clothing system and SCBA. The range of individual differences varied from + 45% to − 28% within the maximal physiological responses of the subjects (Table 3).

Predictors for the maximal power output with the fire-protective clothing system and the SCBA

The most powerful individual predictors for the difference in the maximal walking speed with and without the fire-protective clothing system and SCBA were the amount of body fat and the height as well as the highest RPE and respiratory exchange ratio obtained in the control test. These variables covered 92% of the total variation for the difference ($P < 0.001$; Table 4). Similar analyses were done for the difference in the maximal working time to exhaustion; 78% of the total variation was predicted by the amount of body fat and height as

Table 3 Mass of body and protective equipment in the maximal treadmill tests with and without the fire-protective clothing system and the self-contained breathend apparatus, and the results of maximal work performance (power output) and physiological responses. The values given are means (ranges) for 12 subjects

	Without	With	Difference (%)
Mass of body and equipment (kg)	85.6 (69.1–101.0)	111.2 (97.0–126.0)	30*** (25–40)
Work performance			
Working time (s)	1263 (1140–1425)	922 805–1025)	– 27*** (– 12– – 34)
Walking speed at 10° ($m \cdot s^{-1}$)	1.8 (1.7–1.9)	1.4 (1.3–1.5)	– 22** (– 18– – 28)
Physiological responses			
Pulmonary ventilation ($l \cdot min^{-1}$)	109.3 (67.1–163.6)	104.3 (63.5–172.0)	– 5 (16– – 24)
Oxygen consumption ($l \cdot min^{-1}$)	4.02 (2.70–5.86)	3.80 (2.98–4.56)	– 4 (10– – 28)
Oxygen consumption ($ml \cdot min^{-1} \cdot kg^{-1}$)	46.9 (33.4–73.3)	34.1 28.1–39.8)	– 26*** (– 16– – 46)
Respiratory exchange ratio	0.98 (0.89–1.06)	0.98 (0.86–1.07)	0 (9– – 12)
Heart rate ($beats \cdot min^{-1}$)	186 (168–194)	184 (168–197)	– 1 (2– – 4)
Systolic blood pressure (mmHg)	216 (180–230)	223 (200–240)	+ 4 (17– – 9)
Rate-pressure product	404 (337–446)	414 (374–473)	+ 3 (12– – 9)
Mechanical efficiency (%)	19 (13–25)	20 (17–23)	+ 6 (45– – 11)
Rating of perceived exertion	19 (18–20)	19 (18–20)	0 (6– – 10)

***$P < 0.001$

well as the maximal exercising time and mechanical efficiency in the control test. The predictive power of the equation was not statistically significant.

Submaximal responses

At submaximal exercise levels up to a treadmill gradient of 10° and speed of 1.3 $m \cdot s^{-1}$ (4.5 $km \cdot h^{-1}$), HR, systolic blood pressure and RPE were significantly ($P < 0.05$–0.001) higher with than without the fire-protective clothing system and SCBA (Fig. 1).

Table 4 The most powerful predictors for the difference in the maximal walking speed obtained in the treadmill tests with and without the fire-protective clothing system and the self contained breathing apparatus (*SCBA*) at a 10° gradient. Correlation coefficient = *r*. Predicted proportion (%) of total variation = r^2

Predictors for maximal speed	r	r^2
Body fat	Body fat = 0.55	0.30
Body fat + height	Height = 0.22	0.71**
Body fat + heati + $\mathrm{RPE}_{\mathrm{wo}}$,	$\mathrm{RPE}_{\mathrm{wo}}$ = – 0.00	0.85***
Body fat + height + $\mathrm{RPE}_{\mathrm{wo}}$ + R_{wo}	R_{wo} = 0.18	0.92***

**$P < 0.01$, ***$P < 0.001$

RPE_{wo} Rating of perceived exertion at the end of the test without the fire-protective clothing system and SCBA,

R_{wo} Respiratory exchange ratio at the end of the test without the fire-protective clothing system and the SCBA

Discussion

Subjects

The subjects encompassed 12 firemen. They were healthy, physically active as well as experienced and well-motivated users of the personal protective clothing and equipment, and thus represented a highly selected occupational group of men in the age range of 22–46 years. There was nevertheless a wide variation in their maximal cardiorespiratory capacity. The lowest observed maximal $\dot{V}O_2$ did not exceed the minimal level (3.0 $l \cdot min^{-1}$ or 36 $ml \cdot min^{-1} \cdot kg^{-1}$) recommended for a professional fire fighter exposed to field operations in which the wearing of fire- or gas-protective clothing and SCBA is necessary (e.g. Davis et al. 1982; Louhevaara and Lusa 1993).

Some of the German subjects considered that the fire-protective clothing system used was too heavy, probably because they were not familiar with this type of under and middle clothing designed to be used in conjunction with the multilayer turnout suit. Currently the present fire-protective clothing system is common only in the Nordic countries. In Germany, a fire fighter's habitual two-piece turnout suit is lighter and usually worn over the uniform used for station service.

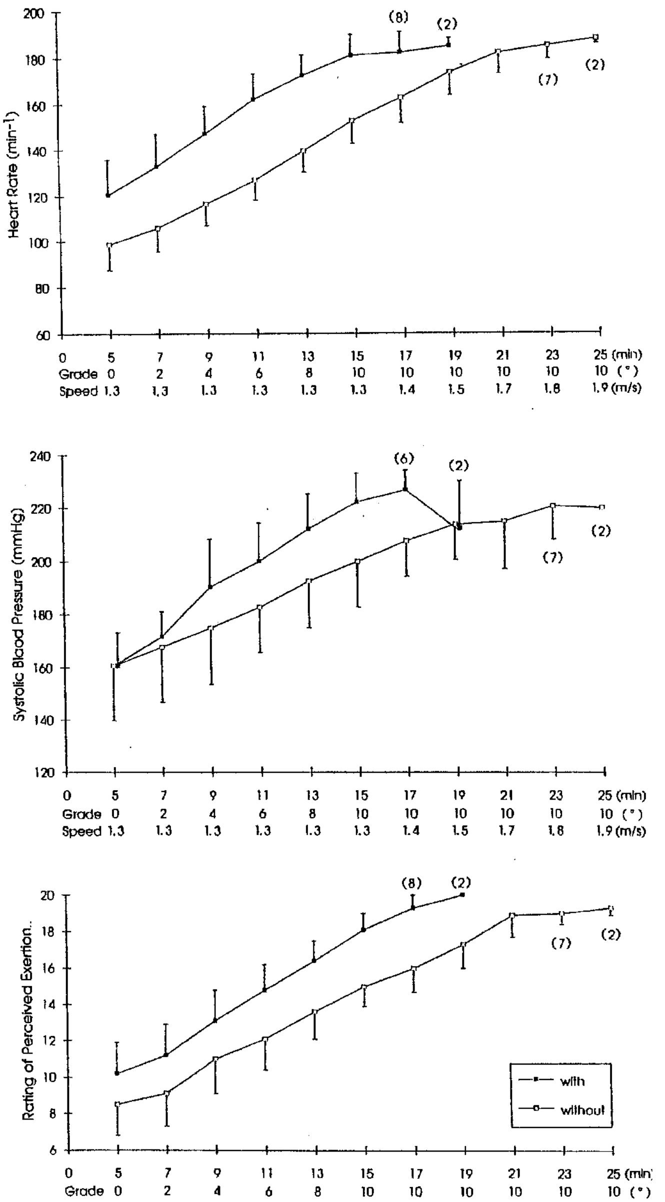

Fig. 1. Heart rate, systolic blood pressure, and the rating of perceived exertion at submaximal and maximal work levels on the treadmill without (control test) and with the fire-protective clothing system and the self contained breathing apparatus. The values are means and SD. The number of the subjects at different exercise intensities is given *in parentheses* when it is less than 12 (heart rate and the rating of perceived exertion) or 9 (systolic blood pressure)

Maximal power output

In physically demanding fire-fighting and rescue tasks with the personal protective clothing and equipment, the most crucial question besides the health and safety of the operative fire fighters and possible victims, is the maintenance of sufficient power output (external physical work performance). In the light of two performance outcomes (maximal walking speed and working time) the power output decreased, on average, by 25% when using the fire-protective clothing system and SCBA. In this study, the decrease in maximal power output was somewhat more than that of 20% observed earlier by Manning and Griggs (1983) and Raven et al. (1977). In the latter study the test unit a Scott Air Pack respirator used without protective clothing) had a lighter mass of 15.8 kg.

The mean mass of the protective clothing system and SCBA was 25.9 kg averaging 30% of the mean body mass of the subjects. In this study the average proportional drop in the maximal power output of 25% (range 12%–34%) was about the same as the extra absolute mass of the personal protective clothing and equipment. So there was a strong negative relationship between the extra mass carried and the power output in the present type of maximal dynamic work on the treadmill. The results of this study agreed with the previous assessments of the negative effects of the extra mass carried during submaximal and maximal physical work performance (Borghols et al. 1978; Louhevaara et al. 1986a; White and Hodus 1987). It should be noted, however, that actual fire-fighting and rescue tasks also include isometric muscle work, in which the additional mass that is to be carried is not so deleterious in respect of the efficiency of work.

In this study, the full-face mask of SCBA was not worn for practical reasons. It is possible that the mask may hamper pulmonary ventilation at high air flows resulting from near maximal or maximal exercise intensities. This additional negative effect on work performance may be quite minor because the pressure-demand type of mask of the SCBA has additional expiratory breathing resistances which are not significantly greater than that of the breathing valves used in the exercise tests (Louhevaara et al. 1986b). For three subjects the measurements of blood pressure were unsuccessful due to technical reasons.

The present subjects were, on average, able to maintain their maximal pulmonary ventilation, absolute $\dot{V}O_2$, and the respiratory exchange ratio at about the same levels with as without the fire-protective clothing system and SCBA. We suppose that this was essential for the maintenance of maximal power output when cardiac functions (HR and systolic blood pressure) reached near maximal levels much faster wearing the fire-protective clothing and SCBA than in the control tests.

Individual characteristics

With the present fairly small and selected group of subjects, the most powerful predictors for the maintenance of the maximal power output with the fire-protective clothing system and SCBA were associated with the robust build of the subjects (body fat and height) as well as mechanical efficiency and respiratory exchange ratio attained in the control test. In this context, the latter two parameters described anaerobic capacity. Thus, the tall but rather lean subjects with a good anaerobic capacity seemed to have the best individual characteristics for the efficient use of heavy personal protective clothing and equipment in strenuous dynamic physical work. The situation may be different if a tall fire fighter is exposed to long-term or repetitive physical efforts particularly in high ambient and radiant heat which may be associated with impaired fluid balance.

With heavy personal protective clothing and equipment, the decrease of external power output is probably more marked in small subjects having a low amount of active muscle mass or, on the other hand, with subjects having a large amount of both active muscle mass and body fat. It may be supposed that excessive body fat limits the efficiency of dynamic work needed for the movements of one's own body mass (e.g. walking and climbing) about as much as the extra mass of the protective clothing and equipment. Therefore, there is a proposal of 20% for the upper limit of the fire fighter's body fat in some European countries (Saila Lindqvist-Virkamäki, personal communication).

The age of the subjects varied from 22 to 46 years. Within this range, age had no adverse effect on maximal physical work performance with the fire-protective clothing system and SCBA. The correlations between age and the decreases in maximal working time and walking speed were 0.24 and 0.32, respectively. On the other hand, the number of subjects was limited, and the plat of the results revealed that the positive correlations were almost entirely due to the oldest subject whose decrease in maximal working time and walking speed was the second smallest (22%) and the smallest (18%), respectively, with the fire-protective clothing system and SCBA. The oldest subject weighed 101 kg (height 184 cm and body fat 14%) and had a maximal $\dot{V}O_2$ of $4.41\ \mathrm{l \cdot min^{-1}}$. When considering generally the cardiorespiratory and thermal demands of the fire-fighting and rescue work, the mean anthropometric characteristics of the present subjects (height 180 cm, body mass 86 kg, and body fat 14%) may be close to optimal for fire-fighters.

Conclusions

The present results justified the following conclusions:

1. The European standard (EN 469) based multilayer turnout suit used in conjunction with Nordic type of clothing and with SCBA (mass 25.9 kg) reduced power output, on average, by 25% in maximal dynamic muscle work in a thermoneutral environment.
2. The drop in maximal power output was related to the extra mass of the fire-protective clothing system and SCBA.
3. Robust build and good anaerobic capacity were the most important individual characteristics predicting efficient work performance, i.e. the smallest drop in maximal power output with the fire-protective clothing system and SCBA in short-term strenuous dynamic work.
4. The total mass of the present type of fire-protective clothing system used with SCBA seems to be too high for an average fit fire fighter in dynamic tasks requiring the efficient moving of his own body mass.
5. All possible means should be considered to reduce the mass of both the fire protective clothing system and SCBA.

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Physical work and strain involved in manual sorting of postal parcels

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Keywords: Manual material handling; Dynamic work; Static work; Work output; Muscle strength; Muscle endurance

A field study was conducted to assess cardiorespiratory and musculoskeletal stress and strain and work output during manual sorting of postal parcels, and to detect the effects of parcel sorting on the maximal muscle strength and endurance. The volunteer subjects comprised 32 healthy male sorters with mean (± s.d.) age of 34 ± 7 years at five different sorting sites. Each subject was studied during one evening work shift. During the shift of 391 ± 46 min the subjects manually sorted 1173 ± 630 parcels and walked 4·7 ± 2·3 km with and without the load. While sorting, heart rate was 101 ± 18 beats min^{-1}. In the heaviest tasks the oxygen consumption was 1·2 ± 0·4 l min^{-1}, and no elevated blood lactate concentrations were found. Work postures in which the back was bent forward averaged 24% of the time for sorting. The overall cardiorespiratory rating and local ratings of perceived exertion for arms, back, and legs did not exceed the 'somewhat strong' level during the work shift. The maximal static strength both for the right and left hand-grip muscles was, on average, 3% lower ($p < 0·05$) after the work shift than before the shift. No significant differences were found in the static or dynamic endurance times for the hand-grip muscles when the results obtained after the work shift were compared to the baseline values. At sorting centres the stress and strain on the cardiorespiratory and musculoskeletal system was evaluated to remain within acceptable limits for healthy male sorters.

1. Introduction

In a previous study of physiological responses to simulated manual sorting of postal parcels (Louhevaara *et al.* 1988), it was shown that this type of manual material handling involves a considerable amount of dynamic muscle work. The cardiorespiratory responses to parcel sorting and dynamic cycle exercise were almost equal, but substantially differed from the responses to the more static arm crank exercise with a limited amount of active skeletal muscle mass (Sawka 1986, Louhevaara *et al.* 1990 b).

During simulated parcel sorting the mean (± s.d.) oxygen consumption ($\dot{V}O_2$) was 1·36 ± 0·38 l min^{-1} and heart rate (HR) 105 ± 22 beats min^{-1} at an individual habitual work output of 8·6 ± 2·4 parcels min^{-1}. The weight of the parcels ranged from 0·5 to 17·5 kg. Parcel sorting was predominantly aerobic muscle work (blood lactate concentration < 4 mmol l^{-1}) up to the work output of about 20 parcels min^{-1}, which approximately corresponded to 70% of the maximal $\dot{V}O_2$ for cycle exercise. The $\dot{V}O_2$ results obtained from the simulated sorting tasks agreed well with the earlier study of Peacock (1980) who observed $\dot{V}O_2$ of 1·2 l min^{-1} when loading and unloading parcel containers with a mean work output of 4 parcels min^{-1}.

During the simulated parcel sorting it was impossible to establish the cardiorespiratory strain and work output levels during the actual manual sorting of postal parcels. Furthermore, the musculoskeletal aspects of parcel sorting work were not considered in the sorting simulations of this stage (see Louhevaara *et al.* 1990 a). The present study, therefore aimed to investigate cardiorespiratory and musculoskeletal stress and strain and work output during manual sorting of postal parcels at sorting sites. An attempt was also made to detect the effects of parcel sorting on maximal muscle strength and endurance. Previously this type of measurement has not been carried out in field conditions.

The purpose of the study was (*a*) to assess cardiorespiratory and musculoskeletal stress and strain, and work output during manual sorting of postal parcels at different sorting sites; and (*b*) to detect the effects of parcel sorting on maximal hand-grip strength and endurance.

2. Material and methods

2.1. *Subjects*

The subjects comprised 32 male sorters of postal parcels at five different sorting sites, i.e., postal sorting centres (A, B, C, D, and E) (see table 1). Female subjects were not available, since parcel sorting is considered physically too strenuous for women. The subjects were healthy, although six of them had recently felt some slight pain symptoms related to musculoskeletal disorders. The subjects' mean (±s.d.) work experience was 9±5 years at the present job. They volunteered for the study and each one signed a statement of informed consent. Seventeen of the subjects had participated in the previous study on simulated sorting of postal parcels (Louhevaara *et al.* 1988), and in the assessments of physical work capacity.

2.2. *Sorting centres of postal parcels*

The sorting centres of postal parcels were selected for the study according to their size and amount of various mechanical auxiliary equipment used for sorting.

The size of the sorting centres studied varied from the largest centre (A) in Finland to a small one (E). The number of parcels sorted at centre A covered about 60% of the total volume of consignments in Finland, but was under 1% at centre E. At centres D and E parcels were sorted manually, whereas simple conveyors were used in the other centres. At centres A and B semimechanized conveyor lines were used for sorting.

2.3. *Procedures*

The study encompassed one random habitual evening work shift between 1200–2200 for each subject. Only the evening shifts were selected because the number of parcels

Table 1. The age and anthropometric characteristics of the subjects at the postal sorting centres. The values given are the means±s.d.

Sorting centre	*n*	Age (years)	Height (cm)	Weight (kg)	Body fat (%)
A	10	38±6	178±7	77±12	19±5
B	6	36±6	178±7	77±12	23±5
C	6	36±7	173±6	80±16	24±3
D	5	29±6	182±10	78±0·4	19±7
E	5	27±3	182±7	81±15	15±6
All	32	34±7	178±8	78±12	20±6

sorted was considerably larger during the evening than during the morning or night shifts, and to avoid interference from shift work problems (Rutenfranz and Colquhoun 1978).

Before the work shift the subject entered a separate room that served as a field laboratory. His anthropometric characteristics including the assessment of body fat (Durnin and Rahaman 1967) and maximal hand-grip strength were assessed. Each subject filled out a short questionnaire to determine his recent symptoms of musculoskeletal disorders (Kuorinka *et al.* 1987).

While the subject sorted postal parcels, three researchers performed observations and measurements during the work shift. The subject's work methods, work–rest regimen, or workpace were not affected by the researchers, and the physiological measurements were done as quickly as possible, in order not to disturb the subject.

After the work shift the subject returned to the field laboratory, and his maximal hand-grip strength was determined as before the shift. His maximal static and dynamic endurance with hand-grip muscles was measured if he had participated in the previous assessments of physical work capacity.

2.4. *Methods*

2.4.1. *Work output, tasks, and postures.* A researcher observed and recorded manually minute-by-minute the subject's work output and tasks. The number of sorted parcels and the amount of walking with and without a load described the work output.

The sorting of postal parcels was classified into seven tasks:

1. *Ramp*: During ramp sorting, parcels were loaded manually from the bottoms of smooth ramps (height of the bottom: 85 cm) in the containers or trollies according to the postal code. The ramp work also included tasks in which bundles of newspapers were unloaded from the containers or trollies on to a conveyor belt.
2. *Container*. During container work, parcels were sorted while manually loading or unloading the containers or trollies.
3. *Transport*: Transport work included pushing and pulling trollies, moving containers with a pumplift, and manual loading or unloading of lorries outdoors on a platform.
4. *Lift*: Lift work comprised activities associated with driving a forklift.
5. *Letter*: Letter work consisted of letter sorting as well as manual bundling and boxing of letters.
6. *Pause*: Pause time included all pauses, delays, and discussions during the work shift when there was no physical activity related to parcel sorting. Official pauses according to the collective labour agreement consisted of meal break of 30 min, and two refreshment pauses of 15 min.
7. *Other*: These tasks encompassed the other unspecified work activities which appeared during the work shift.

The work postures for legs, back, and arms were observed and recorded manually minute by minute for 2 h during each shift in the ramp, container or transport tasks. One subject was observed at a time by a researcher. The entire observation study on work postures was done by two trained researchers. The observation method used was modified from the methods reported earlier by Edholm (1966) and Karhu *et al.* (1977).

The following work postures and one dynamic activity 'walking' formed the alternative items recorded for the different body segments:

Legs	Standing
	Walking
	Squatting, kneeling, etc.
Back	Bent forward (10–90° to the vertical)
	Extremely bent forward (over 90° to the vertical)
	Bent forward and twisted
Arms	Supporting arm(s) below the shoulder level (arm(s) elevated at 30–90° to the vertical)
	Supporting arm(s) above the shoulder level (over 90° to the vertical)

The observed item or items were recorded when their duration was estimated to be continuously or repetitively, or both, more than 30 s during each single minute. All items with the exception of 'standing' and 'walking' were classified as poor work postures.

2.4.2. *Physiological responses of strain.* The subject's HR was continuously recorded every minute during the entire work shift using a telemetric Sport Tester PE 3000 Monitor (Polar Electro, Finland). The equipment included an electrode belt with a transmitter and a receiving microcomputer on a wrist. Due to technical difficulties, one subject's HR recording was not successful.

The subjects' $\dot{V}O_2$ was measured with a portable Oxylog device (P. K. Morgan Ltd, UK) consisting of a half face mask fitted with a turbine flowmeter and a microcomputer-controlled analyser (Louhevaara *et al.* 1985). The measurements of $\dot{V}O_2$ covered three of the heaviest work periods of about 15 min in the ramp, container, or transport tasks. These periods were judged by the subject to be physically the most strenuous during the work shift. According to the data of previous work analyses the work times in the heaviest tasks varied from 10–25 min.

At sorting centres A and E, blood lactate concentration of nine subjects was determined before the work shift, immediately after the heaviest work periods and at the end of the shift. Each blood sample consisted of two separate capillary samples of 25 μl taken from a fingertip. After collection the samples were stored in the freezer and later analysed enzymically by the Flow Injection Method described by Karlsson *et al.* (1983).

Overall rating of perceived exertion on the cardiorespiratory system, and local ratings of perceived exertion on the legs, back and arms were done with the ten-point scale (Borg *et al.* 1985). The ratings were asked in the beginning of the work shift, every second hour and at the end of the shift.

2.4.3. *Environmental conditions.* In the workplace ambient temperature and relative humidity were measured with a digital Vaisala Monitor (Vaisala Oy, Finland) and air velocity was measured with an anemometer (Waisala Oy, USA) in the beginning of the work shift, every second hour and at the end of the shift.

2.4.4. *Maximal muscle strength and endurance.* Before and after the work shift the subjects' static maximal voluntary contraction (MVC) was measured with both his right and left hand-grip muscles. The subjects were instructed to produce a steady maximal contraction for two to three seconds. The measurement was repeated after a

1 min rest period. The maximal hand-grip strength was assessed in a sitting position, and the contracting arm extended on the side at a 10° angle to the vertical.

The maximal static and dynamic muscle endurance times of seventeen subjects were determined after the work shift. The maximal static endurance time was assessed with the right hand-grip muscles at the 50% level of the individual MVC measured before the work shift. The maximal dynamic endurance time was determined with the left hand-grip muscles using intermittent contractions at the 50% level of individual MVC. The frequency was 50 contractions per min.

In the endurance tests the same body position was used as for the measurements of the maximal static hand-grip strength and for the prior determinations of the baseline endurance times. The baseline static and dynamic endurance times were measured twice on the separate days while the subjects participated in the previous study on simulated sorting of postal parcels (Louhevaara *et al.* 1988), and in the assessments of physical work capacity. The mean individual static and dynamic endurance time calculated from the two measurements were used as the final baseline values for each subject.

The strength and endurance measurements were carried out according to the guidelines of Chaffin (1975). Hand-grip strength was measured with a dynamometer which comprised a water-filled rubber tube with a pressure probe connected to an indicator and a power supply (Smolander *et al.* 1984). Paper recordings of all measurements were taken with a portable chart recorder (Yokogawa 3057, Japan).

2.4.5. *Statistics.* The results were evaluated with conventional descriptive statistics. The differences between the sorting centres were tested by one-way analysis of variance. The differences between strength and endurance measurements before and after the work shift were tested with Student's *t*-test for paired observations. The differences were considered statistically significant when $p < 0.05$.

3. Results

3.1. *Work output, tasks, and postures*

The mean (±s.d.) number of parcels sorted during an evening work shift varied from 662±195 to 1579±672 parcels ($p < 0.05$) at the sorting centres. In sorting, the mean work output was 7·3±2·6 parcels min^{-1} with no significant differences between the centres. The amount of walking was 4·7±2·3 km, and differed ($p < 0.001$) from centre to centre (table 2).

Table 2. The work output and the amount of walking during the work shift at the sorting centres. The values given are the means±s.d.

Sorting centre	n	Work output (parcels shift^{-1})	Work output (parcels min^{-1})	Amount of walking (km)
A	10	1508±699	7·6±3·5	3·3±1·6
B	6	1579±672	9·1±2·7	5·6±0·5
C	4	662±195	5·7±1·2	1·7±0·9
D	5	853±104	5·4±0·6	7·9±1·7
E	5	746±164	7·9±0·4	5·4±0·9
		$p < 0.05$	NS	$p < 0.001$
All	30	1173±630	7·3±2·6	4·7±2·3

Table 3. The relative proportion (%) of the length of the work shift spent in different tasks at the sorting centres. The values given are the means ± s.d., the number of the subjects is in parentheses. The number of the work tasks of the subjects differed at each sorting centre, and the percentages are not able to sum to 100.

Sorting centre	Ramp %	Contain. %	Transp. %	Lift %	Other %	Letter %	Pause %	Shift length (min)
A	37 ± 28 (7)	32 ± 22 (7)	17 ± 12 (6)		9 ± 7 (9)		33 ± 10 (10)	390 ± 45 (10)
B	38 ± 13 (6)	3 ± 2 (5)	14 ± 9 (6)	17 ± 18 (5)	5 ± 2 (5)		28 ± 9 (6)	397 ± 40 (6)
C	28 ± 6 (4)	2 ± 2 (4)	8 ± 6 (6)		25 ± 6 (4)	78 ± 1 (2)	30 ± 11 (6)	410 ± 37 (6)
D		37 ± 6 (5)	18 ± 5 (5)	13 ± 6 (5)	4 ± 3 (5)		28 ± 8 (5)	427 ± 21 (5)
E		29 ± 6 (5)	27 ± 16 (5)	14 ± 11 (3)	10 ± 4 (5)	26 ± 4 (3)	16 ± 5 (5)	326 ± 25 (5)
		$p<0{\cdot}001$	NS		$p<0{\cdot}001$		$p<0{\cdot}05$	$p<0{\cdot}01$
All	35 ± 19 (17)	22 ± 19 (26)	16 ± 12 (28)	14 ± 12 (15)	10 ± 8 (26)	46 ± 28 (5)	28 ± 10 (32)	391 ± 46 (32)

At sorting centre A it was possible to measure the total weight of the parcels sorted by four subjects during their shifts. The subjects sorted, on average, 8099 kg per shift. The mean weight of a parcel was 4 kg.

The mean length of the shifts ranged from 326 to 427 min ($p<0{\cdot}01$). Pauses constituted 16 to 33% ($p<0{\cdot}05$) of this time (table 3). The container and transport tasks were done at each centre. Smooth ramps were used for sorting at centres A, B, and C. The sorters drove a forklift at three centres.

Work postures in which back was bent forward amounted to an average of 24% of the time for sorting. Holding a load with both arms were considered to be elevated at 30–90° to the vertical, was observed in 46% of the time for sorting. There were significant differences in the amount of poor work postures for the arms at the sorting centres (table 4).

3.2. *Physiological responses of strain*

During the sorting work HR was 101 ± 18 beats min^{-1}. HR was the highest (111 ± 17 beats min^{-1}) at sorting centre D (table 5).

The relative proportion of the length of the work shift spent at different relative aerobic strain levels was calculated for 17 subjects. These levels were: under 33% (HR $\leqslant 89$ beats min^{-1}), 33–50% (HR 90–109 beats min^{-1}), 51–70% (HR 110–139 beats min^{-1}), and over 70% (HR $\geqslant 140$ beats min^{-1}) of the maximal $\dot{V}O_2$ for cycle exercise. The level of 70% of the maximal $\dot{V}O_2$ for cycling corresponded to the anaerobic threshold observed in the parcel sorting simulations (Louhevaara *et al.* 1988). The actual sorting tasks were predicted to be anaerobic during 2% of the work shift. The relative aerobic strain was calculated to be at 51–70% of the maximal $\dot{V}O_2$ during 9% of the work shift. The highest relative aerobic strain levels were found at centres A and D (figure 1).

In the most strenuous work phases including the ramp, container, and transport tasks, $\dot{V}O_2$ was $1{\cdot}2\pm0{\cdot}4$ l min^{-1}. With the 17 subjects, this corresponded to 37 ± 14% of

Table 4. The relative proportion (%) of the time for sorting spent at different poor work postures for back, arms, and legs at the sorting centres. The values given are the means.

Sorting centre	*n*	Bent %	Back Extr. bent %	Bent & twist. %	Arms		Legs Squat. etc. %
					30–90°[1] %	>90°[2] %	
A	10	25	2	2	53	3	1
B	6	22	1	0	40	2	1
C	6	22	0	0	38	0	0
D	5	26	0	0	58	1	0
E	5	22	1	0	31	1	1
		NS	NS	NS	$p<0{\cdot}001$	$p<0{\cdot}01$	NS
All	32	24	1	1	46	1	1

[1] Holding a load and supporting arms below the shoulder level.
[2] Supporting above the shoulder level.

the maximal $\dot{V}O_2$ for cycle exercise and 55 ± 16% of the maximal $\dot{V}O_2$ for simulated parcel sorting (Louhevaara *et al.* 1988). The peak $\dot{V}O_2$ varied from 0·9 ± 0·3 to 1·5 ± 0·4 l min^{-1} ($p<0{\cdot}05$) at the sorting centres (table 6). The highest $\dot{V}O_2$ measured was 2·6 l min^{-1}.

No significant differences were found in blood lactate concentrations determined before the work shift (1·3 ± 0·2 mmol l^{-1}), after the most strenuous work phases (0·8 ± 0·3 mmol l^{-1}) or at the end of the shift (0·9 ± 0·4 mmol l^{-1}) for nine subjects at centres A and E.

In the beginning of the work shift the ratings of perceived exertion on the cardiorespiratory system, legs, back and arms were estimated as 'nothing at all' (0) or 'very weak' (1). During the shift the sensations of exertion increased and reached the levels from 'weak' (2) to 'somewhat strong' (4). All ratings were constantly lowest for subjects at sorting centres D and E (figure 2).

3.3. *Environmental conditions*

In the work places the indoor temperatures ranged from 4 to 22°C being the highest at centre C (18–22°C) and centre E (20–21°C). The relative humidity was under 40% in all measured work places, and at centres B, C, and D it was under 20%. At centres A, B, and C the air velocity was over 0·1 m s^{-1} during the work shift. During the study the mean outdoor temperatures were 10, −24, −22, −15 and 5°C at sorting centres A, B, C, D, and E, respectively.

3.4. *Maximal muscle strength and endurance*

The static strength during MVC both for the right and left hand grip muscles (114 ± 19 vs. 110 ± 22 kPa and 112 ± 21 vs. 109 ± 22 kPa, respectively) differed 3% ($p<0{\cdot}05$) before and after the work shift (table 7). No significant differences were found in the static endurance times for the right hand-grip muscles nor in the dynamic endurance times for the left hand-grip muscles when the results obtained after the work shift (static: 104 ± 24 s, and dynamic: 204 ± 142 s) were compared to the baseline values (static: 104 ± 25 s, and dynamic: 179 ± 65 s).

Table 5. Heart rate (HR) in the tasks during the work shift at the sorting centres. The values given are the means ± s.d.

Sorting		Number of	HR (beats min^{-1})						All work	
centre	*n*	HR min	Ramp	Cont.	Transp.	Lift	Other	Letter	tasks	Pause
A	10	4059	103 ± 24	100 ± 14	92 ± 14		90 ± 16		99 ± 20	84 ± 17
B	6	2303	99 ± 18	106 ± 15	111 ± 20	94 ± 16	97 ± 19		101 ± 19	90 ± 15
C	6	2408	101 ± 15	108 ± 15	105 ± 13		98 ± 14	101 ± 9	101 ± 13	92 ± 12
D	4	1300		111 ± 16	114 ± 17	112 ± 16	101 ± 18		111 ± 17	91 ± 18
E	5	1691		98 ± 14	100 ± 11	96 ± 10	89 ± 16	86 ± 11	96 ± 13	85 ± 13
				NS	NS		NS		NS	
All	31	11761	101 ± 21	103 ± 15	103 ± 17	98 ± 16	96 ± 16	97 ± 12	101 ± 18	88 ± 16

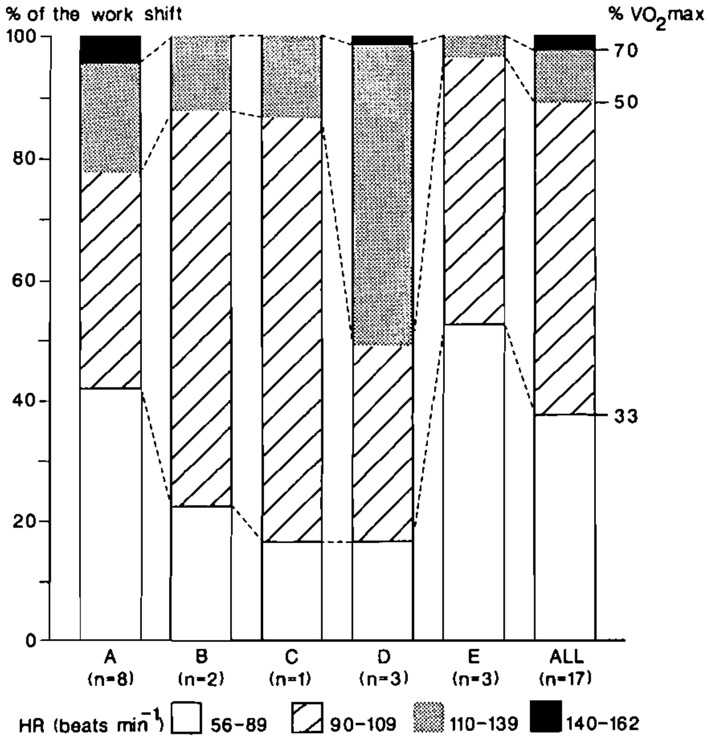

Figure 1. The relative proportion (%) of the length of the work shift spent at the heart rate (HR) levels of 56–89, 90–109, 110–139 and 140–162 beats min^{-1} at the sorting centres. During cycle exercise, the relative aerobic strain level of 33% of the maximal $\dot{V}O_2$ was exceeded at the HR level of about 90 beats min^{-1}, 50% $\dot{V}O_2$ max at the HR level about 110 beats min^{-1} and 70% $\dot{V}O_2$ max (the anaerobic threshold for simulated parcel sorting) at the HR level of about 140 beats min^{-1}. The number of subjects is in parentheses.

Table 6. Oxygen consumption ($\dot{V}O_2$), heart rate (HR), and relative aerobic strain (%$\dot{V}O_2$ max) for cycle exercise and for simulated parcel sorting in the most strenuous work phases at the sorting centres. The values given are the means ± s.d.

Sorting centre	n	$\dot{V}O_2$ (l min^{-1})	HR (beats min^{-1})	n	%$\dot{V}O_2$ max	
					Cycling	Sorting
A	10	0·9 ± 0·3	104 ± 17	8	30 ± 4	48 ± 6
B	6	1·2 ± 0·3	106 ± 19	2	37 ± 5	55 ± 8
C	6	1·3 ± 0·2	104 ± 13	1	40 ± 6	58 ± 8
D	5	1·5 ± 0·4	118 ± 14	3	40 ± 7	58 ± 7
E	5	1·2 ± 0·3	102 ± 12	3	35 ± 5	54 ± 5
		$p < 0{\cdot}05$	NS			
All	32	1·2 ± 0·4	105 ± 16	17	37 ± 14	55 ± 16

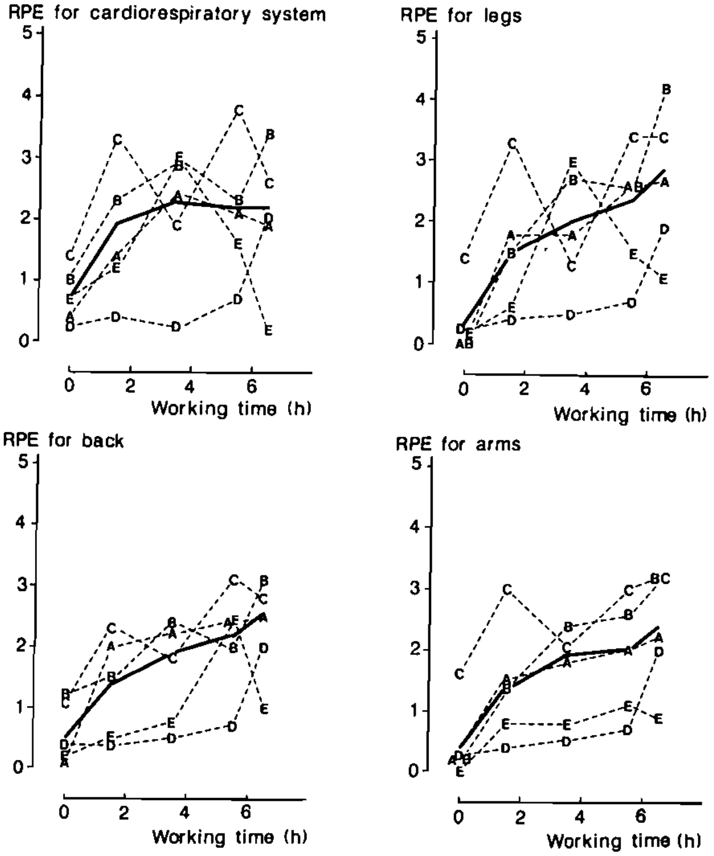

Figure 2. The ratings of perceived exertion (RPE) for the cardiorespiratory system, for legs, back and arms in the beginning of the work shift, during the shift and at the end of the shift. The values given are the means. The solid line in each sub-figure is the mean for 32 subjects.

Table 7. Static strength during maximal voluntary contraction (MVC) with the right and left hand-grip muscles before and after the work shift. The values given are the means ± s.d.

		MVC, right hand			MVC, left hand		
Sorting centre	*n*	Before (kPa)	After (kPa)		Before (kPa)	After (kPa)	
A	10	107 ± 14	105 ± 13	NS	107 ± 12	104 ± 13	NS
B	6	119 ± 15	113 ± 17	$p<0.05$	110 ± 25	104 ± 22	NS
C	6	104 ± 19	97 ± 30	NS	112 ± 15	109 ± 23	NS
D	5	115 ± 21	114 ± 25	NS	104 ± 36	104 ± 36	NS
E	5	132 ± 19	130 ± 23	NS	132 ± 21	129 ± 23	NS
All	32	114 ± 19	110 ± 22	$p<0.05$	112 ± 21	109 ± 22	$p<0.05$

4. Discussion

4.1. *Work output and tasks*

The work output and tasks are affected by the level of engineering and work organization. The sorting centres studied were technically different. The use of semi-mechanized sorting conveyor lines increased the work output during the evening shift about twofold higher than that during more manual sorting, but it did not considerably affect the work output (parcels min^{-1}) during the time for sorting. The physical work required by the sorting lines seemed to consist of fewer work tasks.

The sorting centres had a strong common organizational factor, i.e., a fixed salary with a time premium. This system allows the sorters to be off duty as soon as their daily work output has been completed. The work processes were rather intermittent, and the subjects were quite free to set their own workpace and work–rest regimens. For instance, at sorting centre E the subjects did not spend the entire time allotted for official rest pauses.

4.2. *Cardiorespiratory stress and strain*

At the sorting centres the average HRs for different parcel sorting tasks varied from 89 to 114 beats min^{-1}, depending basically on the amount of walking required by parcel sorting. These HRs were higher than those measured in different municipal occupations (Nygård 1988) and similar to those measured in foundry and shipyard work (Louhevaara *et al.* 1985). Substantially higher HR values have been reported in mail delivery work (Oja *et al.* 1977, Ilmarinen *et al.* 1984), in construction work (Louhevaara *et al.* 1985), in the building industry (Klimmer *et al.* 1983) and in the steel and iron industry (Klimmer *et al.* 1984).

The average HR during parcel sorting (101 beats min^{-1}) corresponded to a $\dot{V}O_2$ of about $1{\cdot}01\,l\,min^{-1}$ according to the HR–$\dot{V}O_2$ relationship assessed during the parcel sorting simulations (Louhevaara *et al.* 1988). The $\dot{V}O_2$ of $1{\cdot}01\,l\,min^{-1}$ was 31% of maximal $\dot{V}O_2$ for cycling and 40% maximal $\dot{V}O_2$ for simulated parcel sorting. During actual parcel sorting the relative aerobic strain was predicted to be over 50% of maximal $\dot{V}O_2$ for cycling during 11% of the evening shift which was 6·5 h, on average. Correspondingly, the anaerobic threshold for simulated parcel sorting (about 70% of maximal $\dot{V}O_2$ for cycling) was calculated to be exceeded in the sorting tasks that covered 2% of the work shift. At sorting centre A the predicted infrequent anaerobic work situations (figure 1) were probably not discerned, and their verification with blood lactate determinations was not successful.

It has been suggested that 33% of maximal $\dot{V}O_2$ for leg exercise is an acceptable level for continuous dynamic physical work during an 8 h shift, and correspondingly 50% of maximal $\dot{V}O_2$ for the prolonged work with sufficient work–rest regimens (Åstrand 1960, Ilmarinen 1984). The latter guideline is probably suitable for the manual sorting of postal parcels as the leg exercise with a cycle-ergometer simulated well parcel sorting (Louhevaara *et al.* 1988). Furthermore, postal sorting was not repetitive lifting work, and the time needed for rest pauses was usually available. Thus, during actual sorting average cardiorespiratory stress and strain could be classified as moderate or acceptable (Andersen *et al.* 1978) with quite rare peak load situations. This result was supported by the ratings of perceived exertion for the cardiorespiratory system. They did not exceed the 'somewhat strong' level. Recently Hultman *et al.* (1984) and Nygård (1988) reported similar values when they used the scale from 6 to 20 for the rating of perceived exertion (Borg 1970) in janitorial work and in municipal occupations.

Almost in every work task the subjects were able to adjust their strain individually. Nevertheless, the self-control of few subjects, probably under the pressure of the time bonus, seemed to be insufficient to prevent them from straining themselves in some tasks beyond the acceptable limits, i.e., 50% of their individual maximal $\dot{V}O_2$ for leg exercise (figure 1).

4.3. *Musculoskeletal stress and strain*

The evaluation of the stress and strain on the musculoskeletal system during parcel sorting was based on quantitative data about work output and tasks, poor work postures of the observation study, and the local ratings of perceived exertion for legs, back and arms.

The mean number of the parcels sorted during the evening shift was about 1200. The average weight of the parcels was 4 or 5 kg, the latter value being based on long-term statistics of the Central Post Office. The heaviest parcels, postal bags and bundles of newspaper, weighed 15–20 kg. It was estimated that about one-third of the parcels were lifted up or down above shoulder level or below knuckle level. Usually a sorter did not open the lower part of the front door of the parcel container. This resulted in increased lifting and lowering in extremely bent forward and stretched body positions when the last and first parcels were handled on the bottom of the container.

The ramp, container and transport tasks included almost continuous manual sorting and handling of parcels, and the amount of poor work postures for the back (bent forward or bent and twisted) and arms (elevated below or above shoulder level) were 26% and 47% of the time for sorting, respectively. In cleaning work, Louhevaara *et al.* (1982) reported bent forward postures for the back during 56% and positions with arms above shoulder level during 38% of the working hours. These percentages were as high as those in the maintenance of agricultural machines and about twice as high as those observed in the sawmill and printing industries (Nygård 1988).

Local ratings of perceived exertion for legs, back and arms during the work shift did not exceed, on average, the 'somewhat strong' level. The present results were similar to the corresponding ratings obtained from janitorial work (Hultman *et al.* 1984) and from professional kitchen work (Nygård *et al.* 1989).

Evaluation of the data indicated that the average stress on the musculoskeletal system was more dynamic than static, and that probably the stress and strain were not excessive for the subjects of this study. This result was supported by the subjective ratings of acceptable load (Griffin *et al.* 1984) done by the subjects. They felt they could sort parcels weighing considerably more than the average weight of the parcels (4–5 kg) in actual work without symptoms of fatigue (Stålhammar *et al.* 1989).

4.4. *Physical work capacity*

When the appropriateness of a sorter's cardiorespiratory and musculoskeletal strain is considered, it must be emphasized that physical strain depends both on the stress factors at work and on an individual's physical work capacity (Rutenfranz 1981). The subjects of this study were healthy men and only few of them had recently had some slight pain symptoms in their musculoskeletal system. The seventeen subjects who participated in the assessment of physical work capacity had an average aerobic power in their age group when their maximal $\dot{V}O_2$ for cycle exercise was $3{\cdot}10\,l\,min^{-1}$ (Andersen *et al.* 1978). The maximal $\dot{V}O_2$ of the fifteen field subjects was not assessed, but there is no reason to believe that their maximal $\dot{V}O_2$ would be substantially different when compared to the subjects measured in the laboratory.

The mean static strength during MVC of all subjects for the right hand-grip was 114 kPa and for the left hand-grip 112 kPa before the work shift. Corresponding results obtained with policemen were 95 and 94 kPa, respectively (Louhevaara, V., Smolander, J. and Korhonen, O. 1982). In the baseline measurements, the mean static endurance time of the seventeen subjects for the right hand was 104 seconds at 46% of MVC. According to the calculations of Monod and Sherrer (1957) the average value might be 72 s. The hand-grip measurements showed that the subjects had good strength and endurance in the flexor muscles of their fingers.

Because the present subjects were healthy volunteers aged 23–45 years, they represented a motivated and physically selected sample of all sorters of postal parcels. Particularly the subjects at centre E were young, strong, and lean. These characteristics are usually good predictors for high physical work capacity. This may have decreased the subjects' need for pauses and their ratings of perceived strain.

The selection of subjects unavoidably operates among the individuals who volunteer for the work capacity tests and also in different field measurements requiring full co-operation (Oja *et al.* 1977). If a sorter's physical work capacity has been decreased, or he is aged (Nygård 1988), the individual characteristics needed for the assessment of strain cannot be predicted according to the results of this study.

4.5. *Muscle strength and endurance*

A small but statistically significant decrease was found in the maximal static strength both for the right and left hand-grip muscles when the values obtained after the work shift were compared to those mesured before the shift. Probably this was a slight indication of acute local muscle fatigue caused by manual parcel sorting.

No significant differences were found in static or dynamic endurance times between the baseline measurements and the measurements after the work shift. The stress of the parcel sorting might be too low to affect the hand-grip endurance times. In the tests, the subjects had difficulties to produce the submaximal target level of strength (50% of individual static MVC). The strength levels varied from 44 ± 3 to 57 ± 4%MVC, and after the shift they were 2–3% lower than the baseline levels. The time gap (6–10 months) between the baseline endurance measurements in the laboratory and the measurements after the work shift may have been excessive. The baseline times for static and dynamic endurance could have been determined before each work shift but it was anticipated that the maximal endurance tests immediately before the shift would have affected both actual sorting work and the measurements after the shift (Funderburk *et al.* 1974).

5. Conclusions

The following main conclusions can be drawn from the present study. First, during the evening shift of sorting of postal parcels the stress and strain on the cardiorespiratory and musculoskeletal system was estimated to remain within acceptable limits for the healthy male sorters with an average aerobic power and good hand-grip muscle strength and endurance.

Second, the use of semi-mechanized sorting conveyor lines increased the work output during the evening work shift about twofold higher than that during more manual sorting, but did not considerably affect physical stress and strain.

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On a effectué une étude sur le site afin d'analyser la contrainte et l'astreinte cardiorespiratoire et musculo-squelettique, ainsi que le rendement pendant le tri manuel de paquets de poste. On se proposait également de mettre en évidence les effets de ce travail sur la force musculaire et sur l'endurance.

Les sujets, tous volontaires, étaient 32 hommes affectés au tri, agés en moyenne (± e.t.), de 34 ± 7 ans et travaillant sur cinq sites différents. Chaque sujet a été observé durant un poste du soir. Durant leur poste de 391 ± 46 min, les sujets ont trié 1173 ± 630 paquets et ont marché 4,7 ± 2,3 km avec et sans charge. Pendant le tri, leur fréquence cardiaque était de 101 ± 18 battements par min. Lors des tâches les plus astreignantes, leur consommation d'oxygène était de $1{,}2 \pm 0{,}4\,\mathrm{l\,min^{-1}}$ et on n'a pas trouvé de concentration élevée de lactate plasmatique. Les postures de travail avec le dos penché vers l'avant occupaient 24% du temps de tri.

Le jugement global de l'astreinte cardio-respiratoire et le jugement local de l'effort perçu dans le bras, le dos et les jambes ne dépassaient pas le niveau 'un peu difficile'. La force statique maximale mesurée sur les poignets était, en moyenne, de 3% ($p < 0{,}05$) plus basse après le poste qu'avant. Il n'y avait pas de différences significatives dans le temps d'endurance statique et dynamique des muscles impliqués, entre avant et après le travail.

On peut conclure que dans les Centres de tri, la contrainte et l'astreinte cardio-respiratoire et musculo-squelettique demeure dans des limites acceptables pour les employés hommes en bonne santé.

Es wurde eine Feldstudie zur Beurteilung der cardio-respiratorischen und musculo-skeletalen Belastung und Beanspruchung und der Arbeitsleistung während des manuellen Sortierens von postalischen Paketen durchgeführt. Weiterhin sollten die Effekte des Paketsortierens auf die maximale Muskelkraft und die Ausdauerzeit herausgefunden werden. Bei den freiwilligen Versuchspersonen handelte es sich um 32 gesunde männliche Sortierer mit einem mittleren Alter von 34 ± 7 Jahren, die an 5 unterschiedlichen Stellen im Sortiervorgang arbeiten. Jede Versuchsperson wurde während einer abendlichen Arbeitsschicht untersucht. Während der Schicht von 391 ± 46 min sortierten die Versuchspersonen manuell 1173 ± 630 Pakete und liefen 4,7 ± 2,3 km mit und ohne Lasten. Während des Sortierens lag die Herzschlagfrequenz bei 101 ± 18 Schlägen pro Minute. Bei den schwersten Aufgaben lag der Sauerstoffverbrauch bei $1{,}2 \pm 0{,}4\,\mathrm{l\,min}^{-1}$ und es wurde keine erhöhte Blutlaktat-Konzentration gefunden. Köperhaltungen mit nach vorne gekrümmtem Rücken traten in durchschnittlich 24% der Sortierzeit auf. Die gesamte cardio-respiratorische Bewertung und lokale Bewertungen der erlebten Anstrengung von Armen. Rücken und Beinen überschritten nicht das 'etwas stark'-Niveau während einer Schicht. Die maximale statische Kraft sowohl für die rechten als auch die linken Greifmuskeln der Hand waren im Durchschnitt nach der Arbeitsschicht 3% niedringer ($p<0{,}05$) als vor der Arbeitsschicht. Es wurden keine signifikanten Unterschiede in den statischen oder dynamischen Ausdauerzeiten für die Greifmuskeln der Hand beim Vergleich der Werte nach der Arbeitsschicht mit den Ausgangswerten gefunden. Die Belastung und Beanspruchung des cardio-respiratorischen und musculo-skeletalen Systems wurde an Sortierplätzen so beurteilt, daß sie für gesunde männliche Sortierer innerhalb akzeptabler Grenzwerte liegt.

郵便小包の手動仕分け中の心肺，筋骨格ストレスとストレインを評価し，最大筋力，持久性に及ぼす小包仕分けの影響を検出するために現場研究を実施した。志願した被験者は5つの仕分け所からの平均年令が34±7歳の32名の男性仕分け人であった。各被験者は1回の夜勤時に検査した。391±46 minの夜勤中に被験者は1173±630個の小包を仕分けし，荷物の有無に関係なく4.7±2.3km歩行した。仕分け中の心拍数は101±18拍／分であった。もっともきつい作業時の酸素摂取量は1.2±0.4 l／minで，血中乳酸塩濃度は高くならなかった。背中を前傾した作業姿勢は平均して仕分け時間の24%であった。全体心肺評点，腕，背中，脚の知覚努力の局所評点は勤務中に「いくらか強い」水準を超えなかった。左右の手の握り筋肉の最大静的筋力は勤務前と比べて勤務後には平均して3%（p <0.05）低かった。勤務後に測定した値を基準値と比較すると，手握り筋肉の静的または動的持久時間に有意差は見られなかった。小包仕分けセンターでの心肺，筋骨格系のストレス，ストレインは健康な男性仕分け人にとって許容範囲内であると評価された。

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Physical work and strain involved in manual sorting of postal parcels

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Keywords: Manual material handling; Dynamic work; Static work; Work output; Muscle strength; Muscle endurance

A field study was conducted to assess cardiorespiratory and musculoskeletal stress and strain and work output during manual sorting of postal parcels, and to detect the effects of parcel sorting on the maximal muscle strength and endurance. The volunteer subjects comprised 32 healthy male sorters with mean (±s.d.) age of 34±7 years at five different sorting sites. Each subject was studied during one evening work shift. During the shift of 391±46 min the subjects manually sorted 1173±630 parcels and walked 4·7±2·3 km with and without the load. While sorting, heart rate was 101±18 beats min^{-1}. In the heaviest tasks the oxygen consumption was 1·2±0·4 l min^{-1}, and no elevated blood lactate concentrations were found. Work postures in which the back was bent forward averaged 24% of the time for sorting. The overall cardiorespiratory rating and local ratings of perceived exertion for arms, back, and legs did not exceed the 'somewhat strong' level during the work shift. The maximal static strength both for the right and left hand-grip muscles was, on average, 3% lower ($p<0·05$) after the work shift than before the shift. No significant differences were found in the static or dynamic endurance times for the hand-grip muscles when the results obtained after the work shift were compared to the baseline values. At sorting centres the stress and strain on the cardiorespiratory and musculoskeletal system was evaluated to remain within acceptable limits for healthy male sorters.

1. Introduction

In a previous study of physiological responses to simulated manual sorting of postal parcels (Louhevaara *et al.* 1988), it was shown that this type of manual material handling involves a considerable amount of dynamic muscle work. The cardiorespiratory responses to parcel sorting and dynamic cycle exercise were almost equal, but substantially differed from the responses to the more static arm crank exercise with a limited amount of active skeletal muscle mass (Sawka 1986, Louhevaara *et al.* 1990 b).

During simulated parcel sorting the mean (±s.d.) oxygen consumption ($\dot{V}O_2$) was 1·36±0·38 $\mathrm{l\,min}^{-1}$ and heart rate (HR) 105±22 beats min^{-1} at an individual habitual work output of 8·6±2·4 parcels min^{-1}. The weight of the parcels ranged from 0·5 to 17·5 kg. Parcel sorting was predominantly aerobic muscle work (blood lactate concentration <4 $\mathrm{mmol\,l}^{-1}$) up to the work output of about 20 parcels min^{-1}, which approximately corresponded to 70% of the maximal $\dot{V}O_2$ for cycle exercise. The $\dot{V}O_2$ results obtained from the simulated sorting tasks agreed well with the earlier study of Peacock (1980) who observed $\dot{V}O_2$ of 1·2 $\mathrm{l\,min}^{-1}$ when loading and unloading parcel containers with a mean work output of 4 parcels min^{-1}.

During the simulated parcel sorting it was impossible to establish the cardiorespiratory strain and work output levels during the actual manual sorting of postal parcels. Furthermore, the musculoskeletal aspects of parcel sorting work were not considered in the sorting simulations of this stage (see Louhevaara *et al.* 1990 a). The present study, therefore aimed to investigate cardiorespiratory and musculoskeletal stress and strain and work output during manual sorting of postal parcels at sorting sites. An attempt was also made to detect the effects of parcel sorting on maximal muscle strength and endurance. Previously this type of measurement has not been carried out in field conditions.

The purpose of the study was (*a*) to assess cardiorespiratory and musculoskeletal stress and strain, and work output during manual sorting of postal parcels at different sorting sites; and (*b*) to detect the effects of parcel sorting on maximal hand-grip strength and endurance.

2. Material and methods

2.1. *Subjects*

The subjects comprised 32 male sorters of postal parcels at five different sorting sites, i.e., postal sorting centres (A, B, C, D, and E) (see table 1). Female subjects were not available, since parcel sorting is considered physically too strenuous for women. The subjects were healthy, although six of them had recently felt some slight pain symptoms related to musculoskeletal disorders. The subjects' mean (±s.d.) work experience was 9±5 years at the present job. They volunteered for the study and each one signed a statement of informed consent. Seventeen of the subjects had participated in the previous study on simulated sorting of postal parcels (Louhevaara *et al.* 1988), and in the assessments of physical work capacity.

2.2. *Sorting centres of postal parcels*

The sorting centres of postal parcels were selected for the study according to their size and amount of various mechanical auxiliary equipment used for sorting.

The size of the sorting centres studied varied from the largest centre (A) in Finland to a small one (E). The number of parcels sorted at centre A covered about 60% of the total volume of consignments in Finland, but was under 1% at centre E. At centres D and E parcels were sorted manually, whereas simple conveyors were used in the other centres. At centres A and B semimechanized conveyor lines were used for sorting.

2.3. *Procedures*

The study encompassed one random habitual evening work shift between 1200–2200 for each subject. Only the evening shifts were selected because the number of parcels

Table 1. The age and anthropometric characteristics of the subjects at the postal sorting centres. The values given are the means±s.d.

Sorting centre	*n*	Age (years)	Height (cm)	Weight (kg)	Body fat (%)
A	10	38±6	178±7	77±12	19±5
B	6	36±6	178±7	77±12	23±5
C	6	36±7	173±6	80±16	24±3
D	5	29±6	182±10	78±0·4	19±7
E	5	27±3	182±7	81±15	15±6
All	32	34±7	178±8	78±12	20±6

sorted was considerably larger during the evening than during the morning or night shifts, and to avoid interference from shift work problems (Rutenfranz and Colquhoun 1978).

Before the work shift the subject entered a separate room that served as a field laboratory. His anthropometric characteristics including the assessment of body fat (Durnin and Rahaman 1967) and maximal hand-grip strength were assessed. Each subject filled out a short questionnaire to determine his recent symptoms of musculoskeletal disorders (Kuorinka *et al.* 1987).

While the subject sorted postal parcels, three researchers performed observations and measurements during the work shift. The subject's work methods, work–rest regimen, or workpace were not affected by the researchers, and the physiological measurements were done as quickly as possible, in order not to disturb the subject.

After the work shift the subject returned to the field laboratory, and his maximal hand-grip strength was determined as before the shift. His maximal static and dynamic endurance with hand-grip muscles was measured if he had participated in the previous assessments of physical work capacity.

2.4. *Methods*

2.4.1. *Work output, tasks, and postures.* A researcher observed and recorded manually minute-by-minute the subject's work output and tasks. The number of sorted parcels and the amount of walking with and without a load described the work output.

The sorting of postal parcels was classified into seven tasks:

1. *Ramp*: During ramp sorting, parcels were loaded manually from the bottoms of smooth ramps (height of the bottom: 85 cm) in the containers or trollies according to the postal code. The ramp work also included tasks in which bundles of newspapers were unloaded from the containers or trollies on to a conveyor belt.
2. *Container*. During container work, parcels were sorted while manually loading or unloading the containers or trollies.
3. *Transport*: Transport work included pushing and pulling trollies, moving containers with a pumplift, and manual loading or unloading of lorries outdoors on a platform.
4. *Lift*: Lift work comprised activities associated with driving a forklift.
5. *Letter*: Letter work consisted of letter sorting as well as manual bundling and boxing of letters.
6. *Pause*: Pause time included all pauses, delays, and discussions during the work shift when there was no physical activity related to parcel sorting. Official pauses according to the collective labour agreement consisted of meal break of 30 min, and two refreshment pauses of 15 min.
7. *Other*: These tasks encompassed the other unspecified work activities which appeared during the work shift.

The work postures for legs, back, and arms were observed and recorded manually minute by minute for 2 h during each shift in the ramp, container or transport tasks. One subject was observed at a time by a researcher. The entire observation study on work postures was done by two trained researchers. The observation method used was modified from the methods reported earlier by Edholm (1966) and Karhu *et al.* (1977).

The following work postures and one dynamic activity 'walking' formed the alternative items recorded for the different body segments:

Legs	Standing
	Walking
	Squatting, kneeling, etc.
Back	Bent forward (10–90° to the vertical)
	Extremely bent forward (over 90° to the vertical)
	Bent forward and twisted
Arms	Supporting arm(s) below the shoulder level (arm(s) elevated at 30–90° to the vertical)
	Supporting arm(s) above the shoulder level (over 90° to the vertical)

The observed item or items were recorded when their duration was estimated to be continuously or repetitively, or both, more than 30 s during each single minute. All items with the exception of 'standing' and 'walking' were classified as poor work postures.

2.4.2. *Physiological responses of strain.* The subject's HR was continuously recorded every minute during the entire work shift using a telemetric Sport Tester PE 3000 Monitor (Polar Electro, Finland). The equipment included an electrode belt with a transmitter and a receiving microcomputer on a wrist. Due to technical difficulties, one subject's HR recording was not successful.

The subjects' $\dot{V}O_2$ was measured with a portable Oxylog device (P. K. Morgan Ltd, UK) consisting of a half face mask fitted with a turbine flowmeter and a microcomputer-controlled analyser (Louhevaara *et al.* 1985). The measurements of $\dot{V}O_2$ covered three of the heaviest work periods of about 15 min in the ramp, container, or transport tasks. These periods were judged by the subject to be physically the most strenuous during the work shift. According to the data of previous work analyses the work times in the heaviest tasks varied from 10–25 min.

At sorting centres A and E, blood lactate concentration of nine subjects was determined before the work shift, immediately after the heaviest work periods and at the end of the shift. Each blood sample consisted of two separate capillary samples of 25 μl taken from a fingertip. After collection the samples were stored in the freezer and later analysed enzymically by the Flow Injection Method described by Karlsson *et al.* (1983).

Overall rating of perceived exertion on the cardiorespiratory system, and local ratings of perceived exertion on the legs, back and arms were done with the ten-point scale (Borg *et al.* 1985). The ratings were asked in the beginning of the work shift, every second hour and at the end of the shift.

2.4.3. *Environmental conditions.* In the workplace ambient temperature and relative humidity were measured with a digital Vaisala Monitor (Vaisala Oy, Finland) and air velocity was measured with an anemometer (Waisala Oy, USA) in the beginning of the work shift, every second hour and at the end of the shift.

2.4.4. *Maximal muscle strength and endurance.* Before and after the work shift the subjects' static maximal voluntary contraction (MVC) was measured with both his right and left hand-grip muscles. The subjects were instructed to produce a steady maximal contraction for two to three seconds. The measurement was repeated after a

1 min rest period. The maximal hand-grip strength was assessed in a sitting position, and the contracting arm extended on the side at a 10° angle to the vertical.

The maximal static and dynamic muscle endurance times of seventeen subjects were determined after the work shift. The maximal static endurance time was assessed with the right hand-grip muscles at the 50% level of the individual MVC measured before the work shift. The maximal dynamic endurance time was determined with the left hand-grip muscles using intermittent contractions at the 50% level of individual MVC. The frequency was 50 contractions per min.

In the endurance tests the same body position was used as for the measurements of the maximal static hand-grip strength and for the prior determinations of the baseline endurance times. The baseline static and dynamic endurance times were measured twice on the separate days while the subjects participated in the previous study on simulated sorting of postal parcels (Louhevaara *et al.* 1988), and in the assessments of physical work capacity. The mean individual static and dynamic endurance time calculated from the two measurements were used as the final baseline values for each subject.

The strength and endurance measurements were carried out according to the guidelines of Chaffin (1975). Hand-grip strength was measured with a dynamometer which comprised a water-filled rubber tube with a pressure probe connected to an indicator and a power supply (Smolander *et al.* 1984). Paper recordings of all measurements were taken with a portable chart recorder (Yokogawa 3057, Japan).

2.4.5. *Statistics.* The results were evaluated with conventional descriptive statistics. The differences between the sorting centres were tested by one-way analysis of variance. The differences between strength and endurance measurements before and after the work shift were tested with Student's *t*-test for paired observations. The differences were considered statistically significant when $p < 0{\cdot}05$.

3. Results

3.1. *Work output, tasks, and postures*

The mean (± s.d.) number of parcels sorted during an evening work shift varied from 662 ± 195 to 1579 ± 672 parcels ($p < 0{\cdot}05$) at the sorting centres. In sorting, the mean work output was $7{\cdot}3 \pm 2{\cdot}6$ parcels min^{-1} with no significant differences between the centres. The amount of walking was $4{\cdot}7 \pm 2{\cdot}3$ km, and differed ($p < 0{\cdot}001$) from centre to centre (table 2).

Table 2. The work output and the amount of walking during the work shift at the sorting centres. The values given are the means ± s.d.

Sorting centre	n	Work output (parcels shift^{-1})	Work output (parcels min^{-1})	Amount of walking (km)
A	10	1508 ± 699	$7{\cdot}6 \pm 3{\cdot}5$	$3{\cdot}3 \pm 1{\cdot}6$
B	6	1579 ± 672	$9{\cdot}1 \pm 2{\cdot}7$	$5{\cdot}6 \pm 0{\cdot}5$
C	4	662 ± 195	$5{\cdot}7 \pm 1{\cdot}2$	$1{\cdot}7 \pm 0{\cdot}9$
D	5	853 ± 104	$5{\cdot}4 \pm 0{\cdot}6$	$7{\cdot}9 \pm 1{\cdot}7$
E	5	746 ± 164	$7{\cdot}9 \pm 0{\cdot}4$	$5{\cdot}4 \pm 0{\cdot}9$
		$p < 0{\cdot}05$	NS	$p < 0{\cdot}001$
All	30	1173 ± 630	$7{\cdot}3 \pm 2{\cdot}6$	$4{\cdot}7 \pm 2{\cdot}3$

Table 3. The relative proportion (%) of the length of the work shift spent in different tasks at the sorting centres. The values given are the means ± s.d., the number of the subjects is in parentheses. The number of the work tasks of the subjects differed at each sorting centre, and the percentages are not able to sum to 100.

Sorting centre	Ramp %	Contain. %	Transp. %	Lift %	Other %	Letter %	Pause %	Shift length (min)
A	37±28 (7)	32±22 (7)	17±12 (6)		9±7 (9)		33±10 (10)	390±45 (10)
B	38±13 (6)	3±2 (5)	14±9 (6)	17±18 (5)	5±2 (5)		28±9 (6)	397±40 (6)
C	28±6 (4)	2±2 (4)	8±6 (6)		25±6 (4)	78±1 (2)	30±11 (6)	410±37 (6)
D		37±6 (5)	18±5 (5)	13±6 (5)	4±3 (5)		28±8 (5)	427±21 (5)
E		29±6 (5)	27±16 (5)	14±11 (3)	10±4 (5)	26±4 (3)	16±5 (5)	326±25 (5)
		$p<0{\cdot}001$	NS		$p<0{\cdot}001$		$p<0{\cdot}05$	$p<0{\cdot}01$
All	35±19 (17)	22±19 (26)	16±12 (28)	14±12 (15)	10±8 (26)	46±28 (5)	28±10 (32)	391±46 (32)

At sorting centre A it was possible to measure the total weight of the parcels sorted by four subjects during their shifts. The subjects sorted, on average, 8099 kg per shift. The mean weight of a parcel was 4 kg.

The mean length of the shifts ranged from 326 to 427 min ($p<0{\cdot}01$). Pauses constituted 16 to 33% ($p<0{\cdot}05$) of this time (table 3). The container and transport tasks were done at each centre. Smooth ramps were used for sorting at centres A, B, and C. The sorters drove a forklift at three centres.

Work postures in which back was bent forward amounted to an average of 24% of the time for sorting. Holding a load with both arms were considered to be elevated at 30–90° to the vertical, was observed in 46% of the time for sorting. There were significant differences in the amount of poor work postures for the arms at the sorting centres (table 4).

3.2. *Physiological responses of strain*

During the sorting work HR was 101 ± 18 beats min^{-1}. HR was the highest (111 ± 17 beats min^{-1}) at sorting centre D (table 5).

The relative proportion of the length of the work shift spent at different relative aerobic strain levels was calculated for 17 subjects. These levels were: under 33% ($\mathrm{HR} \leqslant 89$ beats min^{-1}), 33–50% (HR 90–109 beats min^{-1}), 51–70% (HR 110–139 beats min^{-1}), and over 70% ($\mathrm{HR} \geqslant 140$ beats min^{-1}) of the maximal $\dot{V}O_2$ for cycle exercise. The level of 70% of the maximal $\dot{V}O_2$ for cycling corresponded to the anaerobic threshold observed in the parcel sorting simulations (Louhevaara *et al.* 1988). The actual sorting tasks were predicted to be anaerobic during 2% of the work shift. The relative aerobic strain was calculated to be at 51–70% of the maximal $\dot{V}O_2$ during 9% of the work shift. The highest relative aerobic strain levels were found at centres A and D (figure 1).

In the most strenuous work phases including the ramp, container, and transport tasks, $\dot{V}O_2$ was $1{\cdot}2 \pm 0{\cdot}4\ \mathrm{l\,min}^{-1}$. With the 17 subjects, this corresponded to 37 ± 14% of

Table 4. The relative proportion (%) of the time for sorting spent at different poor work postures for back, arms, and legs at the sorting centres. The values given are the means.

Sorting centre	n	Bent %	Back Extr. bent %	Bent & twist. %	Arms		Legs Squat. etc. %
					30–90°[1] %	>90°[2] %	
A	10	25	2	2	53	3	1
B	6	22	1	0	40	2	1
C	6	22	0	0	38	0	0
D	5	26	0	0	58	1	0
E	5	22	1	0	31	1	1
		NS	NS	NS	$p<0{\cdot}001$	$p<0{\cdot}01$	NS
All	32	24	1	1	46	1	1

[1] Holding a load and supporting arms below the shoulder level.
[2] Supporting above the shoulder level.

the maximal $\dot{V}O_2$ for cycle exercise and 55 ± 16% of the maximal $\dot{V}O_2$ for simulated parcel sorting (Louhevaara *et al.* 1988). The peak $\dot{V}O_2$ varied from $0{\cdot}9 \pm 0{\cdot}3$ to $1{\cdot}5 \pm 0{\cdot}4\,\mathrm{l\,min^{-1}}$ ($p<0{\cdot}05$) at the sorting centres (table 6). The highest $\dot{V}O_2$ measured was $2{\cdot}6\,\mathrm{l\,min^{-1}}$.

No significant differences were found in blood lactate concentrations determined before the work shift ($1{\cdot}3 \pm 0{\cdot}2\,\mathrm{mmol\,l^{-1}}$), after the most strenuous work phases ($0{\cdot}8 \pm 0{\cdot}3\,\mathrm{mmol\,l^{-1}}$) or at the end of the shift ($0{\cdot}9 \pm 0{\cdot}4\,\mathrm{mmol\,l^{-1}}$) for nine subjects at centres A and E.

In the beginning of the work shift the ratings of perceived exertion on the cardiorespiratory system, legs, back and arms were estimated as 'nothing at all' (0) or 'very weak' (1). During the shift the sensations of exertion increased and reached the levels from 'weak' (2) to 'somewhat strong' (4). All ratings were constantly lowest for subjects at sorting centres D and E (figure 2).

3.3. *Environmental conditions*

In the work places the indoor temperatures ranged from 4 to 22°C being the highest at centre C (18–22°C) and centre E (20–21°C). The relative humidity was under 40% in all measured work places, and at centres B, C, and D it was under 20%. At centres A, B, and C the air velocity was over $0{\cdot}1\,\mathrm{m\,s^{-1}}$ during the work shift. During the study the mean outdoor temperatures were 10, −24, −22, −15 and 5°C at sorting centres A, B, C, D, and E, respectively.

3.4. *Maximal muscle strength and endurance*

The static strength during MVC both for the right and left hand grip muscles (114 ± 19 vs. 110 ± 22 kPa and 112 ± 21 vs. 109 ± 22 kPa, respectively) differed 3% ($p<0{\cdot}05$) before and after the work shift (table 7). No significant differences were found in the static endurance times for the right hand-grip muscles nor in the dynamic endurance times for the left hand-grip muscles when the results obtained after the work shift (static: 104 ± 24 s, and dynamic: 204 ± 142 s) were compared to the baseline values (static: 104 ± 25 s, and dynamic: 179 ± 65 s).

Table 5. Heart rate (HR) in the tasks during the work shift at the sorting centres. The values given are the means ± s.d.

Sorting centre	*n*	Number of HR min			HR (beats min^{-1})					
			Ramp	Cont.	Transp.	Lift	Other	Letter	All work tasks	Pause
A	10	4059	103 ± 24	100 ± 14	92 ± 14		90 ± 16		99 ± 20	84 ± 17
B	6	2303	99 ± 18	106 ± 15	111 ± 20	94 ± 16	97 ± 19		101 ± 19	90 ± 15
C	6	2408	101 ± 15	108 ± 15	105 ± 13		98 ± 14	101 ± 9	101 ± 13	92 ± 12
D	4	1300		111 ± 16	114 ± 17	112 ± 16	101 ± 18		111 ± 17	91 ± 18
E	5	1691		98 ± 14	100 ± 11	96 ± 10	89 ± 16	86 ± 11	96 ± 13	85 ± 13
				NS	NS		NS		NS	
All	31	11761	101 ± 21	103 ± 15	103 ± 17	98 ± 16	96 ± 16	97 ± 12	101 ± 18	88 ± 16

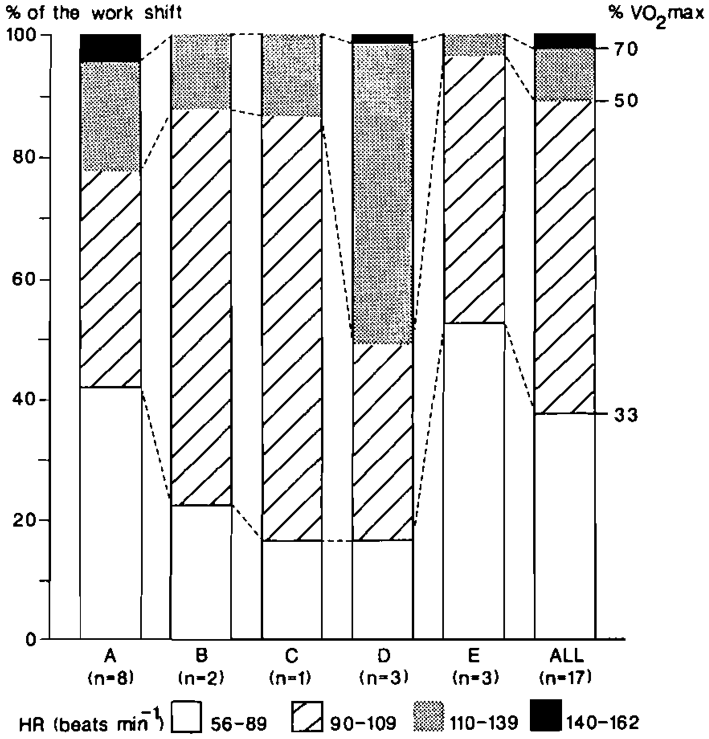

Figure 1. The relative proportion (%) of the length of the work shift spent at the heart rate (HR) levels of 56–89, 90–109, 110–139 and 140–162 beats min^{-1} at the sorting centres. During cycle exercise, the relative aerobic strain level of 33% of the maximal $\dot{V}O_2$ was exceeded at the HR level of about 90 beats min^{-1}, 50% $\dot{V}O_2$ max at the HR level about 110 beats min^{-1} and 70% $\dot{V}O_2$ max (the anaerobic threshold for simulated parcel sorting) at the HR level of about 140 beats min^{-1}. The number of subjects is in parentheses.

Table 6. Oxygen consumption ($\dot{V}O_2$), heart rate (HR), and relative aerobic strain (% $\dot{V}O_2$ max) for cycle exercise and for simulated parcel sorting in the most strenuous work phases at the sorting centres. The values given are the means ± s.d.

Sorting centre	*n*	$\dot{V}O_2$ (l min^{-1})	HR (beats min^{-1})	*n*	% $\dot{V}O_2$ max Cycling	% $\dot{V}O_2$ max Sorting
A	10	0·9 ± 0·3	104 ± 17	8	30 ± 4	48 ± 6
B	6	1·2 ± 0·3	106 ± 19	2	37 ± 5	55 ± 8
C	6	1·3 ± 0·2	104 ± 13	1	40 ± 6	58 ± 8
D	5	1·5 ± 0·4	118 ± 14	3	40 ± 7	58 ± 7
E	5	1·2 ± 0·3	102 ± 12	3	35 ± 5	54 ± 5
		$p < 0{\cdot}05$	NS			
All	32	1·2 ± 0·4	105 ± 16	17	37 ± 14	55 ± 16

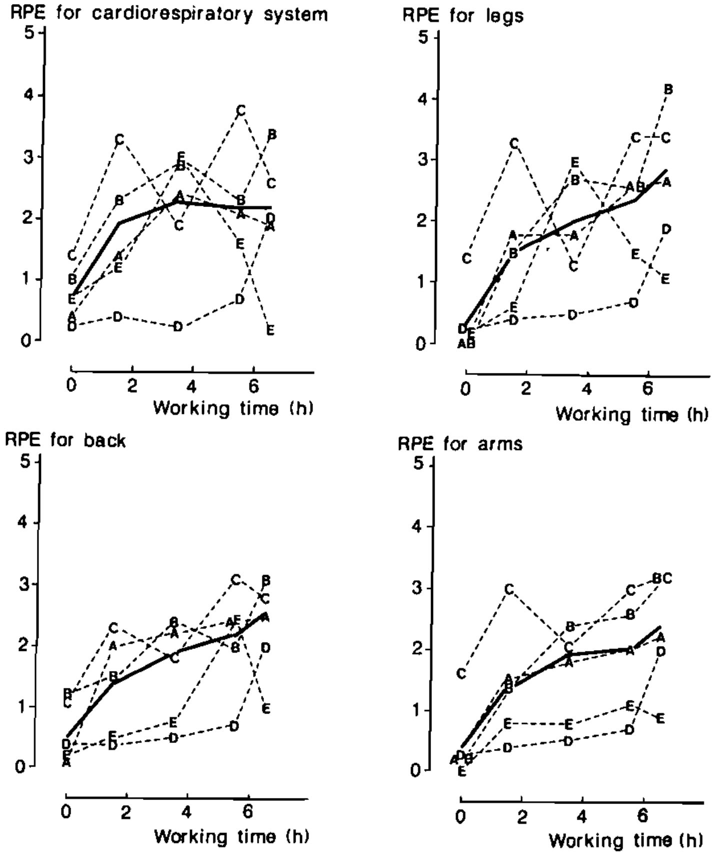

Figure 2. The ratings of perceived exertion (RPE) for the cardiorespiratory system, for legs, back and arms in the beginning of the work shift, during the shift and at the end of the shift. The values given are the means. The solid line in each sub-figure is the mean for 32 subjects.

Table 7. Static strength during maximal voluntary contraction (MVC) with the right and left hand-grip muscles before and after the work shift. The values given are the means ± s.d.

		MVC, right hand			MVC, left hand		
Sorting centre	*n*	Before (kPa)	After (kPa)		Before (kPa)	After (kPa)	
A	10	107 ± 14	105 ± 13	NS	107 ± 12	104 ± 13	NS
B	6	119 ± 15	113 ± 17	$p<0·05$	110 ± 25	104 ± 22	NS
C	6	104 ± 19	97 ± 30	NS	112 ± 15	109 ± 23	NS
D	5	115 ± 21	114 ± 25	NS	104 ± 36	104 ± 36	NS
E	5	132 ± 19	130 ± 23	NS	132 ± 21	129 ± 23	NS
All	32	114 ± 19	110 ± 22	$p<0·05$	112 ± 21	109 ± 22	$p<0·05$

4. Discussion

4.1. *Work output and tasks*

The work output and tasks are affected by the level of engineering and work organization. The sorting centres studied were technically different. The use of semi-mechanized sorting conveyor lines increased the work output during the evening shift about twofold higher than that during more manual sorting, but it did not considerably affect the work output (parcels min^{-1}) during the time for sorting. The physical work required by the sorting lines seemed to consist of fewer work tasks.

The sorting centres had a strong common organizational factor, i.e., a fixed salary with a time premium. This system allows the sorters to be off duty as soon as their daily work output has been completed. The work processes were rather intermittent, and the subjects were quite free to set their own workpace and work–rest regimens. For instance, at sorting centre E the subjects did not spend the entire time allotted for official rest pauses.

4.2. *Cardiorespiratory stress and strain*

At the sorting centres the average HRs for different parcel sorting tasks varied from 89 to 114 beats min^{-1}, depending basically on the amount of walking required by parcel sorting. These HRs were higher than those measured in different municipal occupations (Nygård 1988) and similar to those measured in foundry and shipyard work (Louhevaara *et al.* 1985). Substantially higher HR values have been reported in mail delivery work (Oja *et al.* 1977, Ilmarinen *et al.* 1984), in construction work (Louhevaara *et al.* 1985), in the building industry (Klimmer *et al.* 1983) and in the steel and iron industry (Klimmer *et al.* 1984).

The average HR during parcel sorting (101 beats min^{-1}) corresponded to a $\dot{V}O_2$ of about 1·01 min^{-1} according to the HR–$\dot{V}O_2$ relationship assessed during the parcel sorting simulations (Louhevaara *et al.* 1988). The $\dot{V}O_2$ of 1·01 min^{-1} was 31% of maximal $\dot{V}O_2$ for cycling and 40% maximal $\dot{V}O_2$ for simulated parcel sorting. During actual parcel sorting the relative aerobic strain was predicted to be over 50% of maximal $\dot{V}O_2$ for cycling during 11% of the evening shift which was 6·5 h, on average. Correspondingly, the anaerobic threshold for simulated parcel sorting (about 70% of maximal $\dot{V}O_2$ for cycling) was calculated to be exceeded in the sorting tasks that covered 2% of the work shift. At sorting centre A the predicted infrequent anaerobic work situations (figure 1) were probably not discerned, and their verification with blood lactate determinations was not successful.

It has been suggested that 33% of maximal $\dot{V}O_2$ for leg exercise is an acceptable level for continuous dynamic physical work during an 8 h shift, and correspondingly 50% of maximal $\dot{V}O_2$ for the prolonged work with sufficient work–rest regimens (Åstrand 1960, Ilmarinen 1984). The latter guideline is probably suitable for the manual sorting of postal parcels as the leg exercise with a cycle-ergometer simulated well parcel sorting (Louhevaara *et al.* 1988). Furthermore, postal sorting was not repetitive lifting work, and the time needed for rest pauses was usually available. Thus, during actual sorting average cardiorespiratory stress and strain could be classified as moderate or acceptable (Andersen *et al.* 1978) with quite rare peak load situations. This result was supported by the ratings of perceived exertion for the cardiorespiratory system. They did not exceed the 'somewhat strong' level. Recently Hultman *et al.* (1984) and Nygård (1988) reported similar values when they used the scale from 6 to 20 for the rating of perceived exertion (Borg 1970) in janitorial work and in municipal occupations.

Almost in every work task the subjects were able to adjust their strain individually. Nevertheless, the self-control of few subjects, probably under the pressure of the time bonus, seemed to be insufficient to prevent them from straining themselves in some tasks beyond the acceptable limits, i.e., 50% of their individual maximal $\dot{V}O_2$ for leg exercise (figure 1).

4.3. *Musculoskeletal stress and strain*

The evaluation of the stress and strain on the musculoskeletal system during parcel sorting was based on quantitative data about work output and tasks, poor work postures of the observation study, and the local ratings of perceived exertion for legs, back and arms.

The mean number of the parcels sorted during the evening shift was about 1200. The average weight of the parcels was 4 or 5 kg, the latter value being based on long-term statistics of the Central Post Office. The heaviest parcels, postal bags and bundles of newspaper, weighed 15–20 kg. It was estimated that about one-third of the parcels were lifted up or down above shoulder level or below knuckle level. Usually a sorter did not open the lower part of the front door of the parcel container. This resulted in increased lifting and lowering in extremely bent forward and stretched body positions when the last and first parcels were handled on the bottom of the container.

The ramp, container and transport tasks included almost continuous manual sorting and handling of parcels, and the amount of poor work postures for the back (bent forward or bent and twisted) and arms (elevated below or above shoulder level) were 26% and 47% of the time for sorting, respectively. In cleaning work, Louhevaara *et al.* (1982) reported bent forward postures for the back during 56% and positions with arms above shoulder level during 38% of the working hours. These percentages were as high as those in the maintenance of agricultural machines and about twice as high as those observed in the sawmill and printing industries (Nygård 1988).

Local ratings of perceived exertion for legs, back and arms during the work shift did not exceed, on average, the 'somewhat strong' level. The present results were similar to the corresponding ratings obtained from janitorial work (Hultman *et al.* 1984) and from professional kitchen work (Nygård *et al.* 1989).

Evaluation of the data indicated that the average stress on the musculoskeletal system was more dynamic than static, and that probably the stress and strain were not excessive for the subjects of this study. This result was supported by the subjective ratings of acceptable load (Griffin *et al.* 1984) done by the subjects. They felt they could sort parcels weighing considerably more than the average weight of the parcels (4–5 kg) in actual work without symptoms of fatigue (Stålhammar *et al.* 1989).

4.4. *Physical work capacity*

When the appropriateness of a sorter's cardiorespiratory and musculoskeletal strain is considered, it must be emphasized that physical strain depends both on the stress factors at work and on an individual's physical work capacity (Rutenfranz 1981). The subjects of this study were healthy men and only few of them had recently had some slight pain symptoms in their musculoskeletal system. The seventeen subjects who participated in the assessment of physical work capacity had an average aerobic power in their age group when their maximal $\dot{V}O_2$ for cycle exercise was $3{\cdot}10\,\mathrm{l\,min^{-1}}$ (Andersen *et al.* 1978). The maximal $\dot{V}O_2$ of the fifteen field subjects was not assessed, but there is no reason to believe that their maximal $\dot{V}O_2$ would be substantially different when compared to the subjects measured in the laboratory.

The mean static strength during MVC of all subjects for the right hand-grip was 114 kPa and for the left hand-grip 112 kPa before the work shift. Corresponding results obtained with policemen were 95 and 94 kPa, respectively (Louhevaara, V., Smolander, J. and Korhonen, O. 1982). In the baseline measurements, the mean static endurance time of the seventeen subjects for the right hand was 104 seconds at 46% of MVC. According to the calculations of Monod and Sherrer (1957) the average value might be 72 s. The hand-grip measurements showed that the subjects had good strength and endurance in the flexor muscles of their fingers.

Because the present subjects were healthy volunteers aged 23–45 years, they represented a motivated and physically selected sample of all sorters of postal parcels. Particularly the subjects at centre E were young, strong, and lean. These characteristics are usually good predictors for high physical work capacity. This may have decreased the subjects' need for pauses and their ratings of perceived strain.

The selection of subjects unavoidably operates among the individuals who volunteer for the work capacity tests and also in different field measurements requiring full co-operation (Oja *et al.* 1977). If a sorter's physical work capacity has been decreased, or he is aged (Nygård 1988), the individual characteristics needed for the assessment of strain cannot be predicted according to the results of this study.

4.5. *Muscle strength and endurance*

A small but statistically significant decrease was found in the maximal static strength both for the right and left hand-grip muscles when the values obtained after the work shift were compared to those mesured before the shift. Probably this was a slight indication of acute local muscle fatigue caused by manual parcel sorting.

No significant differences were found in static or dynamic endurance times between the baseline measurements and the measurements after the work shift. The stress of the parcel sorting might be too low to affect the hand-grip endurance times. In the tests, the subjects had difficulties to produce the submaximal target level of strength (50% of individual static MVC). The strength levels varied from 44 ± 3 to 57 ± 4%MVC, and after the shift they were 2–3% lower than the baseline levels. The time gap (6–10 months) between the baseline endurance measurements in the laboratory and the measurements after the work shift may have been excessive. The baseline times for static and dynamic endurance could have been determined before each work shift but it was anticipated that the maximal endurance tests immediately before the shift would have affected both actual sorting work and the measurements after the shift (Funderburk *et al.* 1974).

5. Conclusions

The following main conclusions can be drawn from the present study. First, during the evening shift of sorting of postal parcels the stress and strain on the cardiorespiratory and musculoskeletal system was estimated to remain within acceptable limits for the healthy male sorters with an average aerobic power and good hand-grip muscle strength and endurance.

Second, the use of semi-mechanized sorting conveyor lines increased the work output during the evening work shift about twofold higher than that during more manual sorting, but did not considerably affect physical stress and strain.

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On a effectué une étude sur le site afin d'analyser la contrainte et l'astreinte cardio-respiratoire et musculo-squelettique, ainsi que le rendement pendant le tri manuel de paquets de poste. On se proposait également de mettre en évidence les effets de ce travail sur la force musculaire et sur l'endurance.

Les sujets, tous volontaires, étaient 32 hommes affectés au tri, agés en moyenne (± e.t.), de 34 ± 7 ans et travaillant sur cinq sites différents. Chaque sujet a été observé durant un poste du soir. Durant leur poste de 391 ± 46 min, les sujets ont trié 1173 ± 630 paquets et ont marché 4,7 ± 2,3 km avec et sans charge. Pendant le tri, leur fréquence cardiaque était de 101 ± 18 battements par min. Lors des tâches les plus astreignantes, leur consommation d'oxygène était de $1{,}2 \pm 0{,}4\,\mathrm{l\,min}^{-1}$ et on n'a pas trouvé de concentration élevée de lactate plasmatique. Les postures de travail avec le dos penché vers l'avant occupaient 24% du temps de tri.

Le jugement global de l'astreinte cardio-respiratoire et le jugement local de l'effort perçu dans le bras, le dos et les jambes ne dépassaient pas le niveau 'un peu difficile'. La force statique maximale mesurée sur les poignets était, en moyenne, de 3% ($p < 0{,}05$) plus basse après le poste qu'avant. Il n'y avait pas de différences significatives dans le temps d'endurance statique et dynamique des muscles impliqués, entre avant et après le travail.

On peut conclure que dans les Centres de tri, la contrainte et l'astreinte cardio-respiratoire et musculo-squelettique demeure dans des limites acceptables pour les employés hommes en bonne santé.

Es wurde eine Feldstudie zur Beurteilung der cardio-respiratorischen und musculo-skeletalen Belastung und Beanspruchung und der Arbeitsleistung während des manuellen Sortierens von postalischen Paketen durchgeführt. Weiterhin sollten die Effekte des Paketsortierens auf die maximale Muskelkraft und die Ausdauerzeit herausgefunden werden. Bei den freiwilligen Versuchspersonen handelte es sich um 32 gesunde männliche Sortierer mit einem mittleren Alter von 34±7 Jahren, die an 5 unterschiedlichen Stellen im Sortiervorgang arbeiten. Jede Versuchsperson wurde während einer abendlichen Arbeitsschicht untersucht. Während der Schicht von 391±46 min sortierten die Versuchspersonen manuell 1173±630 Pakete und liefen 4,7±2,3 km mit und ohne Lasten. Während des Sortierens lag die Herzschlagfrequenz bei 101±18 Schlägen pro Minute. Bei den schwersten Aufgaben lag der Sauerstoffverbrauch bei 1,2±0,4 l min^{-1} und es wurde keine erhöhte Blutlaktat-Konzentration gefunden. Köperhaltungen mit nach vorne gekrümmtem Rücken traten in durchschnittlich 24% der Sortierzeit auf. Die gesamte cardio-respiratorische Bewertung und lokale Bewertungen der erlebten Anstrengung von Armen. Rücken und Beinen überschritten nicht das 'etwas stark'-Niveau während einer Schicht. Die maximale statische Kraft sowohl für die rechten als auch die linken Greifmuskeln der Hand waren im Durchschnitt nach der Arbeitsschicht 3% niedringer ($p<0{,}05$) als vor der Arbeitsschicht. Es wurden keine signifikanten Unterschiede in den statischen oder dynamischen Ausdauerzeiten für die Greifmuskeln der Hand beim Vergleich der Werte nach der Arbeitsschicht mit den Ausgangswerten gefunden. Die Belastung und Beanspruchung des cardio-respiratorischen und musculo-skeletalen Systems wurde an Sortierplätzen so beurteilt, daß sie für gesunde männliche Sortierer innerhalb akzeptabler Grenzwerte liegt.

郵便小包の手動仕分け中の心肺，筋骨格ストレスとストレインを評価し，最大筋力，持久性に及ぼす小包仕分けの影響を検出するために現場研究を実施した。志願した被験者は5つの仕分け所からの平均年令が34±7歳の32名の男性仕分け人であった。各被験者は1回の夜勤時に検査した。391±46 minの夜勤中に被験者は1173±630個の小包を仕分けし，荷物の有無に関係なく4.7±2.3km歩行した。仕分け中の心拍数は101±18拍／分であった。もっともきつい作業時の酸素摂取量は1.2±0.4 l／minで，血中乳酸塩濃度は高くならなかった。背中を前傾した作業姿勢は平均して仕分け時間の24%であった。全体心肺評点，腕，背中，脚の知覚努力の局所評点は勤務中に「いくらか強い」水準を超えなかった。左右の手の握り筋肉の最大静的筋力は勤務前と比べて勤務後には平均して3%（p <0.05）低かった。勤務後に測定した値を基準値と比較すると，手握り筋肉の静的または動的持久時間に有意差は見られなかった。小包仕分けセンターでの心肺，筋骨格系のストレス，ストレインは健康な男性仕分け人にとって許容範囲内であると評価された。

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Physiological responses during and after intermittent sorting of postal parcels

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Physiological responses including ventilatory gas exchange, blood lactate (LA) and heart rate (HR) were studied during and after intermittent manual sorting of postal parcels in a simulated workplace constructed in the laboratory. Responses to parcel sorting were compared to those obtained during arm crank and cycle exercise. The subjects were 21 healthy male sorters. Their age was 33 ± 6 years and weight 78·3 ± 12·7 kg. The subjects' maximal oxygen consumption ($\dot{V}O_2$ max) was 2·52 ± 0·32 l min^{-1} for arm cranking, and 3·24 ± 0·44 l min^{-1} for cycling. The subjects sorted parcels with a mean weight of 5·1 kg from a container onto two trollies for 3·5 min at each of the following work rates: slow (3 ± 0 parcels min^{-1}), habitual (8·6 ± 2·4 parcels min^{-1}), accelerated (10·8 ± 3·1 parcels min^{-1}), and maximal (16·9 ± 7·6 parcels min^{-1}). The tasks were separated by rest periods of 30 s for venous blood sampling, and the recovery was followed for 16 min. At the habitual work rate, $\dot{V}O_2$ was 1·36 ± 0·38 l min^{-1}, LA 1·8 ± 0·9 mmol l^{-1}, and HR 105 ± 22 beats min^{-1}. The parcel sorting studied was predominantly aerobic (LA < 4·0 mmol l^{-1}) up to the work rate of about 20 parcels min^{-1}. After the recovery period, breathing frequency and HR remained significantly higher than at rest. The physiological responses to parcel sorting substantially differed from those to arm cranking, whereas they were almost equal to cycling.

1. Introduction

The manual sorting of postal parcels is a world-wide material-handling task involving mixed dynamic and static muscular work. In Finland, during a sorter's workshift of 6–8 hours, the total weight of the parcels handled may exceed 9000 kg, and the amount of walking 10 km with and without a load (Louhevaara *et al.* unpublished results).

Previous studies on aerobic and anaerobic responses to manual material handling have mainly focused on lifting tasks, and the responses were compared with various techniques and frequencies of lifting, and weights of load (Snook 1978, Petrofsky and Lind 1978 a, Garg and Saxena 1979, Peacock 1980). In the experiments of Petrofsky and Lind (1978 a, b), boxes weighing 0·9, 6·8, 22·7 and 36·4 kg were lifted up to or down from a height of 60 cm. At submaximal levels of external work, oxygen consumption ($\dot{V}O_2$) was found to be substantially higher than at the similar levels of dynamic leg exercise on a cycle ergometer. However, the maximal $\dot{V}O_2$ during lifting was always lower than at maximum on the cycle ergometer. The lifting tasks were

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predominantly aerobic up to 35–40% of the maximal $\dot{V}O_2$ for lifting, when the $\dot{V}O_2$ was from 1·0 to 1·5 l min^{-1} depending on the weight of the box. Peacock (1980) studied $\dot{V}O_2$ in various parcel-handling tasks. The mean weight of the parcels was 5·6 kg (range 0·9–9·5 kg), and for the entire work period of 2 hours, work was carried out at a habitual rate. When loading parcels onto a container from a 91 cm high table and for the reverse (unloading), the mean $\dot{V}O_2$ at the work rate of 4·2 parcels min^{-1} was 1·22 and 1·15 l min^{-1}, respectively.

In spite of the high research activity on the physiology of manual material handling (NIOSH 1981, Troup and Edwards 1985), there is a lack of information on respiratory variables, progress of recovery, and in general on tasks requiring, in addition to lifting, continuous moving and carrying of loads. Static work of the upper body in material-handling tasks may restrict breathing and disturb gas exchange. The recovery period is important in applied work physiology when an optimum level of occupational physical stress and proper work–rest regimens are considered for tasks with varying muscular demands. Furthermore, no comparisons are available about aerobic and anaerobic responses to parcel handling in relation to upper body exercise with an arm crank ergometer (Sawka 1986).

Consequently, the purpose of the present study was (a) to examine a gas exchange including the components of pulmonary ventilation, blood lactate, and heart rate in intermittent sorting of postal parcels, and during recovery; and (b) to compare the responses to the parcel sorting to those obtained during arm crank (upper body) and cycle-ergometer (leg) exercise.

2. Material and methods

2.1. *Subjects*

Twenty-one healthy male sorters of postal parcels, aged 24–45 years volunteered for the study (table 1). Their mean (±s.d.) work experience at this job was 10·3±6·2 years. The study procedure followed the Helsinki declaration and was accepted by the Ethical Committee of the Institute of Occupational Health. Each subject signed a statement of informed consent.

2.2. *Test procedures*

The work test simulating manual sorting of postal parcels and the incremental maximal cycle-ergonometer and arm crank test were carried out in the laboratory at an ambient temperature of 22–24°C, and a relative humidity of 30–40%. The cycle

Table 1. Subjects' physical characteristics. Maximal oxygen consumption ($\dot{V}O_2$max) was measured during cycle and arm crank exercise at separate test occasions.

	$n=21$	
	Mean	s.d.
Age (years)	33·3	5·9
Height (cm)	178·4	7·2
Weight (kg)	78·3	12·7
Body fat† (%)	18·4	5·3
$\dot{V}O_2$max (l min^{-1})		
Cycle exercise	3·24	0·44
Arm crank exercise	2·52	0·32

†According to Durnin and Rahaman (1967).

test was followed by either the work or the arm crank test at random. The tests were administered on separate occasions with a mean interval of 9 days. In the tests the subjects wore shorts and sneakers.

The initial measurements of the subjects comprised a medical examination including an electrocardiogram (ECG) recording and determination of blood pressure in a supine position. Before each test, a plastic needle for repeated venous blood sampling was inserted.

The sorting test was carried out in a simulated workplace constructed in the laboratory with equipment supplied by the Central Post and Telecommunications Office. One hundred parcels with standardized weights and sizes were made for the work test. The distribution of the parcel weights was based on long-term statistics of the Central Post Office. Cardboard covers of different sizes recommended by the Central Post Office were used on the parcels (table 2). The parcels were tied up with tape. A string was added when the weight of a parcel was over 7·5 kg. Each parcel had an address label of 11 × 7 cm including a postal code which was either 01260 or 01620 (equal numbers of each). The codes were selected rather similar to attain mental concentration needed at fast rates of sorting. The height of the code number was 1 cm. The parcels were sorted according to the postal code from a parcel container onto two trollies at a distance of 2·5 m. The length of the container was 1·25 m, width 1·05 m and height 1·67 m. The corresponding trolley measurements were 0·84 m, 0·69 m, and 1·55 m, respectively.

At the beginning of the sorting test, the container was full of parcels in a random order. After an initial rest period of 4 min sitting, the subjects sorted parcels with free style at the following work rates: slow, habitual, accelerated (piecework rate), and maximal. The work rate was increased every fourth minute, and calculated by a researcher with visual observations. The test procedure used was selected because work rate increases in the sorting tasks had to be comparable with the work loads of the arm crank and cycle ergometer. Also at submaximal (slow, habitual and accelerated) work rates, steady state is achieved with the subjects before the end of the 4-min tasks. Habitual, accelerated and maximal work rates were selected individually by the subjects. The slow work rate was a constant of three parcels min^{-1}. During sorting, a researcher followed the movements of the subject, and controlled the gas sampling tube and ECG-lead which connected the subject to the measuring equipment.

Table 2. The weights and dimensions of the postal parcels used in the sorting tasks.

Number of parcels	Unit weight (kg)	Dimensions (cm)
20	0·5	19·5 × 15·0 × 9·5
29	2·5	31·0 × 21·5 × 6·0
21	2·5	38·0 × 29·0 × 9·5
10	7·5	38·0 × 29·0 × 19·0
10	12·5	38·0 × 29·0 × 19·0
4	17·5	38·0 × 29·0 × 19·0
6	17·5	38·0 × 29·0 × 28·5
100	5·1†	32·3 × 24·0 × 11·3†

†Mean values.

At the slow, habitual and accelerated work rates, the sorting was interrupted after 3 min work for 30 seconds while a sample of venous blood was taken. Thereafter the sorting was continued at the preceding work rate to the end of the 4-min period. A venous blood sample was also taken before the sorting tasks with the subjects sitting on a stool, immediately after the end of the maximal sorting task, and during the recovery minutes of 1, 4, 8, 12 and 16 when the subjects again sat on a stool.

2.3. *Equipment and measurements*

In the work and exercise tests, ventilatory gas exchange (respiratory frequency, tidal volume, pulmonary ventilation, oxygen consumption, the production of carbon dioxide and respiratory exchange ratio) was continuously measured and automatically printed by a microprocessor-controlled respiratory gas analyser (Morgan Exercise Test System, P. K. Morgan Ltd, UK). The printings represented the mean values of the last 15 s of each test minute. The analyser consisted of a ventilometer with a light-weight paddle wheel mounted axially in the inspiratory airflow of a breathing valve. Rotations of the wheel were detected by a combined infrared emitter and sensor. Oxygen was analysed with a paramagnetic oxygen analyser (Morgan 500d), and carbon dioxide with an infrared carbon dioxide analyser (Morgan 800d). A low-resistance breathing valve (modified Koegel Y-valve) with a mouthpiece and a nose clip were continuously used during the entire test period of 36 minutes. Before every test, the ventilometer was calibrated by four inspiratory strokes with a manual 1-litre pump, and the gas analysers were calibrated with two mixtures of gases with known oxygen and carbon dioxide concentrations.

In the sorting test, the breathing valve and the expiratory hose were attached on a head cap which was specially designed for the purpose. The standard mixing chamber of expired gases involving the Morgan Exercise Test System was replaced with a loop of the expiratory hose. The accuracy of the modified gas-sampling technique was tested in the pilot experiments. Heart rate was recorded every minute with a Sport Tester PE 3000 Monitor (Polar Electro Ky, Finland) which includes an electrode transmitter and a receiver microcomputer on a wrist. The wireless transmission of heart rate is based on the electromagnetic field. In order to minimize health hazards in the test, an ECG recording was made continuously using the Riegel SM801R cardioscope fitted to the Morgan Exercise Test System.

The venous blood samples of 2·0 ml were collected through the plastic needle into disposable syringes. The outer diameter of the needle was 2 mm. The tip of the needle was inserted in the superficial cubital vein. The needle was not interfering with the sorting tasks. Two separate blood samples of 25 μl were taken from the syringe for determination of blood lactic acid concentration (LA). Venous blood samples were used for LA determinations because venous blood was required for further assessments of the response profile of the acid–base variables in venous blood (Teräslinna *et al.* unpublished results). The LA samples compared were always taken at the same point in the middle of the right forearm. Furthermore, at the compared work levels, cardiac output increased considerably, mixing LA throughout the systemic circulation, although at heavy workloads LA in arterial blood tends to be higher than in venous blood (Yoshida *et al.* 1982). The samples were later analysed enzymically with the Flow Injection Method described by Karlsson *et al.* (1983). The mean value of the duplicates was accepted as a result if the sample LA values differed less than 4% (Smolander *et al.* 1986).

2.4. *Statistics*

The data were treated by conventional descriptive statistics, and the significance of the results was evaluated with the analysis of variance and Student's *t*-test for paired observations. The differences were considered to be statistically significant when $p<0{\cdot}05$.

3. Results

3.1. *Work rates during parcel sorting*

During habitual sorting, individually selected work rate (Mean ± s.d.) was 8·6 ± 2·4 parcels min^{-1}, with a walking speed of 0·6 ± 0·2 m s^{-1}, calculated from the covered distance. At the maximal rate, the corresponding values were 16·9 ± 7·6 parcels min^{-1} and 1·0 ± 0·5 m s^{-1}, respectively. The calculated total weight of the parcels sorted per minute at the habitual work rate was 43·9 ± 12·3 kg, and at the maximal rate was 86 ± 38·8 kg (table 3). The coefficient of variation for both the habitual and accelerated work rates, determined as parcels min^{-1}, was 28%, and for the maximal rate it was 45%.

3.2. *Physiological responses to parcel sorting*

The analysis of variance revealed a statistically significant overall *F* value between each physiological response and work task presented in tables 4 and 5. At the habitual work rate, pulmonary ventilation ($\dot{V}_E$) was 27·2 ± 6·9 l min^{-1}, with a respiratory frequency (f) of 18·9 ± 2·5 breaths min^{-1} and a tidal volume (V_T) of 1·46 ± 0·34 l. At the maximal rate, $\dot{V}_E$ increased to 46·5 ± 21·1 l min^{-1} when f was 25·2 ± 6·0 breaths min^{-1} and V_T 1·81 ± 0·43 l. At the end of the 16-min recovery period, f was 2·44 breaths min^{-1} higher ($p(t)<0{\cdot}05$) than measured during sitting at rest (table 4).

At the habitual work rate, oxygen consumption ($\dot{V}O_2$) was 1·36 ± 0·38 l min^{-1}, lactic acid concentration in venous blood (LA) 1·8 ± 0·9 mmol l^{-1}, and heart rate (HR) 105 ± 22 beats min^{-1}. At the maximal work rate, $\dot{V}O_2$ increased to 2·18 ± 0·78 l min^{-1}, LA to 2·7 ± 1·6 mmol l^{-1}, and HR to 139 ± 30 beats min^{-1}. In each sorting task, the LA value was significantly increased when compared to the value at rest. At the end of the recovery period, $\dot{V}O_2$, respiratory exchange ratio (R), and LA did not differ significantly from the resting values, whereas HR remained significantly higher (11 beats min^{-1}, $p(t)<0{\cdot}001$) than at rest (table 5).

3.3. *Comparison of physiological responses to parcel sorting, arm cranking and cycling*

The submaximal and maximal physiological responses to parcel sorting, arm cranking and cycling were compared on equal absolute $\dot{V}O_2$ levels (figure 1). At the mean

Table 3. Work rate, estimated walking speed and total weight of parcels per minute in the sorting tasks when the subjects employed slow, habitual, accelerated and maximal work rates. The values given are the means ± s.d. for 21 subjects.

Work task	Work rate (parcels min^{-1})	Walking speed (m s^{-1})	Weight of parcels (kg min^{-1})
Slow sorting	3 ± 0	0·3 ± 0	15·3 ± 0
Habitual sorting	8·6 ± 2·4	0·6 ± 0·2	43·9 ± 12·3
Accelerated sorting	10·8 ± 3·1	0·7 ± 0·3	55·1 ± 15·8
Maximal sorting	16·9 ± 7·6	1·0 ± 0·5	86·2 ± 38·8

Table 4. Breathing frequence (f), tidal volume (V_T) and pulmonary ventilation ($\dot{V}_{E(BTPS)}$) in the sorting tasks, and during recovery. The values given are the means±s.d. for 21 subjects.

Time (min)	Work task	f (breaths min^{-1})	V_T (l)	$\dot{V}_{E(BTPS)}$ (l min^{-1})
4	Rest	13·4±3·3	0·81±0·28	10·6±3·1
7	Slow	17·6±3·1	1·19±0·28	20·4±3·4
11	Habitual	18·9±2·5	1·46±0·34	27·2±6·9
15	Accelerated	22·6±4·0	1·65±0·42	37·6±11·9
20	Maximal	25·2±6·0	1·81±0·43	46·5±21·1
21	Recovery	19·6±3·3***	1·65±0·39***	32·7±13·0***
24	Recovery	17·4±3·7***	1·05±0·35**	18·7±7·4***
28	Recovery	16·5±3·7**	0·76±0·15	12·3±2·4**
32	Recovery	16·0±3·5*	0·75±0·15	11·7±2·4
36	Recovery	15·8±3·7*	0·74±0·21	11·1±2·3
		p(F)<0·001	p(F)<0·001	p(F)<0·001

*$p(t)<0·05$, **$p(t)<0·01$, and ***$p(t)<0·001$ compared to the values of sitting at rest.

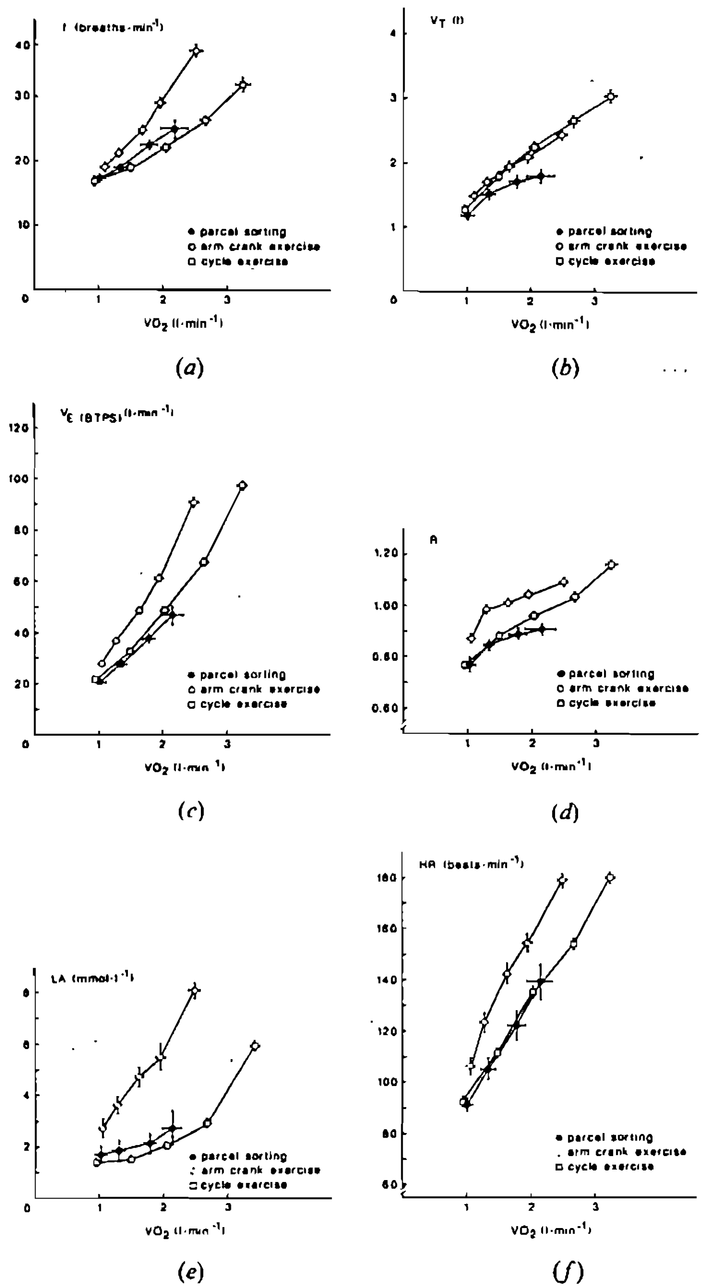
Table 5. Oxygen consumption ($\dot{V}O_2$), respiratory exchange ratio (R), blood lactate (LA), and heart rate (HR) in the sorting tasks, and during recovery. The values given are the means±s.d. for 21 subjects.

Time (min)	Work task	$\dot{V}O_2$ (l min^{-1})	R	LA (mmol l^{-1})	HR (beats min^{-1})
4	Rest	0·33±0·08	0·92±0·16	1·3±0·3	72±11
7	Slow	1·03±0·25	0·77±0·11**	1·7±0·7*	91±14
11	Habitual	1·36±0·38	0·84±0·06*	1·8±0·9***	105±22
15	Accelerated	1·80±0·54	0·88±0·06	2·1±0·9***	122±28
20	Maximal	2·18±0·78	0·91±0·07	2·7±1·6***	139±30
21	Recovery	1·33±0·39***	0·97±0·10	2·7±1·7**	103±27***
24	Recovery	0·50±0·17***	1·14±0·15***	2·4±1·6**	90±20***
28	Recovery	0·34±0·07*	1·01±0·13*	2·1±1·4*	84±16***
32	Recovery	0·34±0·08	0·95±0·11	1·9±1·2*	84±17***
36	Recovery	0·33±0·07	0·92±0·17	1·8±1·0	83±15***
		p(F)<0·001	p(F)<0·001	p(F)<0·001	p(F)<0·001

*$p(t)<0·05$, **$p(t)<0·01$, and ***$p(t)<0·001$ compared to the values of sitting at rest.

$\dot{V}O_2$ level of about 1 l min^{-1}, all tested responses (f, V_T, $\dot{V}_E$, R, LA, and HR), with the exception of f, were significantly lower ($p(t)<0·001$) during parcel sorting than during arm cranking. The largest differences were found in $\dot{V}_E$ (20·4±3·4 vs. 27·3 ±4·3 l min^{-1}) and in HR (91±14 vs. 106±18 beats min^{-1}). However the differences in responses to parcel sorting and cycling were minor (NS).

At the mean $\dot{V}O_2$ level of about 2 l min^{-1}, each response during parcel sorting except f still remained significantly lower ($p(t)<0·05$–$0·001$) than with arm cranking. The differences were significant at the 0·1% level in R (0·91±0·07 vs. 1·04±0·07) and in LA (2·7±1·6 vs. 5·5±1·3 mmol l^{-1}). Furthermore, during parcel sorting, V_T (1·81 ±0·43 l) and R remained significantly smaller ($p(t)<0·05$) than during cycling when V_T and R for cycling were 2·24±0·48 l and 0·96±0·07, respectively. On the other hand, at this $\dot{V}O_2$ level, LA during parcel sorting increased significantly more ($p(t)<0·05$) than during cycling (2·0±0·6 mmol l^{-1}).



(*a*) (*b*)

(*c*) (*d*)

(*e*) (*f*)

Figure 1. (*a*) Breathing frequency (*f*), (*b*) tidal volume (V_T), (*c*) pulmonary ventilation ($\dot{V}_E$), (*d*) respiratory exchange ratio (R), (*e*) blood lactate (LA), and (*f*) heart rate (HR) at absolute submaximal and maximal oxygen consumption ($\dot{V}O_2$) levels in the sorting tasks, during cycle and arm crank exercise. The values given are the means ± s.e.m. for 21 subjects.

4. Discussion

4.1. *Simulated parcel sorting vs. actual work situation*

In the field, 18 of the sorters who participated in the laboratory study were studied during one evening workshift. The work analysis based on a minute by minute observation of the total shift, showed that the simulated workplace used in the sorting test functionally corresponded well to actual work situations. As an example, in the laboratory and during actual manual sorting, the habitual work rates were almost equal (8·6 ± 2·4 vs. 7·3 ± 2·6 parcels min^{-1}; Louhevaara *et al.* unpublished results). In the experiments of Peacock (1980), the mean individual habitual work pace for loading of postal parcels was lower, being about four parcels min^{-1}.

It was calculated that external power output in simulated parcel-sorting tasks remained on the average very low (< 1 W). This was due to the fact that half of the sorting was eccentric (negative) muscle work. Even during the heaviest concentric work phases when parcels were moved by lifting and carrying from the bottom of the container to the top of the trollies, the estimated mean external power output per minute hardly exceeded 10 W.

In the laboratory the mean maximal work rate of the subjects was 16·9 parcels min^{-1} with large individual variation. At maximum, five subjects were able to use a very high work rate of 26–35 parcels min^{-1}. It was clearly noted that during this type of high speed sorting, the individual control over the work method was poor, decreasing the tidiness and accuracy of sorting. Maximum effort also resulted in increased lifting in extremely stretched body positions.

4.2. *Physiological responses*

At the habitual work rate in the sorting test, the mean $\dot{V}O_2$ (1·36 l min^{-1}) was 42% of the $\dot{V}O_2$max for cycle exercise and 54% of the $\dot{V}O_2$max for arm crank exercise. When compared to the $\dot{V}O_2$ value of the maximal sorting task, the relative aerobic strain was 62%. In the field the mean $\dot{V}O_2$ values in the heaviest sorting tasks varied from 1·0 to 1·5 l min^{-1}, corresponding well to the $\dot{V}O_2$ results obtained in the laboratory at slow and habitual work rates (Louhevaara *et al.* unpublished results). The present results also agree with those reported by Peacock (1980) in parcel-handling tasks. Comparable results for ventilatory responses to parcel sorting were not found in the literature.

At slow and habitual work rates, the LA values (1·7 ± 0·7 and 1·8 ± 0·9 mmol l^{-1}, respectively) were significantly higher than for resting, and probably the aerobic threshold was exceeded (Aunola and Rusko 1984). During the high speed sorting (26–35 parcels min^{-1}) used by five subjects the LA was 4·3 ± 2·4 mmol l^{-1}, with the $\dot{V}O_2$ of 3·16 ± 0·89 l min^{-1} amounting to 90% of their mean $\dot{V}O_2$max for cycling and 113% for arm cranking. For the five high speed sorters, the 'standard' anaerobic threshold (LA = 4·0 mmol l^{-1}) was crossed when their relative aerobic strain was about 80% of the $\dot{V}O_2$max for parcel sorting, and 70% of the $\dot{V}O_2$max for cycle exercise. The anaerobic threshold of 80% of the $\dot{V}O_2$max for the present sorting was about twice as high as the corresponding values reported by Petrofsky and Lind (1978 b) for stationary lifting.

Owing to low external power output during parcel sorting, gross mechanical efficiency was estimated to be below 1%. On the other hand, the internal work load of sorting must be quite high, and produced mainly by a sorter's own body movements and the static work required for the lifting and carrying of parcels.

At the end of the 16-min recovery period, f and HR were still significantly higher than the resting values, while the differences in $\dot{V}_T$, $\dot{V}_E$, $\dot{V}O_2$, R and LA were not significant. Hence, the 16-min rest period was too short for complete recovery. Probably the slow recovery of both *f* and HR was primarily attributed to the elevated body temperature (Wyndham 1970). In a practical work situation, HR seems to be a very suitable variable for the estimation of the progress of recovery.

4.3. *Parcel sorting in relation to arm cranking and cycling*

At the mean $\dot{V}O_2$ levels of about 1 and 2 $\mathrm{l\,min^{-1}}$, physiological responses to the arm crank exercise considerably differed from the responses to parcel sorting and cycle exercise. The responses to parcel sorting and cycling were almost equal, showing that this type of sorting included a large component of dynamic muscle work. However, during parcel sorting, $\dot{V}_T$ values constantly remained 6–19% lower than during cycling. This trend was probably influenced by the static work of the upper body, limiting free motion of the thorax. In the continuous material-handling tasks, the reduction of $\dot{V}_T$ may cause hypoventilation and disturb gas exchange. In the present comparisons, the development of insufficient gas exchange during parcel sorting may be seen in the lower R values at the mean $\dot{V}O_2$ level of about 2 $\mathrm{l\,min^{-1}}$ when compared to the cycle exercise.

The present results indicate that the cycle exercise simulates well the aerobic and anaerobic work of a parcel sorter. In all probability this was due to the dominant effect of the large skeletal muscle mass involved in walking and required by the manual sorting of postal parcels. It may be calculated that the relative aerobic strain at the habitual work rate in the laboratory and also in actual sorting tasks was about 40% of the $\dot{V}O_2$max for cycle exercise. The 40% $\dot{V}O_2$max value cannot be considered excessive (Bink 1962, Åstrand 1960). The situation becomes critical when a sorter's $\dot{V}O_2$max in the cycle exercise test is lower than 2·0 $\mathrm{l\,min^{-1}}$.

The present study did not include biomechanical aspects of parcel sorting. Musculoskeletal stress should also be taken into account when work stress and proper work–rest regimens for these types of material-handling tasks are considered.

5. Conclusions

The following conclusions can be reached:

(1) At slow and habitual work rates of 3–9 parcels $\mathrm{min^{-1}}$ with a mean parcel weight of about 5 kg, $\dot{V}O_2$ is 1·0–1·4 $\mathrm{l\,min^{-1}}$, requiring a higher $\dot{V}O_2$max than 2·0 $\mathrm{l\,min^{-1}}$ for a professional sorter.

(2) The static work of the upper body involving parcel sorting may reduce $\dot{V}_T$ and disturb gas exchange.

(3) The cycle exercise simulates well a parcel sorter's aerobic and anaerobic work, whereas the arm crank exercise should not be used for material-handling simulations.

(4) Manual sorting of postal parcels is predominantly aerobic work (LA $< 4{\cdot}0\ \mathrm{mmol\,l^{-1}}$) up to the work rate that corresponds to about 70% of the $\dot{V}O_2$max for cycling.

Acknowledgements

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On a étudié les réponses physiologiques telles que l'échange des gaz repiratoires, le lactate circulant (LA) et la fréquence cardiaque (HR), pendant et après le tri manuel intermittent de paquets postaux, en situations de simulation dans un laboratoire. Ces réponses ont été comparées à celles recueillis lors d'exercices de manivelage et de pédalage. Les sujets étaient 21 employés du tri, d'âge 33 ± 6 a 78,3 ± 12,7 kg. Leur consommation maximale d'oxygène ($\dot{V}O_2$ max) était de 2,52 ± 0,32 l. mn^{-1} pour la manivelage et de 3,24 ± 0,44 l. mn^{-1} pour le pédalage. Les sujets triaient des paquets de poids moyen de 5,1 kg en les déplaçant d'un conteneur vers deux chariots, pendant 3,5 mn, soit à une cadence lente (3 paquets par mn.), à une cadence normale (8,6 ± 2,4 paquets par mn.), à une cadence accélérée (10,8 ± 3,1 paquets par mn), soit à une cadence maximale (16,9 ± 7,6 paquets par mn.). Il y avait des repos de 30s entre les diverses périodes de travail pour recueillir le sang veineux. La récupération e été suivie pendant 16mn.

Pour la cadence normale de travail, la $\dot{V}O_2$ était de 1,36±0,38 l.mn–1, le LA de 1,8±0,9 mmal. l^{-1} et la HR de 10522 battements·mn^{-1}. Le type d'activité étudié était essentiellement aérobie (LA < 4 mmol. l^{-1}) jusqu'à une cadence d'environ 20 paquets par mn. Après la période de récupération, la fréquence respiratoire et la HR étaient demeurées significativement plus élevées qu'au repos. Les réponses physiologiques au tri de paquets étaient nettement différentes de celles du manivelage, mais étaient très proches de celles du pédalage.

Physiologische Meßgrößen, wie der Gasaustauch beim Atmen, das Blutlaktat (LA) und die Herzschlagfrequenz (HR), wurden an einem simulierten Arbeitsplatz, eingerichtet in einem Labor, während und nach dem stoßweisen, manuellen Sortieren von Postpaketen untersucht. Die Ergebnisse wurden mit denen verglichen, die beim Armkurbeln und Zirkeltraining erhalten wurden. Die Versuchspersonen waren 21 gesunde, männliche Sortierer. Ihr Alter betrug 33±6 Jahre und ihr Gewich 78,3±12,7 kg. Der maximale Sauerstoffverbrauch der Versuchspersonen ($\dot{V}O_2$ max) betrung beim Armkurbeln 2,52±0,32 l pro min und beim Zirkeltraining 3,24±0,44 l pro min. Die Versuchspersonen verteilten für die Dauer von 3,5 min 5,1 kg schwere Pakete von einem Container auf zwei Wagen und zwar für jede der folgenden Arbeitsraten: langsam (3±0 Pakete pro min), ständig (8,6±2,4 Pakete pro min), beschleunigt (10,8±3,1 Pakete pro min) und maximal (16,9±7,6 Pakete pro min). Die Aufgaben wurden durch 30-sekündige Ruhepausen, in denen venöses Blut gesammelt wurde, unterbrochen und die Erholungspause folgte mit einer Dauer von 16 Minuten. Bei der ständigen Arbeitsrate war der $\dot{V}O_2$ 1,36±0,38 l pro min, LA 1,8±0,9 mol.pro l und HR 105±22 Schläge pro min. Das untersuchte Sortieren der Pakete bis zu einer Arbeitsrate von 20 Paketen pro min war überwiegend aerob (LA < 4,0 mol pro l). Nach der Erholungspause blieb die Atemfrequenz und die HSF signifikant höher als in der Pause. Die physiologische Meßgrößen beim Sortieren von Paketen unterscheiden sich wesentlich von denen beim Armkurbeln, wohingegen sie denen beim Zirkeltraining fast gleich waren.

換気・血液乳酸塩（ＬＡ），心拍数（ＨＲ）を含む生理的反応を実験室内に設置した模擬職場での郵便小包の間欠的手分け作業中およびその後に調査した。小包仕分けに対する反応はアーム・クランクと自転車の運動中に得た反応と比較した。被験者は21名の健康な男性仕分け人であった。年齢は33±6歳，体重は78.3±12.7kgであった。被験者の最大酸素消費量（$\dot{V}o_2$ max）はアーム・クランク運動で2.52±0.32 l／分，自転車運動で3.24±0.44 l／分であった。被験者は平均重量5.1kgの小包を4つの作業速度の各々で3.5分間1つのコンテナーから2つのトロリーに仕分けした。作業速度は遅い（3±0 小包／分），習慣的（8.6±2.4 小包／分），速い（10.8±3.1 小包／分），最大（16.9±7.6 小包／分）であった。タスクは静脈血採血のための30秒間の休憩で分離され，16分の回復期間が後に続いた。習慣的作業速度で$\dot{V}o_2$は1.36±0.38 l／分，ＬＡは1.8±0.9 mmol／l，ＨＲは105±22 拍／分であった。調査した小包仕分けは約20小包／分の作業速度まで非常に有酸素的である（ＬＡ＜4.0 mmol／分）。回復期間後は換気頻度とＨＲは休憩時よりもかなり高かった。小包仕分けに対する生理的反応はアーム・クランク運動の場合と大きく異なり，自転車運動の場合とほとんど等しかった。

NOMINATION FORM FOR IEA FELLOW AWARD 2017

For use by IEA Member Societies to nominate an individual for the IEA Fellow Award

Submission Instructions:

Please complete this form electronically and e-mail as an attachment (together with other attachments such as CV, letters of support, etc.) to: **PastPres@iea.cc** **and** **vpsg@iea.cc**

Deadline: April 30, 2017

Nominee for IEA Fellow: David Rempel, MD, M.P.H.
Person submission nomination: Andrew S. Imada, Ph.D.
The Nomination: IEA Fellow
Please use as much space as necessary. There is no space limit
NOMINEE:
Full Name (and title): Professor David Rempel
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PERSON SUBMITTING NOMINATION:
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Laguna Niguel, CA 92677 USA
E-mail: asimada@gmail.com
Tel: 1 916.262-5554

1. Eligibility.

Only candidates that meet the two eligibility criteria will be considered for the award. The candidate must have been a Full Member in good standing of a Federated or Affiliated Ergonomics Society for at least the preceding 10 years, and the candidate must have served the ergonomics community at an international level. International service means activities including service to the IEA, and an extensive publication record in international journals or international consulting or service to the United Nations organizations, or similar. Describe below the nominee's service to the society, the IEA, and the ergonomics profession.

Professor Rempel has been an active member of HFES since 1991 and has made important contributions to the science and governance of our society. He currently serves on the Executive Council of the HFES. He is also the HFES representative to the IEA, and is an active member of several Technical Groups. He has served on the Human Factors Journal editorial boards since 2002 and has been on editorial boards or reviewer for 16 other journals. He has served on the ANSI/HFES Z365 Committee (Ergonomics) for 13 years, and has been a presenter in nearly every annual meeting since joining the society 26 years ago.

His contributions to the ergonomics profession beyond HFES are also numerous. He currently serves on the Board of Human Systems Integration, National Academies of Science, Engineering and Medicine. He was one of the key contributors to the landmark Institute of Medicine/National Research Council panel on musculoskeletal disorders in the workplace, and has contributed to numerous NIOSH and OSHA committees, particularly on safe patient handling. He has served as the chair of the IEA Technical Committee on Musculoskeletal Disorders since 2015 and currently represents HFES on IEA Council and has been on the PREMUS International Scientific Committee for many years.

2. Distinction.
Eligible candidates will be evaluated on the basis of demonstrated outstanding theoretical or applied contributions to ergonomics/human factors. There are many ways in which this contribution can be demonstrated. The candidate could have had the primary responsibility for the technical direction, supervision or management of a significant effort during a sustained period of time. The candidate could be a renowned researcher, designer, or consultant of great distinction.
Clear evidence of distinction should be supported by detailed descriptions and attachments. For example, for a researcher, the most significant publications authored or co-authored by the candidate should be attached to the application. For a consultant, the most important consulting contracts should be outlined, together with the outcome of the contracts. For a designer the most important design objects should be specified. Any other information to support or attest to the achievements of the candidate should be furnished to the IEA Awards Committee, in order to support their deliberation of the candidate's merits.
Summarize in the space below the candidate's qualification for the prestigious IEA Fellowship.

Dr. Rempel has made significant contributions in the prevention of work related musculoskeletal disorders (MSD)in the workplace. His leadership and research at both the University of California Berkeley and University of California San Francisco have produced internationally recognized research and a generation of researchers and practitioners in this area.

Dr. Rempel's research contributions focus on two primary areas, laboratory-based injury mechanics studies and field-based workplace intervention studies, both exploring the fundamentals of physical ergonomics. The largest contributions in the injury mechanism research are his studies of carpal tunnel pressure, which define the relationship of external exposure of wrist posture to the internal dose of pressure on the median nerve in the carpal tunnel. With more than a dozen publications on this topic alone, Dr. Rempel is the field's leader exploring the carpal tunnel hypothesis in the development of disabling carpal tunnel syndrome. In addition, Dr. Rempel has completed pioneering biomechanical research of the hand and fingers during repetitive work and explored the physiology of tendons undergoing repetitive loading.

For the past 15 years, Dr. Rempel has led the field completing research studies testing the effectiveness of workplace interventions for upper extremity MSDs. While many of these intervention studies have explored the office environment, his latest projects involve the very challenging industries of construction and health care. In the office environment, Dr. Rempel's studies are among the best and were recently rated as median and high quality studies following the stringent Cochrane review criteria for randomized control trial intervention. In the construction industry, his research applies fundamental physical ergonomic principles to redesigning an overhead drilling operation and then applies human factor usability testing to determine the acceptability of the new tool within the industry. In 2006, his work testing the effectiveness of an arm support won the International Ergonomics Association/Liberty Mutual Prize in Occupational Safety and Ergonomics.

As the director of the Ergonomics Graduate Training Program and faculty member at University of California, Berkeley and University of California, San Francisco, Dr. Rempel made many contributions to ergonomic education. As director, Dr. Rempel has been the mentor for many doctoral students who have also become leaders in ergonomics in academics and in industry. His former students and post-doctoral trainees have developed ergonomic programs at Harvard University, University of Washington, and McMaster University (Canada). Other trainees include directors of ergonomic programs at Microsoft, Magna International, and Genentech. Dr. Rempel has directed a two-day annual continuing education conference on Ergonomics to professional ergonomists in the western states every December since 1992. NIOSH has awarded him continual training grants for occupational biomechanics and ergonomics training since 1997.

Additional Information:

Curriculum Vitae Attached

Endorsement by a Federated Society

Human Factors and Ergonomics Society

Endorsements

Name of endorser: Thomas Armstrong
Position held: HFES Fellow, IEA Fellow
Name of Federated Society: Human Factors and Ergonomics Society

Name of endorser: Pascale Carayon
Position held: HFES Fellow, IEA Fellow, Past IEA Secretary General
Name of Federated Society: Human Factors and Ergonomics Society

Name of endorser: Don Chaffin
Position held: HFES Fellow, IEA Fellow
Name of Federated Society: Human Factors and Ergonomics Society

Name of endorser: Karl Kroemer
Position held: HFES Fellow, IEA Fellow
Name of Federated Society: Human Factors and Ergonomics Society

Name of endorser: Maury Nussbaum
Position held: HFES Fellow, IEA Fellow
Name of Federated Society: Human Factors and Ergonomics Society

Name of endorser: Michelle Robertson
Position held: HFES Fellow, IEA Fellow, Current IEA Executive Committee Member
Name of Federated Society: Human Factors and Ergonomics Society

Letter of Support

Name of endorser: William Marras
Position held: HFES Fellow, Past HFES President, IEA Fellow
Name of Federated Society: Human Factors and Ergonomics Society

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April 18, 2017

IEA Fellow Selection Committee
International Ergonomicss Association

RE: David Rempel, MD, MPH

Dear IEA Fellows Selection Committee:

It is my pleasure to provide a letter of support for Dr. David Rempel's nomination as an IEA Fellow. I have known and followed the work of Dr. Rempel for the past 25 years and feel that I know him very well. He is one of the few occupational medicine physicians who have chosen to focus on the causality and treatment of occupationally related upper extremity disorders and has been able to distinguish himself as one of the world's leading authorities on upper extremity ergonomics issues.

Dr. Rempel is an upper extremity researcher par excellence. He is widely known in orthopaedic biomechanics and ergonomics circles, both nationally and internationally. Professor Rempel is attempting to understand the basic concepts and mechanisms underlying the response of the upper extremity to various work exposures and, in particular, cumulative trauma. In this space, Dr. Rempel is considered one of the top five people in the world addressing these issues. Specifically, he is well known for his work related to human interactions with computer workstations and the effects on the upper extremity, a problem that is becoming ever more important with the proliferation of digital devices in modern society. He is also extremely well known for his work in construction ergonomics where he has studies shoulder and upper extremity risk factors and has developed patented interventions to relieve the musculoskeletal stress associated with overhead work.

A search of the *Web of Science* reveals that David has published 183 articles during his distinguished career with over 4000 citations to his work. This has earned him an h-index ranging from 37 (via the conservative *Web of Science*) to 46 (via Research Gate). These indexes are remarkable especially given that David is a physician-scientist and spends much of his time treating patients.

Not only has Dr. Rempel been able to establish himself as a prolific publisher, but he has credibility as a careful researcher who consistently and deliberately constructs and performs meaningful and relevant studies. In addition, he is an excellent speaker who can articulate his findings and engage researchers relative to technical issues as well as engage workers about the relevance of his findings at a layman's levels. Perhaps one of the most unique aspects about David has been his ability to adapt his work according to where his research findings lead him. For example, his background is in bioengineering and biomechanics, and much of his earlier work has reflected this view of the world. However, his clinical experiences, research in the laboratory, and experience in industry has led him to explore the physiologic responses of the body to cumulative trauma. He is now considered one of the pioneers in the area of pathomechanics of the upper extremity.

Professor Rempel is well respected and has received both national and international recognition for his expertise in our field for his groundbreaking research related to cumulative trauma. Several years ago, I was a member of the National Academies of Sciences, Engineering and Medicine "Steering Committee on the Work-Related Musculoskeletal Disorders." As part of this effort we conducted a workshop and asked prominent scientist to review the literature. David was asked to prepare a commissioned report on "Biological Response of Peripheral Nerves to Loading." The committee was so impressed with his work, he was asked to become a member of a subsequent Congressionally-mandated "Panel on Musculoskeletal Disorders in the Workplace." After that Dr. Rempel was invited to become a member of the National Research Council's "Board on Human Systems Integration" that serves the National Academies of Science, Engineering and Medicine.

I have also had opportunities to review David's proposals as part of the National Institute for Occupational Safety and Health study group on "safety and occupational health." Dr. Rempel's proposals consistently were rated among the very best because they clearly addressed the heart of the issues involving cumulative trauma disorders. As a result of these ideas and appreciation for his work, he has enjoyed consistent funding from NIOSH as well as other groups concerned with occupational musculoskeletal disorders. More recently, Professor Rempel was elected to the Executive Council of the Human Factors and Ergonomics Society within the U.S. As a co-member of that committee I have had the opportunity to observed him contribute to our professional society in a thoughtful and measured manner. He is well respected by his professional colleagues who view him as an outstanding scientist and symbol of professional integrity. Collectively, these efforts and engagements reflect his ability to earn a deep level of respect from the scientific community a national level within the United States.

Internationally, David's work has also been widely recognized. In recent years, he has presented invited lectures at the International Ergonomics Association Triennial Meeting in Australia, as well as international conferences in Brazil, Greece, Finland, Korea, Columbia and Japan.

Dr. Rempel has also been active in providing service to both industry and the scientific community. He regularly organizes conferences and symposia that not only perform a technology transfer function for practitioners in the field but also provide an opportunity for scientist in the field to meet regularly and exchange information. Dr. Rempel's reputation for providing objective assessments as consulting services to industry is well regarded.

I have also had the opportunity to meet and interact with Professor Rempel's students over the years. His students are held in high esteem in the ergonomic community and enjoy the honor of consistently receiving the best job offers in the field. Conversations with his students indicate that they all have the highest regard for his intellectual capacity and his ability to lead. He challenges his students and molds them into productive ergonomic researchers. His reputation as an academic is also evident from the professionals who collaborate with him through sabbaticals.

On a personal note, David is energetic, congenial, articulate, and compassionate. He is a real advocate of the profession and can draw people in to his research very easily through his presentation style.

I hope that the above comments are useful in your deliberations. If my overall evaluation of his quality was not sufficiently clear in those comments, I wish to restate this one more time. Professor Rempel is an outstanding scientist, and has become one of the top scholars in his area. I think his is far overdue to be awarded the distinction as an IEA Fellow.

Sincerely,

William S. Marras, Ph.D. CPE
Honda Chair Professor, Integrated Systems Engineering
Executive Director and Scientific Director
Spine Research Institute

CURRICULUM VITAE

NAME: David Rempel, M.D., M.P.H.

BIRTHDATE/PLACE: 1954, California

CITIZENSHIP: United States & Canada

ADDRESS:
University of California, San Francisco
Ergonomics Program
Division of Occupational and Environmental Medicine
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EMPLOYMENT:

2014-present	Professor of Medicine Emeritus, Department of Medicine, UCSF
2002-2014	Professor of Medicine, Department of Medicine, UCSF
1996-2002	Associate Professor of Medicine, Department of Medicine, UCSF
1992-1996	Assistant Professor of Medicine, Department of Medicine, UCSF
1990-1992	Assistant Clinical Professor of Medicine, Department of Medicine, UCSF
1985-1990	Public Health Medical Officer/Epidemiologist, California Occupational Health Program, California Department of Health Services, Berkeley

ACADEMIC:

2005-present	Professor (in Residence), Department of Bioengineering, UC Berkeley
2014-present	Professor Emeritus, Department of Medicine, UCSF
2015-present	Adjunct Professor, Engineering, Simon Fraser U, British Columbia, Canada
2015	Visiting Professor, Tianjin University, China
2002-2014	Professor, Department of Medicine, UCSF
2013-2014	Visiting Professor, University of Bologna, Italy
2012-2013	Visiting Professor, Simon Fraser University, Vancouver, BC, Canada
2000-2005	Associate Professor, Department of Bioengineering, UC Berkeley
2004-2005	Visiting Professor, University of British Columbia, Canada
1997-2003	Associate Professor, Department of Mechanical Engineering, UC Berkeley
1997-1998	Visiting Associate Professor, Dept of Hand Surgery, Lund University, Sweden
1996-2002	Associate Professor, Department of Medicine, UCSF
1992-1996	Assistant Professor, Department of Medicine, UCSF
1988-1992	Assistant Clinical Professor, Department of Medicine, UCSF
1986-1988	Residency in Occupational Medicine, Department of Medicine, UCSF
1983-1985	Residency in Internal Medicine, Santa Clara Valley Medical Center, San Jose, CA
1982-1983	Internship in Internal Medicine, Kaiser Foundation Hospital, Oakland, CA
1980-1981	M.P.H., Epidemiology, University of California, Berkeley
1977-1982	M.D., University of California, San Francisco
1974-1977	B.A., Bioengineering, University of California, San Diego

ORGANIZATIONS:
Fellow, American College of Occupational and Environmental Medicine
Fellow, American College of Physicians
Fellow, Human Factors and Ergonomics Society
International Congress of Occupational Health
American Conference of Governmental Industrial Hygienists

LICENSURE:
California Medical License, 1982 - p

SPECIALTY BOARDS:
Certified Diplomate by American Board of Internal Medicine, 1985.
Certified Diplomate by American Board of Preventive Medicine, Occupational Medicine, 1989
Certified Professional Ergonomist by Board of Certification in Professional Ergonomics, 1994

AWARDS:
Special Emphasis Research Career Award, 1992
NIH/Fogarty Senior International Fellowship Award, 1997
Jean Spencer Felton Award for Scientific Writing, WOEMA, 2000
IEA/Liberty Mutual Prize in Occupational Safety and Ergonomics, 2006
HFES/User-Centered Product Design Award, 2007
UCSF Occupational Health Nursing Champion Award, 2014
ACOEM Centennial Health Achievement in Occupational Medicine Award, 2016

PATENTS
02/22/00 Ergonomic Mouse Device (6509891; 09/510,725)
06/10/11 Virtual Pedals for Robotic Surgery (61/476,222) (US,Pending)
07/29/14 System and Method for Estimating Blood Volume (8,792,693)

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Journal of the American Medical Association
Journal of Occupational and Environmental Hygiene
Journal of Occupational and Environmental Medicine
Journal of Orthopaedic Research
Journal of Safety Research
New England Journal of Medicine
Occupational and Environmental Medicine
Scandinavian Journal of Work and Environmental Health
The Lancet - Neurology

PEER REVIEWED PUBLICATIONS:

1. Harrison R, Bellows J, Rempel D, Rudolph L, Kizer K, Jin A, Guglielmo J, Bernard B. Assessing Exposures of Health-Care Personnel to Aerosols of Ribavirin - California. Morbidity and Mortality Weekly Report 1987; 37:560-563.
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Harrington D, Barr A, Robbins M, Rempel D. The challenges of moving from innovation to adoption. WestON, Council of State and Territorial Epidemiologists. 2011.

Satish S, Abdulla A, Zhao C, Rempel, D, Gonzalgo, M and Hsieh, M. Virtual Instrument Pedals: Towards Improved Surgeon Ergonomics and Operating Room Safety. National Conference of American Academy of Pediatrics, Oct 15, 2011, Boston, MA.

Rempel D, Barr A, Star D, Robbins M, Janowitz I. Interventions for Concrete Drilling. Applied Ergonomics 2011, Orlando, FL. Rempel D. Interventions for Overhead and Concrete Drilling. American Society of Safety Engineers' June 15, 2011, Chicago, IL.

Rempel D, Robbins M, Barr A, Star D, Janowitz I. Interventions for Overhead Drilling into Concrete. American Industrial Hygiene Annual Meeting. (AIHce), May 14, 2011, Portland, OR.

Rempel D. Emerging Occupational Ergonomic Problems and Solutions. UCSF Occupational and Environmental Medicine CE Conference, March 18, 2011, San Francisco, CA.

RECENT INVITED LECTURES

Design of Workplace RCTs: Preventing Musculoskeletal Disorders, Mt. Sinai School of Medicine, NYC, 2011
Recent Research: Upper Extremity Risk Factors. Puget Sound Human Factors Society (Keynote), Seattle, 2011
Recent findings from the Prospective NIOSH MSD Consortium Studies (Keynote), HFES, Las Vegas, 2011
Risk factors for wrist tendonitis: The San Francisco study. UC Irvine, Dept of Occupational Medicine, 2012
Workplace intervention studies: design and quality. U of Copenhagen, 2012
Design of Hand Tools: Preventing Injuries and Fatigue. U of Bologna, 2013
Evidence Based Medicine and Work-Related Carpal Tunnel Syndrome. U of Bologna, 2013
Causation of Carpal Tunnel Syndrome. Western Occupational Health Conference, Hawaii, 2013
Design of Hand Tools: Applying Physiology and Biomechanics. Northern Illinois U, 2014
Personal and Work-Related Risk Factors for Carpal Tunnel. UC Irvine, Dept of Occupational Medicine, 2014
Managing Neck and Shoulder Pain, UC Berkeley, Meyer Medical Lecture, 2014
Human Factors and Hand Tool Design, Rutgers University, NJ, Industrial Engineering Seminar, 2015
Upper Extremity Disorders: Recent Research and Implications for Design, Simon Fraser U, Vancouver, 2015
Carpal Tunnel Syndrome: New Research Findings (Keynote Address), ErgoX-HFES, Anaheim, 2015
Design of Hand Tools, Tianjin University, China, 2015
Design of Human-Computer Interfaces, Beijing Institute of Technology, China, 2015
Biomechanical risk factors for carpal tunnel syndrome, Universidad Javeriana, Bogota, Columbia, 2016

RECENT SERVICE: UNIVERSITY

Ph.D. Qualifying Exam Committees UCB, UCSF, UCLA (2002 - p): Craig Conlon, Mike Jaasma, Wesley Jackson, Anne Staples, Jill Ulrich, Dan Odell, Steven Hsu, Jennifer Park, Shyam Patel, Cheng Li, Azucena Rodriguez, Mina Nikanjam, Craig Hashi, David Schultz, Melodie Metzger, Sara Atwood, Kyoungchul Kong, Lauren Statman, Laura Croft, Adam Hickenbotham, Marc Sena, Wayne Tung, Lee-Huang Chen.

Ph.D Thesis Committees UCB, UCSF, UCLA (2002 - p): Thomas Hruschka, Namrata Gundiah, Andrew Walsh, Kin Cheung, Craig Conlon, Wesley Jackson, Shyam Patel, Sara Atwood, Marc Sena

UC Berkeley, Environmental Health Sciences Program, School of Public Health, 1992 - p

UCB/UCSF, Center for Occupational and Environmental Health Executive Committee, 1999 - p

UCSF Occupational and Environmental Medicine Residency Advisory Committee, 2003 – p

UCSF VAH Occupational and Environmental Medicine Search Committee, 2013

RECENT SERVICE: GOVERNMENT

Member, Panel on Musculoskeletal Disorders in the Workplace. National Research Council, National Academy of Sciences, and Institute of Medicine, 1999 – 2001

Member, Study Section, Safety & Occupational Health, NIH, CDC, NIOSH, 2007 - 2011

Member, Italian Scientific Commission on Accreditation of Professors of Occupational Medicine, 2013 - p

Consultant to NIOSH ICD-10-CM Ergonomic External Causation Coding Workgroup 2014

Consultant to Cal/OSHA on Safe Patient Handling and Mobility Regulation 2013

Consultant to Cal/DPH on Dental Hygiene Ergonomics Video "Pain is not in the job description" 2014

Member, Board on Human-Systems Integration, National Academy of Sciences, 2010 - p

RECENT SERVICE: PROFESSIONAL

American Academy of Orthopaedic Surgeons, Clinical Practice Guidelines Workgroup on Carpal Tunnel Syndrome, Representative from ACOEM, 2013 – 2016, Published Feb 29, 2016.

American College of Occupational and Environmental Medicine, Ergonomics Committee, 1998 – 2011

American College of Occupational and Environmental Medicine, Evidence Based Practice Committee, 2006–p

American Conference of Governmental Industrial Hygienists, Physical Agents Committee, 2006 – p

International Ergonomics Committee, Musculoskeletal Disorder Committee, 2009 - p

Human Factors and Ergonomics Society, Excellence in HF/E Research Prize Committee, 2010 – p

Human Factors and Ergonomics Society, Fellow Selection Committee, 2013 - 2015

Human Factors and Ergonomics Society, Executive Council, 2015 – p

International Ergonomics Society, Delegate from HFES, 2015 - p

International Ergonomics Society, Chair, Musculoskeletal Disorder Technical Committee, 2015 - p

PREMUS (Prevention of Musculoskeletal Disorders), International Scientific Committee, 2010, 2013, 2016

RECENT SERVICE: COMMUNITY/PUBLIC

Marconi Research Conference Series (Program Director), 1994 - 2016

Consulting: Microsoft, Logitech, Intel, Apple, Toshiba, Herman-Miller, Leap Motion, Lawrence Berkeley Magic Leap, National Laboratory, Human Rights Commission Alberta Canada, Monsanto, Federal OSHA, Pixar, Xoma, California OSHA, California Department of Public Health, City and County of San Francisco, WorkSafeBC, Shell, Amazon, Blackberry.

Bay Area Ergonomics Roundtable, 2003 – 2014

Association of Canadian Ergonomists, 2011-2013

California Department of Industrial Relations, 2014, Evidence Based Medicine and Occupational Medicine

CLINICIAL RESPONSIBILITIES

Hand Clinic, Orthopaedics Dept, UCSF/Mt Zion 1999 - 2004

Upper Extremity Specialty Clinic, Student Health Services, UC Berkeley 2005 - p

TEACHING

UC Berkeley Occupational Biomechanics (BioE279/PH269C; 4 units), Spring 1991-2015

UCB Advanced Ergonomics (PH269D; 2 units), Fall 1999-2015

UCB Masters Translational Medicine Capstone Course (BioE 296; 6 unites), Spring 2014
UCB Bioengineering Undergraduate Research
UCSF/UCB Bioengineering Graduate Research
UCSF Postdoctoral Fellow Research
UCB, Student Health Services, OEM Fellow clinical training

POSTGRADUATE COURSES

UCSF Occupational and Environmental Medicine, 1999 - p
Webinar to WOEMA, COEH, ACE: Chronic Upper Back and Neck Pain Among Workers, 2013-2016
UCLA, COEH, Risk factors for Upper Extremity Disorders, 2016
UC Davis, Occupational & Environmental Medicine, Prevention of Carpal Tunnel Syndrome, 2016

Ph.D. THESIS CHAIR

Edward Klinenberg	Crosshift Vibrometry: Biomarker for Ergonomic Stress?	1994
Elaine Serina	Characterization and Modeling of the Fingertip Pulp Under Repeated Loading	1996
Jack Dennerlein	Finger Flexor Tendon Forces and the Controls of Finger Movements During A Keystroke	1996
Pachongjit Tittiranonda	Workplace Investigation of Alternative Geometry Keyboards: Posture, Productivity, Comfort and Health	1997
Peter Johnson	The Development, Characterization and Implementation of a Technique to Measure Muscle Fatigue During Computer Use	1998
Gita Murthy	Tissue Oxygenation and Muscle Fatigue	1999
Kathy Kursa	Simultaneous *In Vivo* Finger Flexor Tendon Forces and Development of a Model	2004
Dan Odell	Bimanual Computer Input and Forearm Support	2004
Leena Nakama	An Animal Model of Epicondylitis	2006
Hui Dong, DDS	Effects of Dental Tool Design on Muscle Load and Pinch Force	2006
Krishna Asundi	Effects of In Vitro Loading of Tendons on Matrix and Inflammatory Marker Gene Expression	2007
Craig Conlon, MD	Intervention study among Engineers	2007
Molly Story	Improving Accessibility and Design of Medical Equipment	2008
Michael Weiner	An Exoskeleton to Prevent Back Injuries in Warehouse Work	2009
Carissa Harris	Risk Factors for Hand and Wrist Tendonitis	2010
Peiyi Ko	Effects of Computer Display Design on Health and Productivity	2012
Anna Pereira	Computer Input Devices: Design for Well-Being and Productivity	2013
Doohee You	Effect of Wrist Angle on Carpal Tunnel Syndrome in a Prospective Study	2013
Logan Van Engelhoven	An exoskeleton for reducing shoulder load for material handling	-

CONTRACTS AND GRANTS:

"Test Bench for Evaluating Concrete Drilling Methods" CPWR/NIOSH U60-2-OH009762-06, $825,579, 08/31/2014-09/01/2019. Develop a laboratory robotic system for testing productivity and health related risk factors using different techniques for concrete drilling. Principal Investigator.

"A Direct Reading Video Assessment Instrument for Repetitive Motion Stress" NIOSH R01-OH011024, $91,886. 09/01/2016-08/31/2019. Validating an automated video analysis system for quantifying workplace hand biomechanical exposures. Co-investigator, PI: R Radwin, U Wisconsin.

PAST CONTRACTS AND GRANTS (Partial List):

"Occupational Biomechanics (Ergonomics) Training Program." NIOSH T42 OH008429, Northern California Educational Resource Center, $268,569, 07/01/15-06/30/16, Continuing support for development of a graduate training program in Ergonomics and Occupational Biomechanics. Principal Investigator.

“National Robotics Initiative: Reducing Trunk Musculoskeletal Forces During Manual Work” NSF IIS-1317978, $1,009,136. 09/01/13-08/31/16. Develop exoskeleton to reduce lumbar spine loads during industrial stooped work. Co-PI with: H Kazerooni, UC Berkeley.

"Occupational Biomechanics (Ergonomics) Training Program." NIOSH T42 OH008429, Northern California Educational Resource Center, $268,569, 07/01/10-06/30/15, Continuing support for development of a graduate training program in Ergonomics and Occupational Biomechanics. Principal Investigator.

“A Pooled Longitudinal Analysis of Workplace Carpal Tunnel Syndrome” NIOSH R01 OH009712, $1,469,849. 09/01/10 – 08/31/14. Merge prospective data on 3287 workers from seven research groups and evaluate associations between biomechanical factors ant risk and incidence of carpal tunnel syndrome. Principal Investigator.

“Highway and Bridge Construction Drilling” CPWR/NIOSH U54 OH009762, $750,000, 09/01/09 - 08/31/14, A field study to develop and evaluate various interventions to assist in reducing musculoskeletal loads during highway reconstruction. Principal Investigator.

“Video Exposure Assessment of Hand Activity Level” NIOSH/CDC R21 OH010221, $20,240. 07/01/2012-12/31/2013. Develop a method for automated measurement of hand exertions from video-tape. Co-investigator, PI: R Radwin, U Wisconsin.

“Surveillance for Carpal Tunnel Syndrome” PHI/CDPH/CDC 4U60OH008468-07, $43,421, 06/01/2012 – 05/31/2013, Assistance to the California Department of Health Services to develop a statewide surveillance project for work-related carpal tunnel syndrome. Principal Investigator.

“Safe Patient Handling” California Department of Industrial Relations 51140035, $48,600, 12/01/11 – 06/30/12. Assistance to Cal/OSHA with review of literature on safe patient handling and trainings. Principal Investigator.

“A test bench system for concrete drills” CPWR/NIOSH U54 OH009762, $30,000, 10/01/11 - 03/01/13, A laboratory system or evaluating safety and health risk factors for hammer drills. Principal Investigator.

“Effect of tool design on hand pain in dental practitioners” NIOSH R01 OH008892, $465,324. 08/01/08 – 07/31/12. A randomized controlled trial to evaluate the effects of a new dental tool handle design on hand and arm symptoms and function among dental hygienists and dentists. Principal Investigator.

“Scalable and Deformable 3D Hand Model for use with Computer Aided Engineering Design” NIOSH R43 OH009681 (SBIR), $41,793, 09/01/09 - 08/31/10, Develop an animated model of the human hand for use in CAD engineering design of hand tools. Co-investigator, PI: Ozen Engineering.

“Evaluating Interventions for Overhead Drilling” NIOSH U54 OH008307, $750,000, 08/01/04 - 06/30/10, A field study to develop and evaluate various interventions to assist in reducing shoulder load during overhead drilling into concrete. Principal Investigator.

"Ergonomic Evaluation of Endoscopists" American Society of Gastrointestinal Endoscopy. $60,000, 07/01/08 - 06/30/09. Evaluate forces and muscle loads during endoscopy. Co-investigator, PI: A Shergill, UCSF.

“Collaborative Study: Workplace Musculoskeletal Disorders” NIOSH R01 OH007914, $1,164,344, 09/01/03 – 08/31/09. A prospective study of biomechanical risk factors for hand, wrist and elbow disorders among 800 workers in various industries to determine dose-response relationships between risk and disease. Principal Investigator.

"Occupational Biomechanics (Ergonomics) Training Program." NIOSH Northern California Educational Resource Center, $268,569, 07/01/07-06/30/10, Continuing support for development of a graduate training program in Ergonomics and Occupational Biomechanics. Principal Investigator.

"An intervention for overhead drilling into concrete" WorkSafeBC RS2006-0G15, $117,445. 01/01/07 – 12/31/08. Evaluate addition of motorized column and remote control unit to overhead drilling system. Co-investigator, PI: S Robinovitch, Simon Fraser University, Canada.

"Ergonomic Interventions for Garment Work" NIOSH R01 OH07779, $195,231, 09/30/02-09/29/05. A multi-center research project to determine the effectiveness of workstation modifications in reducing musculoskeletal pain, disability and rate of disorders among of garment workers in Los Angeles. Co-investigator.

"Rehabilitation Engineering Research Center on Accessible Medical Instrumentation" US Dept Ed H133E020729, $663,895, 11/01/02 – 10/31/07. A multi-university project to evaluate and design medical equipment to make the equipment more accessible to disabled patients and workers. Co-investigator.

"Occupational Biomechanics (Ergonomics) Training Program." NIOSH Northern California Educational Resource Center, $268,569, 07/01/02-06/30/07, Continuing support for development of a graduate training program in Ergonomics and Occupational Biomechanics. Principal Investigator.

"A Model for Wrist and Elbow Musculoskeletal Disorders." NIH R01 OH07359, $886,680, 07/01/01- 06/30/05, A rabbit finger flexor model is used to investigate the role of force, repetition, and acceleration as causal factors in entrapment neuropathy of the median nerve at the wrist and tendinosis at the epicondyle. Principal Investigator.

"Effectiveness of Interventions for Customer Service Work." ASPH S1205, $237,332, 07/01/00-06/30/04. A study to determine to what extent "best-practices" workplace ergonomic interventions and work organizational interventions for computer based customer service work can reduce upper musculoskeletal pain and lost-time and improve hand function. Principal Investigator.

"Effects of an Ergonomic Intervention for Computer Work." NIH R01 OH04253, $754,596, 09/30/00 - 09/29/04. A study to determine whether or not a state-of-the-art ergonomic intervention applied to computer based customer service work can reduce rates of upper extremity disorders. Principal Investigator.

"Pilot Project Research Training Program". Supplement to NIOSH Northern California Educational Resource Center, $291,953, 07/01/99-06/30/02. Provision of seed funding for 3 to 4 innovative pilot research proposals per year to enable new faculty to successfully compete for funding from traditional sources. Principal Investigator.

"Tendon Force During Occupational Hand Activities." NIH R01 OHAR03414, $518,352, 07/01/98- 06/30/02, A study to determine the dose-response relationships of fingertip load to tendon load in order to provide guidelines for hand tool design and tool use to minimize tendon loading, and thereby reduce the risk of developing tendon related disorders. Principal Investigator.

"Pathophysiology of Carpal Tunnel Syndrome" NIH/Fogarty Senior International Fellowship, F06 TW02250, $46,430. 07/01/97-/6/30/98. Development of an animal model for carpal tunnel syndrome. Principal Investigator.

"Ergonomics Graduate Training Program." NIOSH Northern California Educational Resource Center, $248,678, 07/01/97-06/30/02, Continuing support for development of a graduate training program in Ergonomics and Occupational Biomechanics. Principal Investigator.

"Intracarpal Pressure During Hand Maneuvers" CDC/NIOSH Special Emphasis Research Career Award, K01 OH00121, $150,000, 08/01/92-07/31/95. Principal Investigator.

April 28, 2017

NOMINATION FORM FOR IEA FELLOW AWARD 2017

For use by IEA Member Societies to nominate an individual for the IEA Fellow Award

Submission Instructions:

Please complete this form electronically and e-mail as an attachment (together with other attachments such as CV, letters of support, etc.) to: PastPres@iea.cc **and** vpsg@iea.cc

Deadline: April 30, 2017

Nominee for IEA Fellow: **Dr. Richard Wells**
Person submission nomination: Nancy Black, President, ACE
The Nomination:

Full Name (and title): Richard Wells, Ph.D. (Mechanical Engineering), Professor Emeritus (Department of Kinesiology, University of Waterloo, Associate Director, Centre of Research Expertise for Prevention of Work-Related Musculoskeletal Disorders (University of Waterloo)

Address: University of Waterloo, Department of Kinesiology, 200 University Ave W, Waterloo, ON CANADA; N2L 3G1
E-mail: wells@uwaterloo.ca
Fax: (519)746-6776
Tel: (519)888-4567 ext 33069

Nominating person Name: Nancy Black, President, Association of Canadian Ergonomists / Association canadienne d'ergonomie (ACE)
Address: Faculté d'ingénierie, Université de Moncton, 18 Avenue Antonine Maillet, Moncton, NB E1A 3E9
E-mail: acepresident1@gmail.com
Fax: (506)858-4082
Tel: (506)858-4079

1. Eligibility

Richard has been a member of the Association of Canadian Ergonomists / Association canadienne d'ergonomie (ACE) and before that of the same association under its former name: Human Factors Association of Canada/ Association canadienne d'ergonomie (HFAC/ACE) since approximately 1989. Within that association, at the **National level,** he held a number of key roles, notably

- Member of the Executive Committee of the HFAC / ACE, 1991 – 1993
- Co-Chair, HFAC / ACE Annual Conference, Waterloo, 1996
- Chair of the Membership Committee of HFAC / ACE, 1995 - 2000
- Chair of the Education Committee for Certification, HFAC / ACE, 1996-7 (which led to the determination of the educational requirements for *Canadian Certified Professional Ergonomist* title which since 1999 is verified and controlled by the Canadian College for the Certification of Professional Ergonomists).

He has served the ergonomics community at the **international level** through his roles as

- Director of the Ergonomics and Safety Consulting Service, at the University of Waterloo, 2001- present
- Expert Witness for Occupational and Safety and Health Administration, USA, 2000
- Member of a scientific panel of the Physical Agents Committee of the American Congress of Governmental, Industrial Hygienists, 2000.
- Director of the Resource Centre for Occupational Health and Safety at the University of Waterloo (an information dissemination and consulting Centre), 1991 - 1995.
- Member of the Scientific Panel for Development of Canadian Guidelines for Repetitive Strain Injuries of the National Research Council of Canada/Quebec Institute for Occupational Health and Safety (IRSST), 1991 - 1994
- Co-Chair, North American Congress of Biomechanics, NACOB, 1992

He has contributed to the dissemination of information as a **reviewer** of submissions both ***within Canada*** (ex. Natural Sciences and Engineering Council of Canada (NSERC); Medical Research Council of Canada (MRC); Workers' Compensation Board of British Columbia) and ***internationally*** (ex. National Institute of Occupational Safety and Health (NIOSH), USA Scandinavian Journal of Work Environment and Health).

He has **reviewed articles for ergonomics journals** including the highly regarded *Applied Ergonomics*, *Ergonomics* and *Human Factors*, in addition to ones related to Biomechanics.

He has supported the community through his **consulting** work notably with the Occupational Health and Safety Administration (OSHA), USA and the Workers' Compensation Board of British Columbia

In addition to these roles, he has **published over 98 articles in peer reviewed journals**, collaborating with renowned ergonomics experts and publishing in journals including *IIE Transactions on Occupational Ergonomics and Human Factors, Scandinavian Journal of Work, Environment and Health, Ergonomics, Work, Applied Ergonomics, International Journal of Industrial Ergonomics, International Archives of Occupational and Environmental Health* and *International Journal of Occupational Safety and Ergonomics* among others since 2012

He has co-authored **14 book chapters** and has nearly **200 peer reviewed conference papers or abstracts** published.

He has been an **invited keynote addresses** at several conference including notably the 1988 Conference on Repetitive Strain Injuries, the 1992 conference of the Canadian Centre for Occupational Health and Safety, the 1995 PREMUS (Prevention of Work-Related Musculoskeletal Disorders) conference, the 1997 International Symposium on Global Rehabilitation Trends, and the 2016 Annual conference of the Association of Canadian Ergonomists (Niagara Falls, ON).

He has furthermore been **invited to present at 8 workshops or panels.**

He has represented ergonomics well in the media including on national Canadian news and as an expert witness in British Columbia (CANADA) and Washington DC (USA).

In his role as an academic, Dr. Richard Wells has supervised (or co-supervised) **8 PhD students**, several of whom are now highly respected, productive faculty members in ergonomics fields, including Drs. Patrick Neumann, Steven Fischer and Peter Keir, Anne Moore. Two of these have written letters supporting Dr. Well's nomination to this IEA honor. Dr. Wells also has supervised **24 master's students** some of whom have continued their studies and publications in the field.

2. Distinction.

Eligible candidates will be evaluated on the basis of demonstrated outstanding theoretical or applied contributions to ergonomics/human factors. There are many ways in which this contribution can be demonstrated. The candidate could have had the primary responsibility for the technical direction, supervision or management of a significant effort during a sustained period of time. The candidate could be a renowned researcher, designer, or consultant of great distinction.

Clear evidence of distinction should be supported by detailed descriptions and attachments. For example, for a researcher, the most significant publications authored or co-authored by the candidate should be attached to the application. For a consultant, the most important consulting contracts should be outlined, together with the outcome of the contracts. For a designer the most important design objects should be specified. Any other information to support or attest to the achievements of the candidate should be furnished to the IEA Awards Committee, in order to support their deliberation of the candidate's merits.

Summarize in the space below the candidate's qualification for the prestigious IEA Fellowship.

Dr. Richard Wells is notable particularly for his key role in developing and directing ergonomics as it related to preventing Musculoskeletal Disorders (MSDs) while teaching and researching at the University of Waterloo, CANADA. He was director of University of Waterloo's Resource Centre for Occupational Health and Safety from 1991-1995. Before, during and after that role, he was instrumental in the formation of the renowned and large ergonomics program at University of Waterloo.

His establishment and direction of the ***Centre of Research Expertise for Prevention of Musculoskeletal Disorders (CRE-MSD)*** from 2004 to 2016 is a significant and impactful distinction. CRE-MSD is a multi-university centre hosted at University of Waterloo. It serves as an integral component within Ontario's Prevention System within the mandate of the Ontario Ministry of Labour. Not only does the Centre serve as a forum for connecting research and practice, but the Centre (under Richard's leadership) also played a significant role in developing the MSD Prevention Series Guideline for Ontario (available in English and in French and including 5 sub-documents available at the bottom of the *Musculoskeletal Disorder / Ergonomics* https://www.labour.gov.on.ca/english/hs/topics/pains.php). Indeed, CRE-MSD is listed a key partner in the acknowledgements section). Ten years later via CRE-MSD, Richard is working to update the MSD Prevention Guideline, particularly to be more useful for small business.

Since his official retirement in 2016, he is Associate Director CRE-MSD and is **Professor Emeritus** of the Department of Kinesiology at University of Waterloo.

His research has been extensive and has been recognised by his peers. He was co-winner of the **Elsevier Clinical Biomechanics Award** for his ergonomics-related research:

> Norman, R., Wells, R., Neumann, W. P., Frank, J., Shannon, H., & Kerr, M. (1998). A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clinical Biomechanics, 13*(8), 561-573 https://doi.org/10.1016/S0268-0033(98)00020-5

The results of this article were subsequently incorporated into the ERGOWATCH software package including the 4D WATBAK biomechanical modelling tool which made these research results accessible to practitioners in an easy to use software platform.

He has actively contributed to the development and communications of ergonomics beyond his home institution. Since 1998 he is Adjunct Scientist at the **Institute for Work and Health** in Toronto, CANADA. He is a past member of the **Board of Directors of Occupational Health Clinics for Ontario Workers** (OHCOW). He has been involved in ergonomics standards and regulations with **ACGIH** and **OSHA** in the USA and in the Ontario Strategy for the Prevention of MSD (as mentioned above) and CSA (**Canadian Standards Association**). He was visiting scientist at **National Institute for Working Life** in West, Gothenburg, Sweden (1999-2000) and visiting Associate professor at the **Centre for Ergonomics at University of Michigan** in 1988.

He also acts as a consultant and speaker on ergonomic issues.

While starting as a mechanical engineer in England (University of Manchester) he furthered his training in Canada at McMaster University where his thesis was already ergonomics-focused (1972-4: *Identification and Communication of User Needs to the Designer*). He completed his training with a PhD in applied mechanics focussing on biomechanics during gait (University of Manchester) and joined the Department of Kinesiology at University of Waterloo. He has been a pioneer in the research relating to Musculoskeletal Disorder (MSD) prevention studying it both from biomechanical and most recently organizational perspectives.

The Association of Canadian Ergonomists strongly supports the nomination of Dr. Richard Wells to the honor of Fellow of the International Ergonomics Association.

Nancy Black

Additional Information:

Attached are Richard Well's recent CV, the cited award winning article from Clinical Biomechanics (Norman et al. 1998), and two of the 5 documents in the MSD Prevention Guideline series (Parts 1 and 2).

Endorsement by a Federated Society

The Association of Canadian Ergonomists / Association canadienne d'ergonomie endorses the nomination of Dr. Richard Wells as an IEA Fellow.

April 28, 2017

Letters of support

Name of endorser: Dr. W. Patrick Neumann, Ph.D., L.E.L., Eur.Erg.
Position held: Professor, Mechanical and Industrial Engineering, Ryerson Univesity
Name of Federated Society: Association of Canadian Ergonomists / Association canadienne d'ergonomie

Name of endorser: Dr. Steven Fischer, R. Kinesiologist
Position held: Assistant Professor, Department of Kinesiology, University of Waterloo
Name of Federated Society: Association of Canadian Ergonomists / Association canadienne d'ergonomie

RYERSON UNIVERSITY

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING
FACULTY OF ENGINEERING AND ARCHITECTURAL SCIENCE

April 7, 2017

Attn: Kristen Lépine dos Santos
Executive Director
Association of Canadian Ergonomists
411 Richmond Street East, Suite 200
Toronto, Ontario, M5A 3S5

Dear Ms. Lépine dos Santos:

Please accept this letter in nomination of Dr. Richard Wells for the IEA Fellow Award. Dr. Wells has enjoyed an extensive career in ergonomics research and teaching, and has garnered the respect and admiration of many ergonomics researchers and professionals worldwide. In 2016, he retired as Professor in the Department of Kinesiology at the University of Waterloo, after 39 years of service. During his career, Dr. Wells has supervised and mentored over 30 graduate students, published over 100 peer-reviewed papers and contributed to over 200 conference presentations.

Dr. Wells research portfolio has spanned the range from cell to society. His groundbreaking research into the biomechanical injury mechanisms for musculoskeletal disorders has illuminated how tissue is damaged by workload. His award winning work in the field linked those same biomechanical factors to specific spinal workload measures for production workers. His subsequent participatory ergonomics intervention research projects explored the means and mechanisms by which companies might reduce these risks in their own workplaces. His current work with ergonomics standards has lifted his prevention efforts to a social sector level. Dr. Wells has demonstrated a transdisciplinary approach in his research that spans all system levels.

In 2004 Dr. Wells founded the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD), hosted at the University of Waterloo. Under his directorship, the Centre has flourished and grown to include almost 50 researchers across 15 institutions in Ontario. Though he has recently retired, he continues to remain active in the Centre’s activities in the role of Associate Director.

Over the years, Dr. Wells has generously contributed his expertise and efforts in support of many committees and organizations dedicated to furthering ergonomics research, interventions, and standards for the benefit of workers and workplaces. In recent years, he has contributed his expertise to a number of Canadian Standard Association (CSA) technical committees, such as CSA Z1004 on workplace ergonomics and CSA Z412 on office ergonomics. Dr. Wells is also an active member of the Ontario Ministry of Labour Ergonomics Integrated Planning Advisory Committee (EIPAC) and its various action plans, including the Agriculture/Horticulture Action Plan, the Construction Action Plan, and the Small Business Action Plan.

As tasked by the Ontario Ministry of Labour in 2016, Dr. Wells is leading a multi-stakeholder initiative to develop a new MSD Prevention Guideline for Ontario. The scope of this project is massive, but with Dr. Wells' expertise it is successfully progressing on time and on target. It is expected that the new Guideline will be released in the fall of 2018 and it will no doubt serve as an appropriate culmination for Dr. Wells' prestigious career.

Speaking personally, I have had the pleasure to benefit from Dr. Wells' rigorous approach to ergonomics over many years. First as an undergraduate student studying occupational biomechanics in the 80's, as his employee working as research project coordinator on the General Motors study in the 90's when he was also my MSc supervisor. He then supported my PhD studies on ergonomics in work system design in Sweden in the 2000's. As I launched my independent research career at Ryerson, Dr. Wells became a valuable colleague and collaborator on a range of ergonomics research projects. I have experienced and benefitted from Dr. Wells ongoing efforts to develop and support ergonomics over the last 30 years. With this perspective I can say that he is truly worthy of the honor of becoming an IEA Fellow.

Sincerely,

P. Ne

Patrick Neumann, Ph.D., L.E.L., Eur.Erg.
Associate Professor
Human Factors Engineering Lab
Mechanical and Industrial Engineering Department
Ryerson University
Tel.: +1 – 416 – 979 5000 x7738
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UNIVERSITY OF WATERLOO

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Attn: Kristen Lépine dos Santos
Executive Director
Association of Canadian Ergonomists
411 Richmond Street East, Suite 200
Toronto, Ontario, M5A 3S5

Steven Fischer, PhD, RKin, CCPE
Assistant Professor
Tel: 519-888-4567 ext. 30368
E-mail: steven.fischer@uwaterloo.ca

Dear Ms. Lépine dos Santos:

Please accept this letter supporting the nomination of Dr. Richard Wells for the IEA Fellow Award. Richard Wells recently retired from his position as a Professor in the Department of Kinesiology, Faculty of Applied Health Sciences, University of Waterloo. He is the former Director of the Centre of Research Expertise for Prevention of Musculoskeletal Disorders, a multi-university Centre hosted at the University of Waterloo and currently continues to serve as the Centre's Associate Director, Stakeholder Relations. Dr. Wells also has an appointment as an Adjunct Scientist at the Institute for Work and Health. He is a past member of the Board of Directors of Occupational Health Clinics for Ontario Workers (OHCOW). He has been involved in ergonomics standards and regulations with ACGIH (member of a scientific panel of the Physical Agents Committee of the American Congress of Governmental, Industrial Hygienists, 2000) and OSHA (Expert Witness for Occupational and Safety and Health Administration, USA, 2000) in the USA and in the Ontario Strategy for the Prevention of MSD and CSA (Currently leading an initiative to develop a new MSD Prevention Guide for Ontario). Dr. Wells has also been a longtime advocate and supporter of Ergonomics in Canada, serving in a number of roles with the Human Factors Association of Canada / ACE.

Dr. Wells has had a profound impact on the ergonomics community provincially, nationally and internationally as a researcher, educator and consultant. As a researcher, Dr. Wells has published over 100 peer-reviewed papers on topics with direct relevance to ergonomics and work-related injury prevention. Several of his publications include collaborators and co-authors from around the globe, demonstrating the international breadth of Dr. Wells' influence and collaborative network. While difficult to identify his most impactful contribution, his research as part of the Ontario Universities Back Pain Study (OUBPS) is certainly among the top. Seminal findings from this work prompted a paradigm shift in our thinking, encouraging the ergonomics community to consider cumulative load as a risk factor for low back pain, not just peak loading (Norman, Wells, et al. 1999 cited nearly 500 times!) Dr. Wells has also contributed over 200 conference presentations, sharing research highlights with a range of stakeholders including researchers, practitioners, and policy makers at conference venues around the globe. Most recently, Dr. Wells delivered a keynote plenary presentation for the 2016 Association of Canadian Ergonomists Conference in Niagara Falls.

As an educator Dr. Wells has trained and mentored over 30 graduate students; 8 PhD and over 22 MSc. Seven of his trainees (Keir, Moore, Neumann, Fischer, Yazdani, Hubley-Kozey, Yung) continue his legacy in research, extending our knowledge and understanding of MSD and solutions to reduce MSD risks in the workplace. Many of his remaining trainees have pursued rewarding careers in the fields of ergonomics and occupational health (e.g., Berolo, Morrissey, Enns, Slater, Morose, Reitzel, etc.). Underscoring his commitment to teaching and learning, Dr. Wells served as the chair of the Education Committee for Certification for the Human Factors Association of Canada in 1996. He also helped to establish and served as coordinator for the Ergonomics Option within the BSc Kinesiology degree offered at University of Waterloo. His contributions through teaching and learning have enhanced the crop of knowledgeable, prepared personnel ready and willing to lead the promotion and implementation of sound ergonomics for years to come.

Dr. Wells has consulted for many business and government groups alike. While his CV includes a complete list, highlights include: contributing to a special workshop on exposure measures in occupational epidemiology at the Karolinska Institute in Stockholm Sweden; Reviewing and advising on a proposed province of British Columbia code of practice for physical handling; and, providing expert opinion on cases for the Workers' Compensation Board of British Columbia and Crown Attorney. As a researcher, educator and consultant, Dr. Wells has had a profound impact on the ergonomics community provincially, nationally and internationally.

Again, by way of this letter, I strongly support the nomination of Dr. Richard Wells for the IEA Fellow Award. Dr. Wells is a steadfast leader, promotor and ambassador of ergonomics in Ontario, in Canada, and around the world. Recognition of his contributions in the form of an IEA Fellow Award is a great way to recognize and thank Dr. Wells for his immense contributions to our field and profession.

Sincerely,

Steven Fischer PhD, RKin, CCPE
Assistant Professor
Department of Kinesiology
University of Waterloo
www.uwaterloo.ca/obel

Curriculum Vitae: Richard Wells

Degrees Received

Ph.D.	Applied Mechanics, Mechanical Eng. University of Manchester (UMIST) Manchester, England *Dissertation Topic: Kinematic and Kinetic Aspects of Normal Gait and Swing-Through Crutch Gait*	1974-1977
M. Eng.	Dept. of Mechanical Engineering McMaster University Hamilton, Ontario, Canada *Thesis Topic: Identification and Communication of User Needs to the Designer*	1972-1974
B.Sc.	Department of Mechanical Engineering University of Manchester (UMIST) Manchester, England *Senior Project: Acceleration Experienced by the Head in Boxing*	1969-1972

Employment History

2016 - present	Professor Emeritus	Department of Kinesiology University of Waterloo
2016 - present	Associate Director	Centre of Research Expertise for Prevention of Work-Related Musculoskeletal Disorders, University of Waterloo
2004 - 2016	Director	Centre of Research Expertise for Prevention of Work-Related Musculoskeletal Disorders, University of Waterloo
2001 - 2016	Professor	Department of Kinesiology University of Waterloo
Oct 1999-March 2000	Visiting Scientist	National Institute for Working Life West, Gothenburg, Sweden
1998-present	Adjunct Scientist	Institute for Work and Health Toronto, Ontario
1991 - 1995	Director	Resource Centre for Occupational Health and Safety, University of Waterloo
1990 - 1996	Associate Dean Computing and Special Projects	Faculty of Applied Health Sciences, University of Waterloo
1988	Visiting Associate Professor	Centre for Ergonomics University of Michigan
1987 - present	Associate Professor	Department of Kinesiology University of Waterloo
1978 - 1987	Assistant Professor	Department of Kinesiology University of Waterloo

1977 - 1978	Post Doctoral Research Assistant	Department of Kinesiology University of Waterloo

Scholarly and Professional Activities

Professional Activities

Director of the Ergonomics and Safety Consulting Service, at the University of Waterloo, 2001- present
Expert Witness for Occupational and Safety and Health Administration, USA, 2000
Member of a scientific panel of the Physical Agents Committee of the American Congress of Governmental, Industrial Hygienists, 2000.
Chair of the Membership Committee of the Human Factors Association of Canada, 1995 - 2000
Chair of the Education Committee for Certification; Human Factors Association of Canada, 1996 - 1997
Member of the Executive Committee of the Human Factors Association of Canada, 1991 - 1993
Director of the Resource Centre for Occupational Health and Safety at the University of Waterloo (an information dissemination and consulting Centre), 1991 - 1995.
Member of the Scientific Panel for Development of Canadian Guidelines for Repetitive Strain Injuries of the National Research Council of Canada/Quebec Institute for Occupational Health and Safety (IRSST), 1991 - 1994
Co-Chair, Human Factors Association of Canada Annual Conference, Waterloo, 1996
Co-Chair, North American Congress of Biomechanics, NACOB, 1992

Reviewing

Natural Sciences and Engineering Council Of Canada (NSERC)
Medical Research Council of Canada (MRC)
Workers' Compensation Board of British Columbia
Sport Canada
National Institute of Occupational Safety and Health (NIOSH), USA
Scandinavian Journal of Work Environment and Health
Medicine and Science in Sports and Exercise
Journal of Biomechanics
Journal of Electromyography and Kinesiology
International Journal of Sport Biomechanics
Canadian Journal of Applied Sport Science
Applied Ergonomics
Ergonomics
Human Factors
Journal of Motor Behavior
Acta Anatomica

Consulting

Occupational Health and Safety Administration (OSHA), USA
Workers' Compensation Board of British Columbia
Canadian Industrial Innovation Centre
Crown Attorney
Ontario Retail Accident Prevention Association/IAPA
Industrial, business, and government clients

Curriculum Vitae: Richard Wells
Scholarly Activity
Peer-reviewed Journals

1. Johnson, J., Skorecki, J., and Wells, R.P.* Peak Accelerations of the Head Experience in Boxing. Medical and Biological Engineering, 1975, (13):396-403.

2. #Wells, R.P. The Kinematics and Energy Variations of Swing Through Crutch Gait, Journal of Biomechanics, 1979, 12:579-585.

3. #Wells, R.P. The Projection of the Ground Reaction Force as a Predictor of Joint Moments. Bulletin Prosthetic Research, 1981, 18(1):10-35.

4. Winter, D.A., Wells, R.P., and Orr, G*. Errors in the Use of Isokinetic Dynamometers, European Journal of Applied Physiology, 1981, 46:397-407.

5. #Hubley, C.L*., and Wells, R.P. A Work Energy Approach to Determine Individual Joint Contributions to Vertical Jump Performance, European Journal of Applied Physiology, 1983, 50:247-254.

6. Bishop, P., Norman, R., Wells, R., Ranney, D., and Skleryk, B. Changes in the Centre of Mass and Moment of Inertia of a Headform Induced by a Hockey Helmet and Face Shield, Canadian Journal of Applied Sport Science, 1983, 8:19-25.

7. Smith, A*., Bishop, P., and Wells R. Alterations in Head Dynamics with the Addition of a Hockey Helmet and Face Shield under Inertial Loading. Medicine and Science in Sport, 1984, 10(2): 68-74.

8. #Wells, R. and Ranney, D.A. An Experimental Approach Simulating Lumbrical Function in the Cadaver Hand. Journal of Hand Surgery, 1986, 11A: 574-577.

9. Wells, R.P., Norman, R.W., Bishop, P., and Ranney, D.A. Assessment of the Static Fit of Automobile Lap Belt Systems on Front Seat Passengers. Ergonomics, 1986, 29(8):955-976.

10. #Wells, R.P., Morrissey, M.*, and Hughson, R. Internal Work and Physiological Responses During Concentric and Eccentric Ergometry. European Journal of Applied Physiology and Occupational Physiology, 1986, 55:295-301.

11. #Ranney, D.A., Wells, R.P., and Dowling, J*. Lumbrical Function: The interaction of lumbrical contraction with the elasticity of the extrinsic finger muscles and its effect on metacarpophalangeal equilibrium. Journal of Hand Surgery, 1987, 12A (4):566-75.

12. Wells, R.P., Bishop, P.J., and Stephens, M. Neck Loads During Head First Collisions in Ice Hockey: Experimental and Simulation Results. International Journal of Sport Biomechanics, 1987, 3(4): 432-443.

13. #Wells, R.P., and Evans, N.E*. Functions and Recruitment Patterns of Two-Joint Muscles. Human Movement Science. 1987, 6:349-372.

14. #Wells, R.P. Mechanical Energy Costs of Human Movement: An Approach to Evaluating the Transfer Possibilities of Two Joint Muscles. Journal of Biomechanics, 1988, 12(11): 955-964.

15. #Ranney, D.A., and Wells, R.P. Lumbrical Functions Revealed By a New and Physiological Approach. Anatomical Record, 1988, 222:110-114.

16. Yang, J.*, Winter, D.A., and Wells, R.P. Postural Dynamics in Humans: Part 1 - A Computer Simulation Model. Biological Cybernetics, 1990, 62(4):309-320.

17. Yang, J.*, Winter, D.A., and Wells, R.P. Postural Dynamics in Humans: Part II Computer Simulations and Experimental Results. Biological Cybernetics, 1990, 62(4):321-330.

18. Bishop, P.J., and Wells, R.P. The Inappropriateness Of Helmet Drop Tests In Assessing Neck Protection In Head-first Impacts. American Journal of Sports Medicine, 1990, 18(2):210-205.

19. #Moore, A.*, Wells, R., and Ranney, D. Quantifying Exposure In Occupational Manual Tasks With Cumulative Trauma Disorder Potential. Ergonomics, 1991, 34(12):1433-1453.

20. Cholewicki, J*., McGill, S.M., Wells, R.P. and Vernon, H. Method For Measuring Vertebral Kinematics From Videofluoroscopy. Clinical Biomechanics, 1991, 6:73-78.

21. #Wells, R., Moore, A.*, Potvin, J*., and Norman R. Assessment of Risk Factors for Development of Work-related Musculoskeletal Disorders. Applied Ergonomics, 1994, 25(3):157-164.

22. Ranney, D., Wells, R., and Moore, A.* The Anatomical Location Of Work-related Chronic Musculoskeletal Disorders in Selected Industries Characterized by Repetitive Upper Limb Activity. Ergonomics, 1995, 38(7):1408-23.

23. #Keir, P.*, Wells, R., and Ranney, D. Passive Stiffness Of The Forearm Musculature and Functional Implications. Clinical Biomechanics, 1996, 11(7):401-409.

24. Andrews, D*., Norman, R. and Wells, R. Accuracy and Repeatability of Low Back Spine Compression Force Estimated from Self Reports of Body Posture During Load Handling, International Journal of Industrial Ergonomics, 1996 ,18:251-260.

25. Frank, J., Brooker, A-S., DeMaio, S., Kerr, M., Maetzel, A., Shannon, H., Sullivan, T., Norman, R., and Wells, R. Disability Due to Occupational Low Back Pain: What do we Know About Primary Prevention? Spine, 1996, 21(24):2908-2917.

26. Frank, J., Brooker, A-S., DeMaio, S., Kerr, M., Maetzel, A., Shannon, H., Sullivan, T., Norman, R., and Wells, R. Disability Due to Occupational Low Back Pain: What do we Know About Secondary Prevention? Spine, 1996, 21(24):2918-2929.

27. #Wells, R., Norman, R., Neumann, P*., Andrews, D*., Frank, J., Shannon, H. and Kerr, M*. Assessment of Physical Work Load in Epidemiologic Studies: Common Measurement Metrics for Exposure. Ergonomics, 1997, 40(1): 51-62.

28. Andrews, D*., Norman, R., Wells, R. and Neumann, P. The Accuracy of Self Report and Expert Observer Methods for Obtaining Estimates of Peak Low Back Information During Industrial Work. International Journal of Industrial Ergonomics, 1997, 19:445-455.

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43. Cole, D.C., Wells, R.P., The Worksite Upper Extremity Research Group, Interventions for Musculoskeletal Disorders in Computer-Intense Office Work: A Framework for Evaluation, Work and Stress, 16(2):95-106, 2002.

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46. Cole, D, Wells, R, Kerr, M., Laing, A. & the Ergonomic Intervention Evaluation Research Group (2003), Methodological Issues In Evaluating Workplace Interventions To Reduce Work-Related Musculoskeletal Disorders Through Mechanical Exposure Reduction, Scandinavian Journal of Work, Environment & Health, 29(5):396-405.

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64. #Fischer*, S., Wells, R., Dickerson, C. The effect of added degrees of freedom and handle type on upper limb muscle activity during simulated hand tool use, Journal of Biomechanics, 2009 52: 25-35.

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66. #Wells R. Why have we not solved the MSD problem? Work. 2009; 34(1):117-121.

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69. #Cole, D., Theberge, N., Dixon*, S., Rivilis*, I., Neumann, P., Wells, R. Reflecting on a program of participatory ergonomics interventions: A multiple case study, Work; 34:161-178, 2009.

70. #Wells, R., McFall, K*., Dickerson, C.R. Task selection for increased mechanical exposure variation: Relevance to job rotation, Ergonomics, 53:314–323, 2010.

71. #Wells, R., Hunt, S. Hurley, K., Rosati, P. (2010) Laboratory assessment of the effect of heavy rubber glove thickness and sizing on effort, performance and comfort., International Journal of Industrial Ergonomics, 40:386-391.

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Book Chapters

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12. Wells, R., Forearm and Wrist, in: Delleman, N., Haslegrave, C. and Chaffin, D. (eds), Working Postures & Movements - Tools for Evaluation and Engineering, Taylor and Francis, 2004.

Technical and Consulting Reports

1. Bishop, P., Norman, R., **Wells, R**., and Ranney, D. Changes in the Location of the Centre of Mass and in the Mass Moment of Inertia of the Head in Response to the Addition of a Helmet and a Face Shield.

Hockey Ontario Development Committee, April, 1982, 28 pages.

2. **Wells, R**., Norman, R., Bishop, P., and Ranney, S. Abdominal Injuries to Restrained Front Seat Occupants in Frontal Collisions: Belt Deployment Analysis. Biokinetics and Associates, September, 1982, 120 pages.

3. **Wells, R**. Abdominal Injuries to Restrained Front Seat Occupants in Frontal Collisions: Vehicle Geometry Assessment. Biokinetics and Associates, May, 1983, 20 pages.

4. **Wells, R**. Abdominal Injuries to Restrained Front Seat Occupants in Frontal Collisions: BELTFIT Program Assessment. Biokinetics and Associates, May, 1983, 25 pages.

5. Bishop, P., Norman, R., **Wells, R**., and Ranney, D. A Study of Selected Mechanical Factors Involved in Neck Injuries in Ice Hockey. Hockey Ontario Development Committee, July, 1983, 30 pages.

6. Bishop, P., and **Wells, R.P.** Cervical Element Loading in Head First Collisions in Ice Hockey: The Development and Use of a System to Examine the Effects of Helmets on Neck Loads. Report to Sport Canada, May, 1986, 57 pages.

7. **Wells, R.P.** The Development and Testing of a Deformable Pole for Nordic Skiing. Report to Sport Canada, July, 1988, 29 pages.

8. **Wells, R.**, Ranney, D., and Norman, B., Brawley, L., and Orr, S. Ergonomics of the Supermarket Cashiers' Environment. Contract report submitted to the Ontario Retail Accident Prevention Association (ORAPA), July, 1990, 250 pages.

9. **Wells, R**., Ranney, D., and Moore, A.E. Repetitive Strain Injuries: Measurement and Identification of Predictive Factors. Workplace Health and Safety Agency, March, 1990.

10. **Wells, R**., Ranney, D., and Moore, A. Repetitive strain injuries: Measurement and Identification of Predictive Factors. Final report to the Ontario Workplace Health and Safety Agency/Ontario Ministry of Labour for project #224/R. February, 1992, 200 pages.

11. Norman, R., **Wells, R**., Moore, A., Potvin, J., Bennett, G., Gibson, E., Husted, J., Ranney, D., and Sharratt, M. The feasibility of assessing whether job modifications are cost effective in reducing work site injuries. Final report to the Ontario Workplace Health and Safety Agency, April, 1992, 90 pages.

12. **Wells, R**., and Ranney, D. Repetitive strain injuries: Measures to Evaluate of Ergonomic Interventions. Final report to the Ontario Workplace Health and Safety Agency for project #254/R. April, 1994, 85 pages.

13. **Wells, R.**, Norman, R., and McGill, S. Review of the Proposed Province of British Columbia Code of Practice for Physical Handling. Contract report submitted to the Workers= Compensation Board of British Columbia, December, 1993, 22 pages.

14. Frank, J., Brooker, A-S., DeMaio, S., Kerr, M., Maetzel, A., Shannon, H., Sullivan, T., Norman, R., and **Wells, R**. , Disability Due to Occupational low Back Pain: What do we Know About its Prevention? Review comissioned by Liberty Mutual, 1995.

15. Wells, R. Lee. I., Bao, S. And Trainor, T., Investigations of Musculoskeletal Strain during Mouse and Pen Use at a VDT Terminal. Project Report to Communication Intelligence Corporation, Redwood Shores, CA, 1997.

16. Wells, R. Shannon, H., Cole, D. and Norman, R. Electromyographic Protocols for Measurement of Exposure in VDT Operators, Final Report to Center for VDT and Health Research, Johns Hopkins University, March 15th, 1998.

17. **Wells, R**., Norman R., Brawley, L., Cole, D., Frazer, M., Greco, L., Kerr, M., Kerton, R., Laing, A., Neumann, P., and Theberge, N. 2001a Summary: Implementation and Evaluation of a Participatory Ergonomic Change Process at the Woodbridge Group-Tilbury Plant, Report to Enerflex Division, The Woodbridge Foam Corporation, Jan 2001(a).

18. **Wells, R,** Norman, R, Frazer, M., and Laing, A. Ergonomics Program Implementation Blueprint, Ergonomics and Safety Consulting Services, University of Waterloo, Jan 2001(b).

Whilst I was Academic Director of the Centre for Occupation Health and Safety I was involved in a few dozen short contract reports for clients.

Other Publications

1. **Wells, R.** Planiversal Piano, A Symposium on Two Dimensional Science and Technology, (ed.) A.K. Dewdney, University of Western Ontario, Canada, pp. 224-225, May, 1981.

2. Winter, D.A., and **Wells, R.P.** Letter to the Editor, Journal of Bone and Joint Surgery, 63A, 1350, 1981.

3. **Wells, R.P.**, and Ranney, D.A. Lumbrical Length Changes in Finger Movement; A new Method of Study in Fresh Cadaver Hands. In Dobyns, J., Chase, R., and Amadio P. (eds.) The Yearbook of Hand Surgery, Year Book Medical Publishers, Chicago, pp. 263-264, 1988.

4. **Wells, R.P.** So you think a supermarket cashier has an easy job? Centre for Applied Health Research (CAHR) Newsletter 5, pp. 2, October, 1988.

5. **Wells, R.P.** Occupational Repetitive Strain Injuries: A Research Perspective in Occupational Repetitive Strain Injuries: A workshop. Document P88-17E, Canadian Centre for Occupational Health and Safety, pp. 7-18, November, 1988.

6. **Wells, R**., Moore, A*.and Ranney, D., Cumulative Trauma Disorders: Measurement and Identification of Predictive Factors, International Conference on Occupational Disorders of the Upper Extremities. Ann Arbor, Michigan: University of Michigan Center for Occupational Health and Safety Engineering,1990.

7. **Wells, R.P.** Current Stage of Knowledge and Research in Repetitive Strain Injuries. Canadian Centre for Occupational Health and Safety, p. 92-1E., 1992.

8. **Wells, R**. Design in Motion, Occupational Health and Safety Canada, Buyers Guide, pp92-97, 1992

9. Ranney, D., **Wells, R**., and Moore, A*. Forearm Muscle Pain And Tenderness And Work Exposures, in: Armstrong T., (ed) Proceedings of the International Conference on Occupational Disorders of the Upper Extremities. Ann Arbor, Michigan: University of Michigan Center for Occupational Health and Safety Engineering, (no page numbers), 1992.

10. **Wells, R.**, Ranney, D., and Moore, A*. Relationship Between Forearm Muscle Pain/tenderness And Work Exposures: Results From Repetitive Manual Tasks in: Armstrong T., (ed) Proceedings of the International Conference on Occupational Disorders of the Upper Extremities. Ann Arbor, Michigan: University of Michigan Center for Occupational Health and Safety Engineering, (no page numbers), 1992.

11. **Wells, R**., and Moore, A*. Biomechanical Models and Cumulative Trauma Disorders, in: Rempel, D. and Armstrong T., (eds) Marconi Keyboard Research Conference, San Francisco,(no page numbers), 1994.

12. Ranney, D., **Wells, R.P.**, and Moore, A. If it isn't tennis elbow, what might it be? Canadian Journal Of Surgery, December, 1993 (abstract).

13. **Wells, R**. And Kourinka, I. Developing Guidelines for Prevention , Occupational Health and Safety Canada, Jan/Feb, pp68-81, 1994.

14. **Wells, R. P.**, Keir, P.J*., Moore, A.E*. and Ranney, D. A. Muscle Activity in the Hand and Forearm using a Traditional and a Chording Keyboard, in: Rempel, D. and Armstrong T., (eds) Proceedings of the 2nd Marconi Keyboard Research Conference, San Francisco, (no page numbers), 1996.

15. **Wells, R**. Checkout Challenge, Occupational Health and Safety Canada, July/August, pp62-64, 1995.

16. **Wells, R**. Advice on Mice, Occupational Health and Safety Canada, July/August, pp50-52, 1996.

17. **Wells, R**., Woo, H., Norman, R., Cole, D., Shannon, H., Bao,S. Electromyography of the Forearm as an Exposure Method in Epidemiologic Studies of WMSD and Computer Use, in: Rempel, D. and Armstrong T., (eds) Proceedings of the 3rd Marconi Research Conference, San Francisco, (no page numbers), 1997.

18. **Wells, R**., Lee, I.,*Bao, S., Investigations of Optimal Upper Limb Support Conditions for Mouse Use, in: Rempel, D., and Armstrong T., (eds) Proceedings of the 3rd Marconi Research Conference, San Francisco, (no page numbers), 1997.

Presentations to Scholarly Groups (# = Reported also in Proceedings)

1. Ranney, D., and **Wells, R.P.** Computer Simulation of Finger Movement. Presented at the International Society of Hand Surgery Conference, Colorado, USA, August, 1985.

2. Ranney, D.A., and **Wells, R.P.** Integration of Contractile and Elastic Forces in the Control of Finger Movement. presented at the International Conference of Clinical Kinesiology on Biomechanics and Clinical Kinesiology of Hand and Foot, Madras, India, December 16-18, 1985. **Keynote Address**

3. Bishop, P.J., and **Wells, R.P.** Cervical Spine Injuries in Ice Hockey. Presented at the 4th International Sport Science Conference, Halifax, June, 1986.

4. **Wells, R.P.** Problems in Hand Biomechanics. Presented to the Centre for Ergonomics, University of Michigan, Ann Arbor, Michigan, April 21, 1987.

5. Bishop, P.J., and **Wells, R.P.** Future Directions in Impact Biomechanics: Cervical Spine Injury due to Axial Compression. Presented to Society of Automotive Engineering Conference on the Future of Impact Biomechanics, Washington, May 18, 1987.

6. Ranney, D.A., and **Wells, R.P.** Function of the Lumbrical. Presented at the Paul Brand International Symposium on Hand Surgery - The 13th International Rocky Mountain Hand Symposium, Denver, Colorado, August 3-5, 1987.

7. **Wells, R.P.** Repetitive Strain Injuries: Causes and Solutions. Presented at the IAPA, Wentworth Division, November 15, 1988.

8. **Wells, R.,** and Ranney, D. Chronic Musculoskeletal Disorders in the Workplace: Where are We?, **Invited Address** at the 22nd Annual Conference of the Human Factors Association of Canada, Toronto, Canada, 1989.

9. Bishop, P.J., and **Wells, R.P.** A Computer Simulation Model for Studying Cervical Spine Injury Prevention. AGARD 67th Aerospace Medical Panel Meeting on Neck Injury in Advanced Military Aircraft Environments, Munich, Germany, April, 1989.

10. **Wells, R**., and Keir, P*. Changes in the geometry of the carpal tunnel contents due to wrist posture and tendon load: An MRI study on normal wrist. Presented at Conference on Advances in the Biomechanics of the Hand and Wrist, Belgium,1992.

11. **Wells, R**. Multimedia for Dynamic Visualization, Presented at Learning Technologies ‘94, TRACE Colloquium on Technology in Education, University of Waterloo, March 31st , 1994.

12. **Wells, R.** Exposure Measurements in Office Environments, **Invited Presentation** to an Workshop on Exposure Measurement, Centre for VDT and Health Research, San Francisco, December 3rd, 1994.

13. **Wells, R.**, Causal Mechanisms of Work -Related Musculoskeletal Disorders, **Keynote Address** to 2nd Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders (PREMUS), Montreal, September, 1995.

14. Kerr, M, Bombardier, C. Frank, J, Shannon,H. Neumann, P., **Wells, R.,** Norman, R. et al., Summary of self-reported clinical measures in a case control study of occupational low back pain, Presented at the ICOH Conference, September 1996.
15. **Wells, R.** Causation and Prevention of Musculoskeletal Disorders: Neck and Upper Extremities, Panel Member, State-of-the-Art-Conference, American College of Occupational and Environmental Medicine, Toronto, October 27-31, 1996.
16. Frank, J. Shannon, H. Kerr, M. Norman, R. **Wells, R**. and Neumann, P. A study of biomechanical and psychosocial risk factors for low-back pain. Presented at: "Work, Stress & Health '99: Organization of Work in a Global Economy" sponsored by the American Psychological Association and NIOSH. 1999, Mar 11-13. Baltimore.
17. Kerr M. Shannon, H., Frank, J., Norman, R. **Wells, R**. and Neumann, P Relating psychological demands with measured and self reported physical demands. Presented at: "Work, Stress & Health '99: Organization of Work in a Global Economy" sponsored by the American Psychological Association and NIOSH. 1999, Mar 11-13. Baltimore.
18. Theberge, N, Granzow, K, Cole, D., Neumann, P., Frazer, M., Laing, A., **Wells, R**., "Participatory Processes in Worker Health and Safety: An Analysis of an Intervention in an Industrial Setting." Presentation at annual meetings of the North Central Sociological Association, Windsor, Ontario, April 18-21, 2002.
19. Wells, R. Evaluation of interventions designed to prevent MSD, in: Proceedings of the Seventh International Conference on the Prevention of Work-related Musculoskeletal Disorders (PREMUS 2010), August 29th to September 3, 2010. Angers, France.
20. [$]Kramer, D.M., Wells, R.P., Carlan, N., Bigelow, P., Garritano, E., and Vi, P. (2013) They Adopted the Tool! Using a Framework to Evaluate a Diffusion-of-Innovations Intervention in the Construction Sector (poster presentation). Global Implementation Conference, Washington D.C. August.
21. [$]Yung, M., Carlan, N., Bigelow, P., Kramer, D., Wells, R., Vi, P., Garritano, E., Everett, J., Marsala, P. (2013) New Tools - New Issues: What do we know about crimping? Poster at Partners in Prevention Conference. Toronto, April.
22. [$]Bigelow, P., Carlan, N., Kramer, D., Wells, R., Vi, P., Garritano, E. (2013) Factors that Enhance the Adoption of New Tools: A survey to use. Poster at Partners in Prevention Conference. Toronto. April.
23. [$]Kramer, D., Wells, R., Carlan, N., Garritano, E., Bigelow, P., Vi, P. (2013) Innovations to Prevent Musculoskeletal Disorders (MSDs) in the construction sector. Presented at Partners In Prevention, Toronto. April.
24. [$]Kramer, D., Garritano, E., Bigelow, P., Carlan, N., Vi, P., Wells, R. (2013) Researching the Construction Sector: Bridges and Barriers. Presented at Partners In Prevention, Toronto. April.

Invited Presentations to Professional, Business and Industry Groups

1. The Static Fit of Automobile Lap Belt Systems on Front Seat Passengers. Presented to General Motors Biomedical Research Laboratories, Warren, Michigan, February 28, 1987.

2. Occupational Repetitive Strain Injuries: A Research Perspective., Conference on Repetitive Strain Injuries, Canadian Centre for Occupational Health and Safety, March, 1988. **Keynote Speaker.**

3. Cumulative Trauma Disorders: Measurement and Identification of Predictive Factors, International Conference on Occupational Disorders of the Upper Extremities. Ann Arbor, Michigan: University of Michigan Center for Occupational Health and Safety Engineering,1990.

4. Chronic Musculoskeletal Injuries, Presented to McMaster Occupational Health, Hygeine and Toxicology , February 13th, 1991.

5. Musculoskeletal Disorders, Presented to Toronto Workers= Health and Safety Legal Clinic, Toronto, April 30th, 1991.

6. Methods for Design and Modification of Workstations, Presented to Canadian Society for Safety Engineering, Montreal, August 11th, 1991.

7. Ergonomics: a Problem of Productivity, Presented to Canadian Society for Industrial Engineering, Kitchener, October 30th, 1991.

8. Regulation of RSI, Winnipeg Community Advisory Panel of the Canadian Standards Association, December 3rd, 1991.

9. Current Stage of Knowledge and Research in Repetitive Strain Injuries. Conference by Canadian Centre for Occupational Health and Safety, 1992. **Keynote Speaker**

10. Relationship Between Forearm Muscle Pain/tenderness And Work Exposures: Results From Repetitive Manual Tasks International Conference on Occupational Disorders of the Upper Extremities. Ann Arbor, Michigan: University of Michigan Center for Occupational Health and Safety Engineering, 1992.

11. Repetitive Strain Injuries: Guidelines and Standards, Annual Occupational Health and Safety Conference , Toronto, October, 1993.

12. Biomechanical Models and Cumulative Trauma Disorders, Marconi Keyboard Research Conference, San Francisco, Feb, 1994.

13. Legislation and Guidelines for the Prevention of Work-Related Musculoskeletal Disorders, Invited Presentation to the British Columbia Federation of Labour Annual Conference, Vancouver, September 6th, 1994.

14. Are We Ready for Ergonomic Legislation? Lunchtime Talk at @Ergonomics@, Canadian Institute, Toronto, November 14th, 1994.

15. Causation of Cumulative Trauma Disorders, International Conference on Occupational Disorders of the Upper Extremities. University of Michigan Center for Occupational Health and Safety Engineering, San Francisco, December 2nd, 1994.

16. Understanding Soft Tissue Injuries, Presentation to New Challenges in Work and Health: Reducing Disability Associated with Soft Tissue injuries, Institute for Work and Health, Toronto, April 18th, 1995.

17. Update on Repetitive Strain Risk Factors, OSH=95, Annual Occupational Health and Safety Conference, Toronto, October 3rd, 1995

18. State-of-the-Art in Ergonomics, International Symposium on Global Rehabilitation Trends, Toronto, January 18th, 1997. **Keynote Speaker**

19. Ergonomics and RSI, Presentation to the Rehabilitation Staff of the Ontario Workers Compensation Board, April 24, 1997.

20. Electromyography of the Forearm as an Exposure Method in Epidemiologic Studies of WMSD and Computer Use, Presentation to 3rd Marconi Research Conference, San Francisco, April, 1997.

21. Investigations of Optimal Upper Limb Support Conditions for Mouse Use, Presentation to 3rd Marconi Research Conference, San Francisco, April, 1997.

22. Experience with the Use of EMG in a Case Control Study in the Automotive Industry, Presentation to Muscle Fatigue Workshop Ergonomic Task Group, American Automobile Manufacturers Association, Detroit, July 22-23, 1997.

23. Work-Related Musculoskeletal Disorders(WMSD) of the Upper Limbs and Back: Tools for the Assessment of Risk and Intervention Priority. Invited workshop at the HFAC Annual Conference, Winnipeg, September 1997.

24. Assessment of Biomechanical Exposures in Occupational Research. Invited one day workshop given at August

Krogh Institute, Copenhagen, Denmark for the <u>SOUND Network</u>, October 13-15, 1997.

25. Research into Work-Related Musculoskeletal Disorders, Invited one day workshop for the <u>Nordic Institute for Advanced Training in Occupational Health,</u> Copenhagen, October 5-10, 1997.

26. Ergonomic Issues in Repetitive Strain Injuries, Invited keynote and seminars at Work Related Musculo Skeletal Disorders, Foothills Hospital, Calgary, Alberta, March 28, 1998.

27. The Ontario Universities Low Back Pain Study, Invited presentation to Managing Ergonomics, Las Vegas, April 29, 1998.

28. The Effects of Deadlines on Workload, Behavior and Muscle Activity in Newspaper Work, Invited Presentation to International Conference on Occupational Disorders of the Upper Extremities, San Francisco, December 10-11, 1998.

Invited Scientific Workshop/Panel Participation

1. Exposure Assessment for Upper Limb Cumulative Trauma Disorders. Ad-Hoc Exposure Committee, National Institute of Occupational Safety and Health (NIOSH), Cinncinati, January 6-7th, 1993.

2. Exposure Measures for a Case-Control Study of Low Back Pain, Presentation to a <u>Special Workshop on Exposure Measures in Occupational Epidemiology</u>, Karolinska Institute, Stockholm, August 26-7th, 1993.

3. Exposure Assessment**,** Workshop on Exposure Assessment for Ergonomic Studies of Workers Using Keyboards, Centre for VDT and Health Research, San Francisco**,** CA, December 3rd, 1994.

4. Exposure Assessment, Workshop on Exposure Assessment for Ergonomic Studies of Workers Using Keyboards or Other Data Input Devices, Centre for VDT and Health Research, Annapolis, MA, April 6-7, 1998.

5. Biomechanics and Injury Tolerance, NACOB Panel on Injury and Tolerance, North American Congress on Biomechanics, Waterloo, August 1998**.**

6. Work Factors: Musculoskeletal Loading and WMSD, Presentation at the National Academy of Sciences Workshop on Work-Related Musculoskeletal Injuries: Examining the Research Base, Washington, Aug 21-22, 1998.

7. Precision and Recording Time in Occupational EMG, Chair of Panel at 4rd Marconi Research Conference, San Francisco, December 12-13, 1998.

8. How Epidemiologic, Biomechanical, Physiological and Psychophysical Methods Interact in the Setting of Thresholds for Upper Limb Musculoskeletal Disorder Exposure: A Discussion Paper. Ergonomics TLVs: Scientific basis for preventing upper extremity musculoskeletal disorders, ACGIH, April 15-17, Los Angeles, CA., 1999.

Media and Other Appearances

1. Interview on CBC Radio Morningside concerning Repetitive Strain Injuries, February 22nd, 1994.

2. Presentation to the Public Hearings on the Draft Ergonomics Legislation of the Workers Compensation Board of British Columbia, Campbell River, BC, September 7th, 1994.

3. Interview on CBC 6pm News concerning Repetitive Strain Injuries, Jan 18th 1997.

4. Expert witness presentation for Occupationa Safety and Health Administration (OSHA), USA on the Proposed Ergonomic Program Standard, Washington DC, March 16, 2000.

Invited Workshop and Course Preparation for Professional, Business and Industry Groups

1. Wells, R. Repetitive Strain Injury, 2 hour course segment at *Ergonomics 88*, University of Waterloo, June, 1988.

2. Wells, R.P. Occupational Repetitive Strain Injuries: Causes, Treatment and Prevention. *Centre for Occupational Health and Safety Course on Ergonomics, Health and Productivity*, Toronto, November 18, 1988.

3. Wells, R. Repetitive Strain Injury: Causes and Preventative Strategies, 2 hour course segment at *Ergonomics >89*, University of Waterloo, June, 1989.

4. Wells, R. Repetitive Strain Injury: Causes and Preventative Strategies, 2 hour course segment at *Ergonomics >90*, University of Waterloo, June, 1990.

5. Wells, R. and Harrington, G. Work Related Musculoskeletal Disorders, 2 hour course segment at *Ergonomics '91*, University of Waterloo, June, 1991.

6. Wells, R. and Harrington, G. Work Related Musculoskeletal Disorders, 2 hour course segment at *Ergonomics '92*, University of Waterloo, June, 1992.

7. Wells, R. and Harrington, G. Work Related Musculoskeletal Disorders, 2 hour course segment at *Ergonomics '93*, University of Waterloo, June, 1993.

8. Wells, R. and Harrington, G. Work Related Musculoskeletal Disorders, 2 hour course segment at *Ergonomics '94*, University of Waterloo, June, 1994.

9. Wells, R. Canadian Standards in RSI, 1 hour course segment at *Ergonomics >94,* University of Waterloo, June, 1994.

10. Wells, R. and Moore, A. Office Ergonomics, 2 hour course segment at Ergonomics >95, University of Waterloo, June, 1995.

11. Wells, R. Biomechanical Analysis of Work, 4 hour course segment presented to General Motors Advanced Ergonomic Training Course, Warren MI, October 6th, 1995.

12. Wells, R. and Moore, A. Office Ergonomics, 2 hour course segment at Ergonomics >96, University of Waterloo, June, 1996.

13. Wells, R., Saari, J., and Norman, R. Opportunities for Improvement*,* A 2 day course delivered to supervisory personnel at General Motors of Canada, Oshawa, June20-21st, 1995.

14. Ergonomics: Epidemiology and Pathophysiology of Upper Limb Work-Related Musculoskeletal Disorders, Postgraduate Seminar Presented at the State-of-the-Art-Conference, American College of Occupational and Environmental Medicine, Toronto, October 27-31, 1996.

15. Ergonomic Issues in Repetitive Strain Injuries, Seminar, Work Related Musculo Skeletal Disorders, Foothills Hospital, Calgary, Alberta, March 28, 1998.

16. Repetition, One day Workshop for Ontario Chapter of the Human Factors Association of Canada, November 1998.

17. Task Analysis: From Traditional to Object-Oriented, One day Workshop for Human Factors Association of Canada Conference, September, 1998 (with Dr. C. MacGregor).

Researcher(s)	**Agency**	**Amount per yr.**	**Tenure**	**Title**
Wells, R.	University Research Committee	$1, 675	1978	Internal Mechanical Work in Crutch Walking
Wells, R.	Fitness & Amateur Sport	$1,925	1981	Examination of Situps
Bishop, P. Norman, R. Wells, R. Ranney, D.	Ontario Hockey Foundation	$3,500	1981	Investigation of Neck Injuries in Hockey
Wells, R. Norman, R. Bishop, P. Ranney, D.	Biokinetics and Associates	$30,000	1982	Lap Belt Deployment Analysis
Bishop, P. Norman, R. Wells, R. Ranney, D.	Ontario Hockey Foundation	$13,500	1982	Investigation of Neck Injuries in Hockey
Wells, R.	Biokinetics and Associates Ottawa	$1,940	1983	Vehicle Geometry Assessment
Wells, R.	NSERC	$5,800	1984-85	Mechanical Work and Energy Transfer in Human Movement
Wells, R.	Canadian Industrial Innovation Centre	$7,500	1985-86	Home Gym Consulting
Wells, R. Norman, R.	Sport Canada	$11,516	1986	Development of Deformable Ski Pole
Bishop, P. Wells, R. Tator, C.	Sport Canada	$15,000	1986-88	Cervical Injury in Head First Collisions
Wells, R. Ranney, D.	NSERC	$15,000/yr	1987-90	Musculoskeletal Loading During Movement with Application to Repetitive Strain Injury
Wells, R.P. Norman R.W.	Sport Canada	$10,500	1987-88	Development and Test of a Deformable Ski Pole
Wells, R.P. Ranney, D.A.	Ministry of Labour	$51,000/yr	1987-90	Repetitive Strain Injuries: Measurement and Identification of Predictive

				Factors
Bishop, P. Wells, R.P.	Sport Canada	$18,000	1988-89	An Examination of Methods of Reducing Compressive Loads on the Cervical Spine Using a Computer Simulation Model
Wells, R., Brawley, L. Prkachin, K. Ranney, D. Norman, R. McDonald, H.	IAPA/URIF	$98,000	1988-89	Repetitive Strain Injuries to Supermarket Cashiers in Ontario
Wells, R. Ranney, D.	NSERC	$30,000/yr	1990-93	Musculoskeletal Loads During Hand Function Anthropometry and Modeling
Wells, R. Ranney, D.	Ontario Ministry of Labour	$80,000/yr	1990-93	Repetitive Strain Injury Measures to Evaluate Ergonomic Intervention
Norman, R. Brawley, L. Ranney, D. Wells, R.	Ontario Ministry of Labour	$30,000	1990-91	An Evaluation of Ergonomic Interventions in Ontario Workplaces: Feasibility Study
Norman, R. Wells, R.	Ontario Workers Compensation Institute	$1,073,263	1992-97	Quantification of Ergonomic Stressors: A Case Control Study
Wells, R.	NSERC	$3,000	1991-92	Clinical Gait and Posture Conference
Wells, R. Norman, R.	Ontario Workers Compensation Institute	$29,000	1992-93	Quantification of Ergonomic Stressors: Case Control Study of Etiology and Prognosis Upper Limb Disorders; Pilot Study
Norman, R. Wells, R.	General Motors of Canada, AG Simpson, The Woodbridge Group	$1,000,000	1994-99	Chair in Workplace Injury and Illness Prevention
Wells, R., Shannon, H., Cole, D. and Norman, R.	Centre for VDT and Health Research, Johns Hopkins University	$67,500.	1995-96	Electromyographic Protocols for Measurement of Exposure in VDT Operators
Wells, R. Norman, R.,	Healnet Theme	$45, 000/yr	1995-98	Development of Workplace

Saari, J and Kuorinka, I.	Research Competition			Risk Assessment and Control Software
Wells, R.	Communication Intelligence Corporation, California	$2,200	Oct 1995-June 1996	Evaluation of the CIC Handwriter
Wells, R. Lee, I.H.	The Office Ergonomics Research Committee, USA	$6, 900	Dec 1996-July 1997	Investigation Of The Optimal Upper Limb Posture To Perform Mouse Operations
Wells, R	The Office Ergonomics Research Committee, USA	$10,200	Jan-July 1998	Systems Design Approach to VDT Workstations
Wells, R. Norman, R. Cole D. Shannon, H. and Kerr, M	Healnet Theme Research Competition	$55, 000	1998-9	Evaluation of Ergonomic Interventions
Wells, R., Shannon, H., Cole, D., Norman, R., and Hogg-Johnson, S.	Centre for VDT and Health Research, Johns Hopkins University	$68,000/yr	1999-01	Precision and Responsiveness of Physical Exposure Measures in an Office Environment
Wells, R., Norman, R. , Frazer, M. Cole, D., Shannon, H., Kerr, M., Brawley, L. and Kerton, R.	Workplace Safety and Insurance Board	$149,000/yr	1999-01	Evaluation of Participatory Ergonomic Interventions in Large and Small Industries
Norman, R. Wells, R., Frazer, M. Cole, D., Shannon, H., Kerr, M., Brawley, L. Kerton, R., Stock, S., Cooper, J., Yassi, A. and Ostry, A	Heal*Net*	$74,995	1999-02	Assessment of the Effectiveness of Evidence-Based Ergonomic Decisions in Workplaces on Prevention of Work-Related Musculoskeletal Disorders
Cole, D., Hogg-Johnson, S.	NIOSH/NIH	$396,354	2000-03	Evaluating Interventions among Office Workers

Shannon, H., Hyatt, D., Beaton, D., Ferrier, S., Robson, L., Polanyi, M., Smith, J., Manno, M., and Wells, R.				
Wells, R., Norman, R. , Frazer, M. Cole, D., Shannon, H., Kerr, M., Brawley, L. and Kerton, R.	Workplace Safety and Insurance Board	$147,000/yr	2001-03	Costs and Benefits of Ergonomic Interventions
Wells, R, Eaton, J.,n Kerr, M., Ferrier, S., Polanyi, M., King, A., Frumin, E., Gunning, J., Naqvi, S.	Workplace Safety and Insurance Board	$131,000/yr	2001-03	Prevention of WMSD in the Ontario Clothing Industry: A focus on small business
Wells, R. Frazer, M. and Norman, R.	HEAL*Net*	$38, 145	2001-2002	Commercialization Of Workplace Research: Development Of New Modules For Upper Limb And Extensions To The Low Back Module Of ERGOWATCH
Theberge, N, Cole, D., Frazer, M., Wells, R.	CIHR-UW seed grant	$6000	October, 2002-2003	Workplace Interventions to Reduce Occupational Injuries
R. Wells, S. McGill, M. Frazer, H. Green, N. Theberge, D Ranney, J Medley, C. MacGregor, D. Cole, P. Keir, A. Moore, J. Callaghan, T. Haines, M. Kerr, S. Naqvi, J. Potvin	Workplace Safety and Insurance Board	$400 000/ year	2003-2008	A Proposal to set up Centre of Research Expertise Entitled: Action Centre for the Prevention of Work-Related Musculoskeletal Disorders
Wells, R., Cole, D., Frazer, M., Kramer, D. Theberge, N., Naqvi, S., Tompa, E.	Workplace Safety and Insurance Board: Solutions for Workplace Change	$270 059	2004-2005	Ergonomic Interventions for Prevention of WMSDs: Evaluation and Sustainability
Wells, R., Frazer., Maracle, S.,* Dunk, W.,* Carnahan, H.	Workplace Safety and Insurance Board: Solutions for Workplace	$29, 000	2005-2006	Powerline maintainer's gloves; approaches to reducing hand loading improving performance and reducing injury risk factors

	Change			
Shannon, H., Hogg-Johnson,S., Walters, S., Cole Wells, R	CIHR	$67,000/ yr	2004-2006	The use of Individual Participant Data (IPD) for examining heterogeneity in meta-analysis of observational studies: An application to biomechanical workplace risk factors and low back pain
Wells, R., Potvin, J., Keir, P., Moore, A., Carnahan, H., Frazer, M., Dickerson, C.	Workplace Safety and Insurance Board: Solutions for Workplace Change	$28,695	2006-2007	Multi-task Jobs and Job Rotation
Mijatovic, D.,* Wells, R., Cole., Naqvi, S.*	Workplace Safety and Insurance Board: Bridging the Gap	$36,650	2006	Evaluation of the impact of a participatory ergonomics intervention in a medium size facility.
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Wells, R., Kramer, D., Bart, C., Dickerson, C. Clarke, W.	Workplace Safety and Insurance Board: Bridging the Gap	$39, 928	2006-2007	Developing a tool for engineering design that will predict the effort required by the hand and wrist during manual work
Boyle E., Steenstra, I., Hayden, J., Cassidy, JD., Wells, R., Wyeld, S.	Workplace Safety and Insurance Board: Bridging the Gap	$29, 966	2006-2007	What Workplace Characteristics Have an Impact on an Injured Worker’s Return to Work? A Qualitative Study
Wells, R., Diacur, M., Kramer, D., Bigelow, P.	Workplace Safety and Insurance Board	$307, 465	2006-2008	Ergonomics in the Transportation Sector: The development of best practices in MSD-reduction strategies
Moore, A.E., Vi, P., Wells, R.	Workplace Safety and Insurance Board: Bridging the Gap	$29,000	2007	Assessment tools in Construction
Shannon, H., J., Cote, P., Frank, J., Griffith, L., Wells, R.	WorkSafeBC: Systematic Review Request for Proposals 2006	$108,500	2007-2008	Systematic Review of Low Back Pain in Workers

Wells, R., Maracle, S.	Workplace Safety and Insurance Board: Bridging the Gap	$30,160	2008- 2009	Evaluating the effects of cold and glove use on manual dexterity and performance and the testing of potential solutions.
Wells, R., Diacur, M., Kramer, D., Bigelow, P.	Workplace Safety and Insurance Board	$307, 465 Total	2007-2008	Ergonomics in the Transportation Sector: The development of best practices in MSD-reduction strategies
Shannon, H., J., Cote, P., Frank, J., Griffith, L., Wells, R.	WorkSafeBC: Systematic Review Request for Proposals 2006	$108,500 Total	2007-2008	Systematic Review of Low Back Pain in Workers
*Wells, R., Maracle, S.	Workplace Safety and Insurance Board: Bridging the Gap	$30,160	2008- 2009	Evaluating the effects of cold and glove use on manual dexterity and performance and the testing of potential solutions.
*Wells, R., Tupling, R., and Hunt, S.	Workplace Safety and Insurance Board	$84,000/ year	2008-2011	A versatile and comprehensive model to predict the effort required by the hand and wrist during manual work: development and evaluation
*Kramer, D., Bigelow, P., Vi, P., Garritano, E., Wells, R.	Workplace Safety and Insurance Board	$348,870 TOTAL	2008-2011	Encouraging construction companies to adopt innovations to reduce MSDs using different knowledge transfer techniques.
*Wells, R and Amick, B.	Office Ergonomics Research Committee	$23,720	2008-2009	The prevalence of hand disorders amongst hand held device users and their relationship to patterns of device usage
*Stock, R., Vezina, N., Wells, R., Amick, B., Shannon, H. et. al.,	CIHR: Team Grant – Strategic Teams in Applied Injury Research (STAIR)	$10,000	2008-2009	LOI: Development and evaluation of strategies and tools for workplace interventions to prevent work-related musculoskeletal injuries and work disability
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Wells. R. Amick, B. Steenstra, I.	Workplace Safety and	$29,782	2009-2010	Development of valid and reliable physical exposure

	Insurance Board: Development Grant			measures for users of hand-held mobile communication devices:
Wells. R., McMillan, Kramer, D., Bigelow, P., Naqvi, S., Robson, L, Steenstra, I..	Workplace Safety and Insurance Board	$83,497	2009-2011	Developing and Evaluating a Workplace–Level MSD Physical Risk Factor Survey: A Researcher-Labour Collaborative Project
Cassidy, D., Kramer, D., Soklaridis, S., and Wells, R., (2010).	. WSIB –RAC (#09112).	$50,831.00.	2009-2011	Buddies in tough times: Co workers' experiences of supporting injured colleagues' return to work
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Kramer, D., Aversa, T., McMillan, K., Naqvi, S., Steenstra, I., van Eerd, D., Wells, R.	WSIB RAC	$134,292	2012-2014	Evaluation of a Workplace-level MSD-Prevention Knowledge Transfer Intervention, and the Creation of an on-line MSD Prevention Planning

				Tool
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Graduate Student Supervision

a) Supervisor

PhD

Sirin, A.	Adaptations of the Neuromuscular system during prolonged submaximal cycling, 1991. Joint supervision with A. Patla.
Keir, P.	Functional Implications of the Musculoskeletal Anatomy and Passive Tissue Properties of the Forearm, 1995.
Moore, A.	Biomechanical and Psychophysical Studies of Repetitive Manual Tasks, 1999.
Neumann, P.	(University of Lund, Sweden, Co-supervisor with J. Winkel,)
Fischer, S	A biomechanical investigation in the link between simulated job static strength

	and psychophysical strength: Do they share a 'weakest link' relationship? 2011 (Co-supervised with C. Dickerson)
Berolo, S.	Demonstrating relationships between workplace demands and exposures related to musculoskeletal disorders and stress-related health outcomes 2015 (Work and Health option)
Yazdani, A.	Incorporating Musculoskeletal Disorder Prevention into Organizations' Management Systems 2015 (Work and Health option)
Yung, M.	Fatigue at the Workplace: Measurement and Temporal Development 2016 (Work and Health option)

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Sutherland, D.	Cycling Effectiveness: A Comparison of Three Techniques. Withdrew from program.

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Trainor, T.	Installing Lift Assists in Manufacturing Industry, July 2000
McRobbie, H.	Changes in Exposure and Health after Redesign of a Grinding Department , June 2000
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Morose, T.	Case study presentation using electronic media, 2007
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Ngo, Binh	Assessing workers' ability to recognize lifting height as a risk factor for low back pain: Investigating the efficacy of a simple educational message, 2015.

Teaching Expertise

Biomechanics of Human Movement;
Graduate and Undergraduate Assessment of Motor Performance;

Undergraduate Instrumentation;
Graduate and Undergraduate Courses in Injuries to Musculoskeletal System and Ergonomics
Task Analysis

University and Department Committees

University Senate	1998-1999, 2009-present
University Senate Finance Committee	1998-1999
University Computing Committee	1990-1996
University Appointment Review Committee	1994-2000
University Ad-Hoc Committee UWinfo (Chair)	1999
University Ad-Hoc Committee Newsgroups (Chair)	1998
Waterloo Advisory Council Liaison	1990-1996
Faculty Executive Committee	1990-1996
Faculty Administrative Council	1990-1996
Department Computing Committee	1997-2000
Department Executive Committee	
Department Undergraduate Studies Committee	
Department Graduate Committee	
Ergonomic Option Coordinator	1997-1999, 2001-present
United Way Co-Chair	2006- present

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CLINICAL BIOMECHANICS

Erratum

ISB Clinical Biomechanics Award 1997 (sponsored by Elsevier Science Ltd)

The award winning paper by R Norman *et al.* was published in *Clinical Biomechanics* (1998; 13: (8): 561–573). In error, the award winning status of the paper was not announced and we apologise for this oversight.

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CLINICAL BIOMECHANICS

A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry

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Abstract

Objective. To determine the relative importance of modelled peak spine loads, hand loads, trunk kinematics and cumulative spine loads as predictors of reported low back pain (LBP).

Background. The authors have recently shown that both biomechemical and psychosocial variables are important in the reporting of LBP. In previous studies, peak spinal load risk factors have been identified and while there is in vitro evidence for adverse effects of excessive cumulative load on tissue, there is little epidemiological evidence.

Methods. Physical exposures to peak and cumulative lumbar spine moment, compression and shear forces, trunk kinematics, and forces on hands were analyzed on 130 randomly selected controls and 104 cases. Univariable and multivariable odds ratios of the risk of reporting were calculated from a backwards logistic regression analysis. Interrelationships among variables were examined by factor analysis.

Results. Cases showed significantly higher loading on all biomechanical variables. Four independent risk factors were identified: integrated lumbar moment (over a shift), 'usual' hand force, peak shear force at the level of L_4/L_5 and peak trunk velocity. Substituting lumbar compression or moment for shear did not appreciably alter odds ratios because of high correlations among these variables.

Conclusions. Cumulative biomechanical variables are important risk factors in the reporting of LBP. Spinal tissue loading estimates from a biomechanical model provide information not included in the trunk kinematics and hand force inputs to the model alone. Workers in the top 25% of loading exposure on all risk factors are at about six times the risk of reporting LBP when compared with those in the bottom 25%.

Relevance

Primary prevention, treatment, and return to work efforts for individuals reporting LBP all require understanding of risk factors. The results suggest that cumulative loading of the low back is important etiologically and highlight the need for better information on the response of spinal tissues to cumulative loading.

Keywords: Low back pain; epidemiology; auto assembly; spinal load; trunk kinematics; biomechanical spine model; shear; compression

1. Introduction

Physical loading on the low back at work, in particular high peak forces and adverse trunk postures and movements, have been presented as contributors to the reporting of low back pain (LBP) in industry [1–3]. Cumulative physical loading of spinal tissues is often also assumed to be a risk factor related to occupational LBP, and some in vitro biomechanical evidence regarding adverse effects of excessive cumulative loading on tissues is available [4,5], but epidemiological evidence is meagre. Indeed, the only study found by the authors that presented any data to relate the reporting of LBP to accumulated load estimates was by Kumar [6] which suggested that estimates of compression and shear accumulated historically over the entire work experience were significantly higher in

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male institutional aides with back pain than in those without it. It must be noted, however, that measures of physical demands of jobs have not been unaminously acknowledged as risk factors for the reporting of LBP [7–9].

The data presented in this paper focus on the biomechanical part of a case-control epidemiological study in which possible psychosocial, biomechanical and demographic risk factors that might be related to the reporting of LBP by assembly and assembly support workers were measured in detail in a large automobile company. When all three types of potential risk factors were studied simultaneously, the data showed that both biomechanical and psychosocial variables are important and result in statistically significant, independent risk contributions according to a multivariable statistic analysis model that clearly separated those who reported (cases) and those who did not report LBP (controls) at work. Specifically, the following variables emerged as independent risk factors for LBP: peak shear force on the lumbar spine, cumulative compression on the lumbar spine integrated over the duration of a shift, usual force (as opposed to peak force) on the hands, worker perceptions of high physical demand, poor workplace social environment, low job control but, high (not low) co-worker support, high (not low) job satisfaction and better education relative to those who performed similar jobs. The results of the combined analysis suggest that if workers were high on all of those risk factors the odds for reporting LBP would be approximately 15:1. Although there were no significant differences between cases and controls in personal variables such as body mass index, age or smoking, the final model included terms to adjust for these demographic variables as well as a term for prior LBP history since, as expected, cases had a stronger history than controls [10, 11].

A complete analysis of the combined biomechanical, psychosocial and demographic variables will be reported in another paper. However, because the results of the combined data suggest that there is an independent role for the biomechanical demands of work in the onset of LBP, and because the study collected, for the first time to the knowledge of the authors, extensive data on all three types of variables on the same workers, it is, therefore, important to thoroughly analyze the ability of biomechanical variables alone to distinguish between cases and controls, in the absence of the psychosocial risk factors. This focused analysis of biomechanical data is the substance of this paper.

Several types of biomechanical exposure variables related to low back troubles have been reported. They include external loads in the hands [12–14], kinematic variables such as torso angle [2,3] and velocity [2], and kinetic variables such as lumbar moments of force [2] and estimates of forces on lumbar spine structures from biomechanical spine models [1]. To assess job risk, biomechanists sometimes compare peak spinal loads, such as lumbar compression estimated from biomechanical models, to ultimate compressive strength of cadavar lumbar motion units [15].

For people who go off work because of pain, one might expect that biomechanical variables that approximate forces on tissues would be better exposure measures than 'surrogates' of tissue loading, such as external forces on the hands or trunk kinematic variables. The argument is that pain is a result of irritation or damage to tissue and the closer one can come to measuring exposure at the tissue level the stronger one might expect the relationships with reported pain to be. Spinal compression and shear and the extensor moment of force in the lumbar spine, produced primarily by muscle and ligament, are examples of tissue loading variables. Of course, if spine model outputs are merely combinations of hand force and kinematic inputs and reveal no more information about tissue loading than the individual inputs themselves, appropriate statistical treatment should eliminate one or more members of highly correlated combinations of these variables. If variables from the outputs of a biomechanical spine model are, indeed, eliminated from multivariable statistical models of risk factors, the continued use of spine models to assess occupational LBP risk could be questioned because of lack of epidemiological evidence to offset controversy surrounding assumptions in different models and problems in their direct validation.

1.1. *Purpose of the paper*

The purpose of this paper is to identify, by means of data from a case-control epidemiological study, biomechanical risk factors related to the reporting of LBP in the auto assembly industry. In particular, assessments were made to determine whether 'cumulative' physical loads on the lumbar spine are associated with risk of reporting LBP and whether estimates of lumbar spine tissue loading variables from a biomechanical spine model better separates cases from controls than the more straightforward measures of forces on the hands and/or trunk kinematic variables that are inputs to spine models.

1.2. *Hypotheses*

1. There are biomechanical variables, of varying strength of association, that distinguish people who

report LBP (cases) from those who do not report pain (controls).

2. There are variables that characterize 'cumulative exposure' to load that provide information that is different from 'peak load' variables in the prediction of those workers who report LBP and those who do not.
3. Estimates of spinal compression, shear and the torso extension moment of force at the level of L4/L5, regardless of whether they are peak or cumulative loading estimates, will be better able to distinguish cases from controls than 'surrogates' of these forces on tissues such as kinematic or external loading variables.

2. Methods

A case-control study was conducted to identify the main work-related biomechanical and psychosocial risk factors for reported LBP in a large automotive assembly facility. The study base consisted of over 10000 hourly paid workers, including skilled trades, maintenance, and assembly line workers. Cases were defined as any full-time, hourly-paid worker who reported LBP to one of the nursing stations on site. Cases were not required to have lost time from work or to have submitted a disability claim, but they were eligible only if they had not reported LBP within 90 days of their current report of LBP. Controls were selected randomly from computerized employee rosters and rectruited simultaneously with the reporting of LBP by cases to achieve incidence density sampling, where odds ratios in case-control studies accurately estimate the relative risks obtained in prospective cohort designs.

Each participant received a home visit for a detailed, interviewer-administered questionnaire on psychosocial, demographic and clinical factors. After the baseline evaluation of these factors was complete, workers' exposure to physical loading in the workplace was assessed using a comprehensive set of biomechanical methods while the participants were working on their regular jobs [16]. The data presented in this paper were obtained from a video-based posture analysis system [17] and a 2D, quasi-dynamic biomechanical model of L_4/L_5 spinal loading forces from video-captured coordinate data [18]. In all, extensive biomechanical measures were made over a two-year period on more than 250 workers for observation durations ranging from two to eight hours during a normal work shift. Typically, workers were observed for approximately half a shift, about four hours.

In some situations, such as when an injured worker did not return to work, or the worker changed jobs following recovery from injury, it was not possible to collect workplace physical loading data on the case participant. In these instances a trained observer identified the case's job and attempted to find a 'job-matched control', defined as someone performing the same work duties at the same rate as the missing case. Data from these job-matched controls were substituted into the analyses as a proxy to the missing case data, a procedure that has been used previously [3]. Twenty out of 104 cases were represented by proxies, a substitution that was intended to increase statistical power, although it also carried the risk of possibly reducing differences in measured risk factors between cases and controls, should any exist.

3. Spinal tissue load estimation

Spinal loading was monitored on the work site by a trained observer while the worker was performing regular work duties. The observer would identify all occurrences of 'substantial' spinal load by estimating instants of high spinal moments resulting from forward inclined trunk postures and/or high forces on the hands. The observer would then record the posture, size and directions of forces on the hands, duration of the effort, and the number of repetitions of that instant of increased loading. Forces acting on the hands were usually measured using a force transducer. In cases where the transducer could not be inserted between the worker and the work, the worker was asked to push or pull the transducer against resistance to the side of the workstation until he/she produced their estimate of the same effort. The directions of forces on the hands were estimated and recorded by one of the observers trained in the use of the biomechanical spine model. Each of these tasks was then located on the video recording of the participant and the frame which best characterized the peak spine loading instant of the task was captured for computer analysis. In many cases several frames around the suspected peak instant were analyzed for a task and these frames, which provided a sagittal view of the worker, were then manually digitized to provide joint coordinate data and combined with the hand force information recorded in the field to provide input for a biomechanical spine model. The highest spinal load estimate resulting from all of the task peak instants identified for one job was taken to be the peak spine load for that worker.

Jobs comprised several tasks. The cumulative load exposure due to each task identified in a job was estimated by multiplying each of the task peak instants by the number of times that task was performed during the shift and by the duration of the exposure for each task. The integrated load experienced by the worker over the course of a complete shift was then calculated by summing these separate task integrals. Spinal loading during the time spent between work tasks was included in this estimate by multiplying the spinal load estimated in an upright standing posture by the total time spent in this waiting phase. Workers would stand and talk or sometimes support the weight of their head, arms and trunk by leaning on a bench while they read a few paragraphs in a newspaper or book during waiting periods. The cumulative loading estimates assume that the supported trunk postures resulted in spinal loading that was no greater than that observed during upright standing in all of these waiting periods.

The biomechanical model of the lumbar spine used in this study merits description because outputs from the model were extensively used. It is a quasi-dynamic, two-dimensional, 15-member, linked-segment model. Asymmetric body postures can be input. Magnitudes and directions of dynamic or static forces acting on each hand separately were entered into the model. When dynamic forces acting on the hands were input, their effects were seen in the model output; body segment inertial forces were not included. Thus, the model (watbak) is partially dynamic and for this reason the term quasi-dynamic was used to describe it [18]. This quasi-dynamic approach has been shown to produce higher estimates of spinal loading than those from fully dynamic linked-segment models [18]. The time cost of reducing data from more than 230 workers and more than 1000 tasks was dramatically lower than it would have been if a fully dynamic model had been used. The quasi-dynamic model partially incorporates the well-known and important effects of dynamic loading on the spine [18,19]. The effects of the accelerations of loads on the hands are included but effects of body segment accelerations are not. Anthropometrics for segment masses and locations of mass centres for men and women were taken from Plagenhoef [20] and Zatsiorsky and Seluyanov [21]. The participant's body weight and gender were specified. Postural input was obtained from digitized *x,y*-coordinates of body jonts or, if digitized video data were unavailable, via on-screen manipulation of a moveable mannequin.

The model calculated forces and moments at each joint starting at the wrist of each arm and proceeding to the elbow, shoulder, seventh cervical vertebra and down to the L_4/L_5 joint. Compression and shear forces at the L_4/L_5 level were estimated from knowledge of the moment of force and reaction forces at this motion unit. A 6-cm moment arm length was used to represent the geometry of a single equivalent torso extensor 'muscle' for the estimation of the compression component. This moment arm length was incorporated as a result of findings from work with a fully dynamic, much more anatomically detailed, EMG-assisted model [22], [23]. Anatomical dissection of lumbar musculature shows that there is a posterior pulling component of a substantial number of fascicles that tend to reduce anterior shear of the upper body when lumbar muscles are active [22–24]. These muscles are active if the lordotic curvature is maintained. If it is lost, ligaments are activated to support the load moment but they increase anterior shear [22–24]. The model incorporates these effects on shear forces acting on the lumbar spine and the output is called 'joint shear', as distinct from 'reaction shear'. In the data presented, only reaction shear is analyzed and both anterior reaction shear of L_4 on L_5 (i.e. head, arms and trunk tending to slide forward on L_5) and posterior reaction shear were calculated and entered into the regression model. Anterior shear was more common because this direction of shear is observed with the torso in a forward inclined posture, with or without load on the hands, and during pulling activities in an upright posture. Shear in the lateral transverse plane or shear as a result of spinal torsion was not calculated and would have elevated the shear force estimates reported in tasks with substantial lateral bend or torsional moments. All trunk kinematic and spine loading data entered into the model were in the sagittal plane.

4. Posture analysis system

Working postures, as distinct from spinal loading estimates described in the previous paragraphs, were analyzed using a computer-assisted video analysis system whose reliability and accuracy are documented elsewhere in the literature [17]. The system allowed an operator to use joystick input to track the joint postures seen in a section of digitized video over the course of the video clip. The computer handled all data synchronization and correction functions and provided visual feedback to the operator through an animated mannequin figure.

During the field data collection process the trained observer identified the separate components of the job to be analyzed. A representative trial of each of the components was then located on the video recording, digitized, and analyzed for trunk flexion/extension, torsion and lateral bending movements. Torsion was recorded as 'yes/no' if estimated to be greater than 20°. For short, highly repetitive work components, several cycles of repetitions were digitized and analyzed as a group while longer sections of work had representative portions digitized. Trunk flexion and lateral bend were defined as the angle of inclination of the L_4–C_7 line with respect to the vertical. The trunk angle over the course of each section of video was sampled at 30 Hz and the raw data were low pass filtered at 3 Hz.

The amplitude probability distribution function (APDF) of the trunk flexion/extension trace for each work component was combined into a time-weighted average to represent the APDF of trunk posture for an entire shift. Peak posture variables used for this study included the peak trunk flexion and the peak trunk velocity. The 99th percentile of the APDF was used to represent the peak values instead of the highest single value because the highest single value in the sample could have been caused by operator overshoot during the data processing stage. Cumulative postural exposure over the full shift was represented by the average number of trunk movements and by the average number of degrees moved per minute. A trunk movement was defined as any unidirectional movement with an amplitude of at least 20°. The APDF also permitted calculation of the percentage of the job cycle duration for which any particular trunk angle of interest was adopted by the worker.

In summary, many trunk kinematic and spinal tissue loading variables were recorded or calculated. They included peak and average trunk flexion angles, number of trunk movements (flexions or extensions) per minute, presence or absence of trunk twist or lateral bend, percentage of cycle time spent at various angles, peak and average trunk flexion and extension velocity, peak and accumulated L_4/L_5 moment, compression and shear. The 'peak load' variables that were statistically analyzed and presented in this paper are: lumbar spine compression, shear, and moment at the L_4/L_5 level, trunk flexion angle, trunk flexion velocity, and force on the hands experienced during a shift. These peak load variables were matched, respectively, with the following 'cumulative loading' variables: integrated spine compression, shear, and moment at L_4/L_5 over a shift, the time averaged number of degrees of flexion/extension excursion per minute, the number of flexion/extension moves per minute and the 'usual' force on the hand.

5. Statistical analysis

The interrelationships between variables were examined by constructing a Pearson correlation matrix. An exploratory factor analysis with a varimax rotation was then performed on the data to further examine intercorrelations of variables and to see which variables could be grouped to better explain the total exposure variance. Mean levels of all biomechanical variables were also examined independently to test for differences between cases and controls using a Student's *t*-test. Univariable odds ratios (ORs) were calculated for all variables using logistic regression procedures (SAS).

The complex relationships between the study variables and risk of reporting LBP were examined using multiple logistic regression with backwards elimination of variables that did not significantly contribute to the statistical model. To avoid over-restricting the choice of variables included in the preliminary models, we first identified variables that, univariabily, met a significance threshold of $P = 0.10$. These variables were candidates in the multivariable analysis although only those risk factors in the regression significant at $P = 0.05$ were retained in the final model. The multivariable technique allows for the identification of the study variables with the greatest independent contribution to outcome by simultaneously accounting for all variables that are entered into the analysis. The extent of the independent relationships of the study variables with LBP was assessed by calculating the odds ratio (OR), the estimator of risk for case-control studies. A value of 1.0 for the OR indicates an absence of risk. The statistical precision of the OR estimates was determined by calculating the corresponding 95% confidence intervals (95% CI). These intervals provide the most likely upper and lower bounds for the OR estimate. OR estimates of variables not statistically significant at the $P = 0.05$ levels have a 95% CI that includes 1.0 [25].

Since all of the biomechanical variables were on continuous scales, the size of the OR depends on the size of the unit exposure difference used to calculate it. While the default difference in exposure is a single unit of the variable in question (e.g. 1 Newton compression) such a unit difference is not relevant for exposure variables which have very large ranges (e.g. thousands of Newtons). Therefore, to better represent the risk associated with the study variables, two different ranges of exposure difference were chosen to report the odds ratio. A conservative estimate of risk was calculated by using the inter-quartile spread (IQS) as the unit difference. In this study, the IQS was taken to be the difference between the 25th and 75th percentile of exposure levels seen in the randomly sampled control group of plant workers. An estimate of the maximum risk was derived using the full range of exposure (100% range) seen in the data from the jobs of the randomly selected control group. The maximum risk estimate indicates the risk difference between the single least exposed and the single most exposed worker for that variable, an analytic strategy used previously [3]. The OR calculated across the IQS will always be smaller than the OR calculated across the 100% range but may provide a more realistic target for job improvements. The use of these ranges to calculate the OR permits interpretation of the risk levels within the context of exposure ranges present in the plant.

In this data base, in which only complete data sets on all of the biomechanical variables of interest were analyzed, data on 104 cases (including 20 job-matched proxies) and 130 random controls are presented.

6. Results

The demographic data on cases and controls are presented in Table 1. There were no significant differences at $p<0.05$ on any variable. Therefore, age, height, weight and work experience were not controlled in the logistic regression analyses presented in this paper because they did not distinguish cases from controls [10,11].

Biomechanical data means, standard deviations, and the results from the *t*-tests are presented in Table 2. There were significant differences between cases and controls for all biomechanical variables presented in this paper; peak variables were all significant at $p<0.001$ and cumulative variables were all significant at $p<0.05$.

The matrix of Pearson correlation coefficients is presented in Table 3. Strong correlations were found within the peak spinal loading variables and within the cumulative loading variables but the correlations between the two types of variables were low. Peak hand force correlated strongly with usual hand force, while both hand force variables correlated only moderately with the peak spinal tissue load variables of compression, moment and shear. Peak velocity, average number of trunk movements, and the average number of degrees moved per minute were all strongly intercorrelated and all of these posture variables were moderately correlated to peak flexion level.

The results from the factor analysis, using four orthogonal factors, are presented in a factor loading matrix shown in Table 4. Together, four factors in the analysis accounted for 89% of the total variance and all variables had a final communality ranging from 0.70 to 0.97 indicating that most of the variance of each contributing variable was accounted for in a four-factor

Table 1
Demographic data on those who reported LBP (cases) and those who did not (controls)

	Cases		Control		Prob
	Mean	SD	Mean	SD	
Age (yr)	41.1	8.5	41.5	8.2	0.63
Height (cm)	177.2	7.1	176.2	7.0	0.23
Weight (kg)	83.6	14.2	83.4	13.3	0.87
Body mass index (BMI)	26.6	3.9	26.8	3.9	0.60
	Case (%)		Control (%)		χ^2 p-value
Gender (male)	92.0		92.7		0.80
Current smoker	45.3		41.9		0.55
Main wage earner in household	81.8		78.8		0.51
Lives with pre-school children	21.2		19.0		0.63
Married	76.5		84.8		0.06

Table 2
Comparisons of peak and cumulative load variables including mean, standard deviation (SD), and probability level for case versus control differences (Prob). Integrated load variables are calculated over a complete shift

Variable	Cases			Controls			t Value	Prob.
	n	Mean	SD	n	Mean	SD		
Peak compression (N)	104	3423	1421	130	2733	1073	4.10	0.0001
Peak moment (N m)	104	182	84.3	130	140	62.7	4.15	0.0001
Peak shear (N)	104	465	176	130	353	159	5.10	0.00001
Peak hand force (N)	104	222	201	129	134	123	3.87	0.0002
Peak flexion (deg)	104	51.2	22.4	130	39.3	23.3	3.94	0.0001
Peak trunk velocity (deg s^{-1})	104	41.5	15.14	130	34.1	17.2	3.42	0.0007
Integrated compression (MN s)	104	21.0	4.72	130	19.5	3.84	2.68	0.0079
Integrated moment (MN m s)	104	0.55	0.24	130	0.47	0.15	2.96	0.0036
Inegrated shear (MN s)	104	1.52	0.64	130	1.32	0.45	2.61	0.0097
Usual hand force (N)	104	86	67	129	56	52	3.85	0.0002
Average moves (min^{-1})	104	2.9	2.1	130	2.3	2.3	2.08	0.0384
Average flexion (deg min^{-1})	104	307.5	137	130	252.3	133.3	3.11	0.0021

(MN s = megaNewton seconds per shift; MN m s = megaNewton meter seconds per shift)

Table 3
Pearson correlation coefficients matrix for all variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Peak compression	1.00											
2. Peak moment	**0.97‡**	1.00										
3. Peak shear	**0.83‡**	**0.89‡**	1.00									
4. Peak hand force	*0.66‡*	*0.63‡*	*0.58‡*	1.00								
5. Peak flexion	0.33‡	0.40‡	0.48‡	0.24‡	1.00							
6. Peak trunk velocity	0.16†	0.22‡	0.26‡	0.09	*0.68‡*	1.00						
7. Integrated compression	0.24‡	0.24‡	0.30‡	−0.03	0.14‡	0.06	1.00					
8. Integrated moment	0.15†	0.17‡	0.24‡	−0.04	0.30‡	0.21‡	**0.88‡**	1.00				
9. Integrated shear	0.12	0.15†	0.25‡	−0.05	0.39‡	0.27‡	**0.78‡**	**0.93‡**	1.00			
10. Usual hand force	*0.59‡*	*0.56‡*	*0.49‡*	**0.82‡**	0.09	−0.05	0.00	−0.01	−0.04	1.00		
11. Average moves	0.04	0.08	0.14†	0.04	*0.60‡*	**0.82‡**	0.04	0.21‡	0.28‡	−0.07	1.00	
12. Average flexion	0.12	0.15†	0.17†	0.07	*0.52‡*	**0.84‡**	0.07	0.22‡	0.26‡	−0.05	**0.78‡**	1.00

†Statistically significant correlation $p < 0.05$.
‡Statistically significant correlation $p < 0.01$.
Strong correlation $r < 0.70$.
Moderate correlation $r < 0.50$.

model. These results support data from the correlation matrix indicating strong interrelationships within the distinct sets of peak and cumulative spine loading variables, but not between these sets. Therefore, it appears that the cumulative loading variables are not simply the values of peak variables multiplied (or divided) linearly by time.

The univariable odds ratios were significant for all variables and are summarized in Table 5 for the IQS and in Fig. 1 for the 100% range from observations of the random control group exposure. The IQS odds ratios are statistically significant for all variables and indicate substantial risk. Peak shear force and peak torso flexion stand out with the ORs of reporting back pain, respectively, of 2.3 and 2.4 between workers with exposure differences equal to the inter-quartile spread. The OR estimates based on 100% of the range (the extremes of exposure), are much larger.

The final multivariable logistic regression model of the biomechanical measures, in the absence of any psychosocial variables, contained four risk factors. Table 6 shows the ORs of each variables for the IQS and 'full range' of their values. Since each OR is adjusted for the effects of the other three variables, these four variables constitute independent risk factors. Based on the underlying assumptions of the logistic regression model used, the combined OR is calculated by multiplying the individual risk factor ORs in the multivariable model. For workers exposed to levels of all four biomechanical variables equal to the IQS, a completely feasible possibility, the combined risk estimate is over 6.0. Two peaks and two cumulative variables emerged in the final model: peak lumbar shear force; peak torso flexion velocity; the integrated lumbar moment over the duration of the shift; and the time averaged 'usual hand force'. For the same

Table 4
Rotated factor loading matrix from principal components analysis using four factors. Each variable's largest loading factors are marked in bold. Factor loadings <0.1 are excluded

Variable name	Factor 1 Trunk kinematics	Factor 2 Peak spine load	Factor 3 Integrated spine load	Factor 4 Hand force
Peak compression (N)		**0.89**		0.34
Peak moment (N m)		**0.93**		0.28
Peak shear (N)	0.15	**0.89**	0.18	0.22
Peak hand force (N)		0.45		**0.83**
Peak flexion level (deg)	**0.71**	0.40	0.17	
Peak trunk velocity (deg s^{-1})	**0.94**	0.12		
Integrated compression (N s)		0.19	**0.92**	
Integrated moment (N m s)	0.15		**0.97**	
Integrated shear (N s)	0.23		**0.92**	
Usual hand force (N)		0.34		**0.90**
Average moves (min^{-1})	**0.92**			
Average flexion (deg min^{-1})	**0.90**			

Table 5
Univariable odds ratios (ORs), 95% confidence interval (CI), and model details from logistic regression analysis. Odds ratios were calculated for exposure differences equal to the random control inter-quartile spread (IQS) for both peak and cumulative loading variables. Odds ratios for which the 95% confidence interval does not span 1.0 are significant at $p < 0.05$

Variable	Chi-square	IQS difference	OR at IQS difference	95% CI
Peak compression (N)	15.24	1348	1.9	1.4–2.6
Peak moment (N m)	15.54	79.9	1.9	1.4–2.6
Peak shear (N)	20.79	203	2.3	1.6–3.4
Peak hand force (N)	13.63	167	1.8	1.3–2.5
Peak flexion (deg)	14.04	39	2.4	1.5–3.8
Peak trunk velocity (deg s^{-1})	10.76	22.6	1.9	1.3–2.7
Integrated compression (MN s)	7.01	4.62	1.5	1.1–2.0
Integrated moment (MN m s)	8.26	0.21	1.6	1.2–2.2
Integrated shear (MN s)	6.55	0.53	1.4	1.1–1.9
Usual hand force (N)	13.19	70	1.9	1.4–2.7
Average moves (min^{-1})	4.18	2.9	1.4	1.0–2.0
Average flexion (deg min^{-1})	8.93	176.6	1.7	1.2–2.5

(MN s = megaNewton seconds per shift; MN m s = megaNewton meter seconds per shift)

variables, but assigning the unit differences as the 100% range of the random control observations instead of the IQS, the combined relative risk for people working at the high end on all four variables is very large. It is, however, improbable that someone would be exposed to extreme levels on all four variables.

7. Discussion

Although several biomechanical (and psychosocial) variables clearly separated cases from controls and an array of specific, independent biomechanical variables surfaced as risk factors, there are a number of limita-

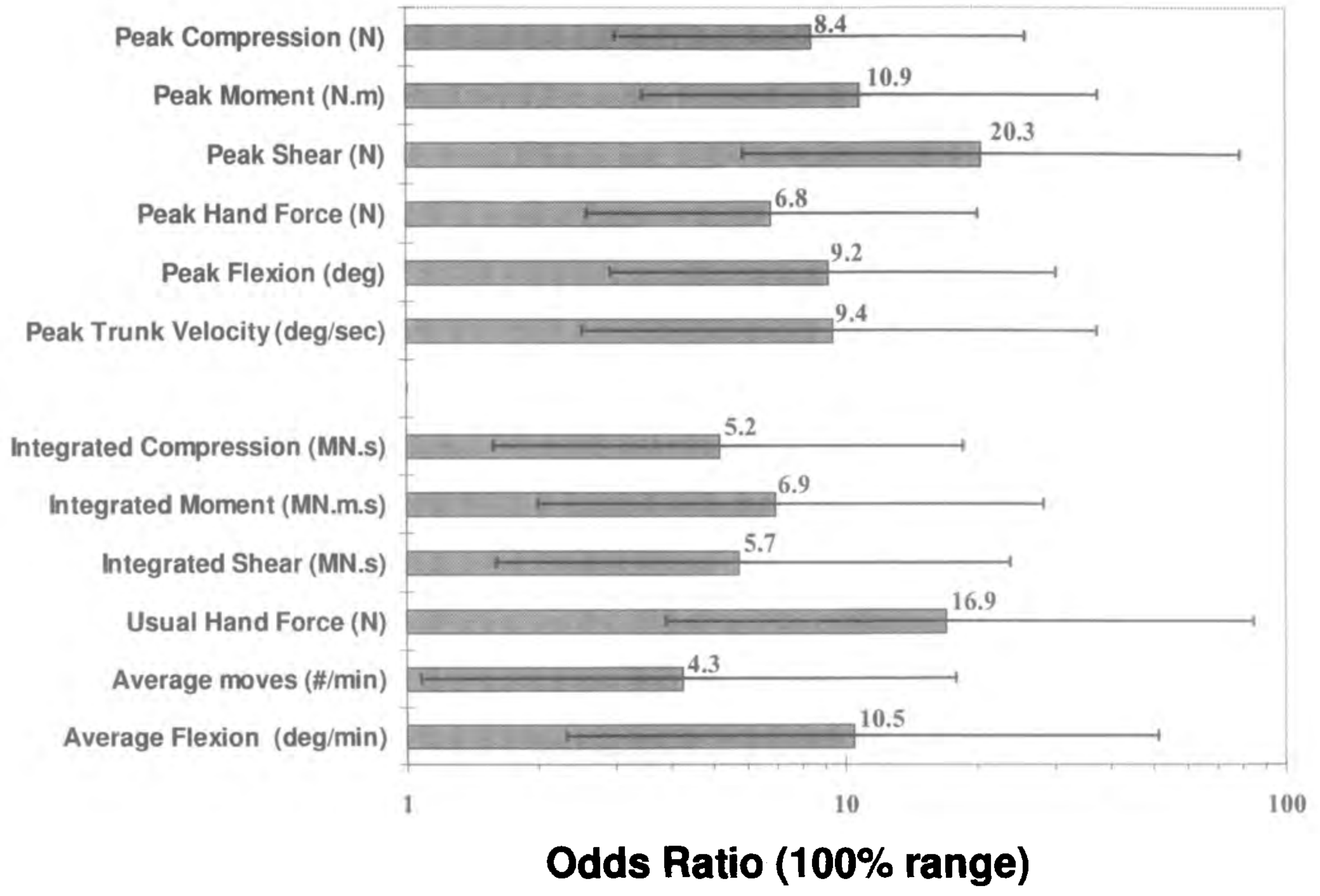

Fig. 1. Odds ratios and 95% confidence intervals calculated univariably for all 12 exposure variables. The odds ratios calculation was based on an exposure difference equivalent to 100% of the range of the randomly selected jobs in the plant.

Table 6
Multivariable logistic regression model resulting from a backwards selection procedure. Odds ratios (ORs) and 95% confidence intervals (CIs) are presented for exposure differences equal to both the inter-quartile spread (conservative) and full range (maximum risk) as seen in the randomly selected jobs in the manufacturing plant. Estimates of combined risk can be obtained by multiplying the relevant odds ratios

Variable	Inter-quartile spread			100% Range		
	IQS	OR	95% CI	Range	OR	95% CI
Peak shear (N)	203	1.5	1.0–2.4	727	4.7	1.0–22.6
Peak trunk velocity (deg s^{-1})	22.6	1.6	1.1–2.5	81.4	5.8	1.3–26.7
Integrated moment (MN m s)	0.21	1.4	1.0–2.0	0.88	4.5	1.1–21.0
Usual hand force (N)	70	1.7	1.2–2.6	314	10.5	1.9–65.6

tions to the study. The variables that emerge in a study of this nature depend on what it measured, how well it is measured and how one defines case and control group classification. An analysis of some of these limitations follows.

About 30% of the control subjects reported some back pain to the research staff but had not reported it to a nursing station in the previous 90 days; therefore, they remained classified as controls. Furthermore, this study is about reported pain, not medically diagnosed pathology. Although all participants did receive a simple clinical examination by a trained, non-clinical researcher during an in-home interview regarding psychosocial factors, no specific medical diagnosis was required to be a case. Including subjects in the control group who had LBP but had not reported it to the nursing station could have resulted in misclassification of some of the controls, an error that would likely result in underestimates of the true effect sizes for the observed ORs. On the other hand, the results of the study are, perhaps, more representative of the full workforce than if a large number of the potential controls had been excluded because of 'mild' back pain. Moreover, the pain reported by the cases did not have to result in time lost from the job. The only basic criterion for eligibility for both cases and controls was no previous LBP report in the previous 90 days. Consequently, the inclusion criteria for both cases and controls were far from stringent. However, analysis of the clinical data indicated that cases were representative of patients seen in primary care for treatment of routine LBP. While cases and controls were different in their LBP status, weak inclusion criteria would tend to narrow any differences in sizes of exposure measures between cases and controls and reduce ORs.

Nearly 20% of the data that were entered as 'case' biomechanical data were, in fact, obtained on 'job-matched control' proxies. Punnett *et al.* [3] reported that this method, which elevates statistical power by increasing the case sample size, did not affect their conclusions unreasonably. Analysis of the biomechanical data of the proxy participants in the present study showed that they tended to fall between the values of the cases and those of the random controls. Therefore, while the proxy data tended to narrow gaps in exposure levels between cases and controls, imprecision in the data would, again, have the effect of reducing rather than inflating the ORs.

The estimates of forces on spinal tissues entered into logistic regression procedures were specific to the spine model used and the question of validity of spine models frequently arises. In the opinions of the biomechanists on the study team, none of the spine models that have been presented to data in the literature have been directly validated by comparing model estimates of muscle force, spinal compression or shear with direct, in vivo measures of these same variables in the same units of measurements. Technically, this type of validation is currently not possible. Consequently, anatomical and physiological content validity in the structure and function of these types of models are important. An attempt has been made to incorporate as much content validity as possible into the spine model used in this study, but assumptions and simplifications are present in all models. This problem notwithstanding, calculations of forces on spinal tissues were made using the same biomechanical spine model on all participants.

Perhaps a more serious limitation is that a two-dimensional rather than a three-dimensional spine model was used, even though the model could handle asymmetric, dynamic forces on the hands. Moments, compression and shear attributable to lateral bend or pure spinal torsion were not calculated for the data presented and the values entered into the statistical model were undoubtedly underestimates of the sizes of these variables in tasks in which this type of loading was present. In addition some overestimation of compressive forces would have occurred in tasks in which the inertial forces on the hands were large since the quasi-dynamic model produces larger compressive estimates than a fully dynamic model used to estimate the same lifting tasks [18].

Despite error in model assumptions, the utilization of a two- rather than a three-dimensional model and a quasi-dynamic rather than a fully dynamic model, both cases and controls are treated statistically equally since the same model was used on all participants. The model outputs proved to be able to distinguish differences in loading on spinal structures between cases and controls, identifying statistically significant risk factors. In this sense, the biomechanical spine model used in this study has been validated for its ability to produce an estimate of risk of LBP.

The computerized video posture program that was developed and used for the kinematic variables was capable of recording lateral bend and spinal torsion, but these variables did not produce significant univariable ORs in this study, unlike the findings of Marras *et al.* [2] and Punnett *et al.* [3]. Therefore, they were not used in the data base analyzed here. It is possible that our measures of non-sagittal trunk kinematics were not as good as those of Marras *et al.* [2] who used an electrogoniometer approach. However, both our computerized video system and the type of work analyzed were similar to those of Punnett *et al.* [3]. It is worth noting that the interobserver agreement was better for sagittal kinematics than lateral bend or twist [17].

The measurement of sizes and directions of forces on the hands in field studies is always difficult. Whenever possible, force transducers were used. Assessment of direction required the judgment of observers. They were extensively trained but any subjective judgment is error prone. Workers simulated efforts against the force transducers when they could not be inserted between their hands and the tool or material. Discrepancies between the actual force applied on the job and the worker estimates during the simulations of effort are probably present but are unlikely to have been differentially biased for cases and controls.

In spite of the limitations discussed above, these results have shown that cases experienced significantly higher biomechanical loading than controls in all variables. Differences in univariable ORs among exposure variables suggest that some measures are more sensitive than others in distinguishing cases from controls. All of the ORs calculated in this data set were statistically significant. Peak shear and peak torso flexion showed high ORs for both the IQS and 100% range data. Hypothesis no. 1 is, therefore, supported: there are physical work exposure variables that distinguish people who have reported LBP (cases) from those who have not (controls), but with varying predictive strength.

There is considerable evidence to support hypothesis no. 2: that there are variables that characterize 'cumulative exposure' to load that provide information about LBP that is different from 'peak load' variables. All of the cumulative loading variables were significantly higher for the cases than for the controls and showed substantial univariable ORs at both the IQS and 100% range unit values.

The low correlations between the peak and corresponding cumulative measures of compression, shear and moment show that the integrated data are not simply a result of multiplying peak values linearly by time to obtain the integral or dividing by time to obtain an average. These variables are, apparently, measuring different demands of the jobs. Moreover, in the multivariable analysis only one of the peak and one of the cumulative spine loading variables entered any one model. This suggests that peak and cumulative or time-averaged loading variables are also measuring different aspects of risk. This cannot be said for the external load (hand force) and kinematic variables. These variables showed much higher correlations between the peak and cumulative versions and a peak or a cumulative version of the variable, not both, showed up in the multivariable logistic regression analyses as mutually exclusive risk factors, in addition to the 'peak spine load' and 'cumulative spine load' factors.

Further support for hypothesis no. 2 is evident from the factor analysis which clearly showed a 'cumulative loading' factor that was different from a 'peak loading' factor. Therefore, hypothesis no. 2 is supported by results of the analysis of the three spinal tissue loading variables; spinal compression, shear and moment. Spinal moment, one could argue, is a close analog of tissue loading since the external moment is supported primarily by lumbar muscle fascicles if the lordosis is maintained and by muscle and ligament or ligament if the lordosis is partly or completely lost [23,24].

No distinction was possible in this study between cumulative loading that is the result of high repetition and that which was the result of prolonged duration. It would have been useful to have been able to separate these because their potential injury-inducing pathways are probably different. The former may result in repetitive micro-trauma of tissue, the latter in excessive strain on tissue because of creep.

Hypothesis no. 3 was not supported; all four types of variables showed substantial associations with risk of LBP reporting. While peak spinal loading tended to account best for differences between cases and controls, the ORs associated with all of the variables were both statistically significant and similar in magnitude. The factor analysis convincingly showed that there were not only peak and cumulative spinal tissue loading factors but that the external forces on the hands and the kinematic variables were sufficiently independent of these factors and from each other to appear as separate risk factors. This independence is confirmed by the multivariable logistic regression analysis which identified one variable from each of the four factor groupings. Therefore, hand forces and trunk kinematics are not merely surrogates for the biomechanically modelled spinal tissue loads; these variables are contributing information about risk of LBP that is different from the information contributed by the estimates of load on spinal tissues. Conversely, output from the biomechanical spine model provided information that was different from the inputs of trunk kinematics and forces on the hands, justifying the continued use of these models to assess risk of LBP.

The factor interpretation in Table 4 is not an output of the analysis. Factor titles were based upon both the variables loading heavily on the factor and the low back exposure constructs present in the literature. The individual factor loading weights for each variable indicate how strongly the variable correlated to the corresponding factor. The largest factor loading weight for each variable in Table 4 is indicated in bold and is the primary loading factor for that variable. The factors were then named according to which variables had their primary loading on that factor.

Peak flexion level, peak flexor velocity, the average moves per minute, and average degrees moved per minute all correlated strongly as factor 1, which we called Trunk Kinematics. These exposure variables have been used by many authors under names such as postural load, trunk angle, trunk flexion, repetitiveness and dynamic trunk motion. Factor 2 had primary loading from the peak compression, peak moment, and peak shear variables; this factor was called Peak Spinal Load. This is perhaps the most commonly used exposure measure for occupational biomechanics studies and has been reported by many authors (see for example [12,15,18]). Factor 3 had primary loadings exclusively from the integrated spine load variables and was named Cumulative Spinal Load. The notion of potentially harmful effects of excessively prolonged loading is quite common yet it is not frequently used as an exposure measure. Both the peak hand force and the usual hand force loaded primarily on the fourth factor, called Hand Force. The amount of total variance accounted for by the factors decreases as we move away from factor 1 to factor 4 in Table 4. The exposure variables have extremely high loading with the four main factors identified and only minor loading on the other factors. A few variables have non-trivial loading on more than one factor; Peak Flexion Angle, for example, contributes to factors 1 and 2. Extreme trunk flexion increases the lumbar moment and, thus, the spinal load so this intercorrelation is not surprising. The four factors that described the 12 peak and cumulative exposure variables accounted for 89% of the total variance.

The factor analysis results can be used to help interpret the multivariable logistic regression model. The final regression model included four variables; peak shear, peak flexor velocity, integrated moment and usual hand force. Examination of Table 4 shows that a representative variable from each of the four factors is in the regression model. This is to be expected because the multivariable model chooses variables with the strongest independent contributions to case-control status, while the factor analysis groups related variables into independent factors. Several other four-variable models were constructed which had similar power to predict case or control status. For example, substituting integrated compression for integrated moment resulted in a model with similar performance characteristics. In each case, however, the model would contain one variable from each factor, a clear indication of the important contribution each type of factor has to the risk of reporting LBP in the study site.

While all peak spine load variables were associated with the risk of LBP according to the univariable ORs, peak shear tended to remain in any multivariable model for which it was considered. Once this variable entered a logistic regression model any strongly correlated variables, such as peak moment and peak compression, were automatically excluded. The strong predictive power of the shear variable may be due to the responsiveness of shear to push and pull efforts. A push or pull effort performed at the waist (L_4/L_5) level will have little effect on the calculated moment and compression values but the shear will increase substantially under these forces. Push-pull efforts are common in an automotive assembly plant and in most other manufacturing environments. On the other hand, in the tasks observed, when the moment at L_4/L_5 was high, both compression and shear were high. There was very little pure axial loading that would produce high spinal compression but low shear. It is, therefore, more common for shear to be a factor both in the presence and in the absence of high compression or moment than the other way around. As a result, peak shear may be able to account for more of the case-control differences than peak compression or peak moment.

Kumar [6] reported differences in accumulated lumbar shear forces between institutional aides with and without back pain. Beyond this study, the authors are unaware of other studies that have epidemiological evidence that identifies shear forces as a risk factor for LBP. There are several biomechanical reasons why anterior shear of the superior lumbar vertebra on the inferior vertebra might result in at least irritation of inflamed tissues, if not observable tissue damage. McGill and Norman [23] and Potvin *et al.* [24] showed up to threefold increases in shearing forces supported by the facets, the annulus of the disc and posterior intervertebral ligaments if the lumbar extensor muscles were inactivated as a result of excessive torso flexion. Muscle activity, produced as long as the lumbar lordosis is maintained, reduces the size of the shear forces supported by other spinal structures. In extreme anterior shear loading, the pars interarticularis fractures but in the intact spine the disc sustains the largest portion of the anterior shear load [26]. Krypton *et al.* [27] also produced disc damage as well as facet and lamina fractures in shear loading of facet joints and deformation of annular fibres in the disc could conceivably result in pain in people who, for example, might have already sustained micro-trauma or have pre-existing inflammation of structures that must support shear forces. Free nerve endings have been shown in these spinal structures in rabbit and human specimens [28,29].

There are many reports from in vitro studies of damage to spinal structures arising from excessive peak forces [15,30]. There are some epidemiological studies of biomechanical risk factors that have shown that peak kinematic variables, such as torso angles beyond 20° [3] or torso velocities above certain values [2], can distinguish workers who report LBP from those who do not or those who work on 'high risk' jobs from those in jobs of lower risk. In addition, Herrin *et al.* [1] and Marras *et al.* [2] showed that some peak kinetic variables, spinal compression and lumbar reaction moment of force, were also able to distinguish workers in high injury incidence jobs from those in jobs of lower injury incidence. These three epidemiological studies of low back troubles all involved large numbers of participants and extensive data collection but used relatively short durations of worker monitoring (a few minutes or a few job cycles) and the recording of 'peak' rather than 'cumulative' loading variables. Analyses in all these studies showed statistically significant odds ratios or significant relationships between the size of the biomechanical exposure measures and LBP incidence.

The present study supports the general findings of these studies, that biomechanical loading is a strong risk factor in the reporting of work-related LBP. In addition, this study documents the importance of cumulative loading and strongly points to the importance of shear forces acting on the lumbar spine as risk factors. Another paper will show that these findings hold after accounting for the effects of psychosocial variables such as perceptions of job control, the workplace social environment and job satisfaction.

8. Conclusions

There are a number of limitations of this study. In particular, the following should be noted: the relatively weak criteria for classification of 'cases' and 'controls'; the use proxies for almost 20% of the biomechanical data to represent cases; logistical problems and measurement error in taking biomechanical methods out of the laboratory to obtain detailed measures in the field on more than 200 participants for observation periods ranging from two to eight hours. All of these limitations would tend to make it harder to find differences between cases and controls which, perhaps, attests to the robustness of the findings. Based upon the data presented in this paper, the following conclusions about biomechanical risk factors for reported LBP in an auto assembly facility seem to be justified:

1. Biomechanical work-exposure variables are strongly associated with the risk of reporting LBP at work, but with varying strength of association across different variables.
2. Cumulative spinal load per shift provides information that is different from peak spinal load in distinguishing those who report LBP in the workplace from those who do not.
3. Estimates from a biomechanical spine model of spinal compression, shear and torso extension moment of force at L_4/L_5, regardless of whether they are peak or cumulative loading estimates, while separating cases from controls, are not always better able to do this than kinematic and external loading variables.
4. Four factors emerged to distinguish cases from controls; peak spinal load, cumulative spinal load, kinematic variables related to torso motion involved in the job, and external forces on the hands. Trunk kinematics and external force variables are not merely 'surrogates' of spine tissue loading estimates from biomechanical models. They provide information about LBP risk that is different from that provided by the tissue loading estimates even though they are inputs to the spine model. Conversely, outputs from the spine model provide risk factor information that is different from that of the inputs to the model alone and are useful exposure measures.
5. There is more than sixfold increase in the risk for reporting LBP for workers with high levels of exposure to all four major risk factors indentified: peak shear; integrated lumbar moment over the duration of the shift; peak torso flexion velocity; and usual hand force over the course of the shift.
6. Although the best statistical model included the combinations of variables listed in no. 5, above, very little predictive power was lost by substituting variables such as spinal compression or moment, which were eliminated from the 'best' multivariable model because of high correlation with spinal shear force. It would, therefore, be unwise to dismiss compression or moment as risk factors only because they did not emerge in the best multivariable statistical model.

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Occupational Health and Safety Council of Ontario (OHSCO)

MUSCULOSKELETAL DISORDERS PREVENTION SERIES

PART 1:

MSD Prevention Guideline for Ontario

MSD

Musculoskeletal Disorders

PREVENTION GUIDELINE

Disclaimer

The material contained in this guideline is for information and reference purposes only and not intended as legal or professional advice. The adoption of the practices described in this Guideline may not meet the needs, requirements or obligations of individual workplaces.

Use, reproduction and/or duplication of this guideline is recommended and encouraged.

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PART 1:

MSD Prevention Guideline for Ontario

Table of Contents

MSD
MUSCULOSKELETAL DISORDERS

Acknowledgements

This document, the Musculoskeletal Disorder (MSD) Prevention Guideline for Ontario, is part 1 of the Occupational Health and Safety Council of Ontario's Musculoskeletal Disorders (MSD) Prevention Series. It was developed in partnership with the members of the Occupational Health and Safety Council of Ontario (OHSCO), with the support of the Centre of Research Expertise for the Prevention of Musculoskeletal Disorder (CRE-MSD), and in consultation with representatives from Ontario's labour organizations, employer associations, and individual employers and workers.

Supporting organizations include:

- Construction Safety Association of Ontario
- Education Safety Association of Ontario
- Electrical & Utilities Safety Association
- Farm Safety Association
- Industrial Accident Prevention Association
- Institute for Work & Health
- Mines and Aggregates Safety and Health Association
- Municipal Health and Safety Association
- Occupational Health Clinics for Ontario Workers
- Ontario Forestry Safe Workplace Association
- Ontario Ministry of Labour
- Ontario Safety Association for Community and Healthcare
- Ontario Service Safety Alliance
- Pulp and Paper Health and Safety Association
- Transportation Health and Safety Association of Ontario
- Workers Health and Safety Centre
- Workplace Safety and Insurance Board (Ontario)

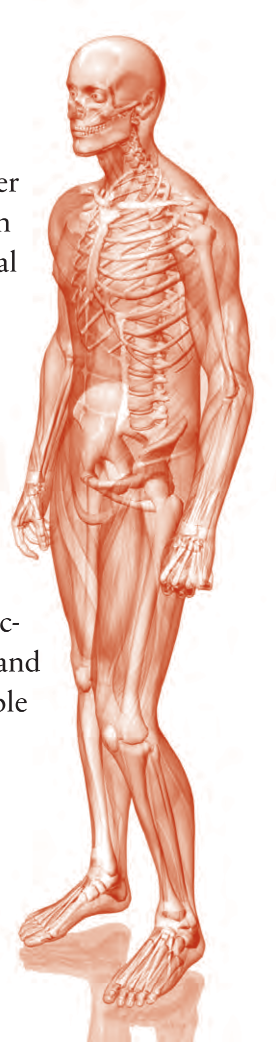
The support and participation of everyone who contributed to the development of the MSD Prevention Guideline for Ontario and its related documents is greatly appreciated.

Scope of the Guideline

The MSD Prevention Guideline for Ontario is being made available through the partners of the Ontario health and safety system. Its primary purpose is to provide Ontario's employers and workers with information and advice on a recommended generic framework for preventing musculoskeletal disorders in the workplace.

OHSCO's MSD Prevention Series includes two related documents to support the MSD Prevention Guideline for Ontario:

- Part 2: Resource Manual for the MSD Prevention Guideline for Ontario, and
- Part 3: MSD Prevention Toolbox.



To obtain Part 2 or Part 3 of OHSCO's MSD Prevention Series contact one of Ontario's health and safety organizations (see Resources for contact information).

A wide variety of health and safety experts and associations, employers, employer associations, and unions were consulted in developing the guideline. Experience in other jurisdictions was considered, as were the opinions and advice of international experts.

The MSD prevention framework presented in this guideline is consistent with best practices and effective approaches based on current information and experience. The framework represents only one way of addressing MSDs in a workplace. Other MSD prevention processes and programs that include worker training and involvement and a process to recognize, assess and control MSD hazards (including those that may have been established through a collective agreement) may be equally effective.

The MSD prevention framework is consistent with the requirements for an effective health and safety program. Therefore, workplace MSD prevention efforts can and should be fully integrated into an existing health and safety program where possible and practical.

The information in the MSD Prevention Guideline for Ontario and its related documents is generic and not targeted at any specific type of workplace, industry sector or work task. Although the particular hazards and jobs or tasks present in different workplaces vary, the hazards that can lead to MSD are the same for all workplaces.

The MSD Prevention Guideline for Ontario and its related materials:

- do not describe all elements of an effective health and safety management system that should be implemented in all workplaces
- do not cover all of the legislated workplace health and safety requirements
- do not specifically apply to Early and Safe Return-to-Work programs
- do not address issues related to personal wellness, fitness, diet or lifestyle, and
- do not describe the full scope of workplace ergonomics.

The primary audience for the MSD Prevention Guideline for Ontario and the related materials are the workplace parties including employers, managers, supervisors, workers, joint health and safety committee (JHSC) members, health and safety representatives (H&S reps) and workplace union representatives. Unions, employer associations, health and safety professionals, health and safety associations, ergonomists, etc., may also find the information useful when helping workplaces.

Section 1: Introduction

Musculoskeletal disorders (MSDs) are the number one type of work-related lost-time claim reported to the Workplace Safety and Insurance Board (WSIB) in Ontario. MSDs:

- cause pain and suffering for thousands of workers every year, and
- cost Ontario's workplaces hundreds of millions of dollars due to absenteeism and lost productivity.

MSD FACTS

In Ontario, MSDs account for:

- 42% of all lost-time claims
- 42% of all lost-time claim costs, and
- 50% of all lost-time days.

(Averages for 1996–2004)

DEFINITION OF MSD

MSDs are injuries and disorders of the musculoskeletal system. They may be caused or aggravated by various hazards or risk factors in the workplace.

The musculoskeletal system includes:

- muscles, tendons and tendon sheathes
- nerves
- bursa
- blood vessels
- joints/spinal discs, and
- ligaments.

MSDs do not include musculoskeletal injuries or disorders that are the direct result of a fall, struck by or against, caught in or on, vehicle collision, violence, etc.

MSD is an umbrella term for a number of injuries and disorders of the muscles, tendons, nerves, etc. Other terms that mean the same include:

- repetitive strain injury (RSI)
- cumulative trauma disorder (CTD)
- work-related musculoskeletal disorder (WMSD)
- musculoskeletal injury (MSI, MSK)
- occupational overuse syndrome (OOS), and
- sprain and strain.

MSDs are strongly linked to known risk factors or hazards in the workplace. We can take action to prevent MSDs in Ontario.

Purpose of the MSD Prevention Guideline for Ontario

The purpose of the MSD Prevention Guideline for Ontario is to provide Ontario employers and workers with information and advice on a recommended generic framework for preventing MSDs in the workplace.

For workplaces that already have an MSD prevention program in place, the MSD Prevention Guideline for Ontario and related materials may be helpful when considering whether existing program elements can be modified or improved.

For workplaces that do not have an existing MSD prevention program, the guideline and related materials can be used to implement an effective MSD prevention framework and/or integrate MSD prevention into the existing health and safety program.

POINT TO REMEMBER

Controlling MSD hazards in a workplace is not only the right thing to do; **it is the law.**

The *Resource Manual for the MSD Prevention Guideline for Ontario*, part 2 of the Occupational Health and Safety Council of Ontario's Musculoskeletal Disorders (MSD) Prevention Series provides detailed information and advice on how to implement the framework to prevent MSDs.

The *MSD Prevention Tool Box,* part 3 of the Occupational Health and Safety Council of Ontario's Musculoskeletal Disorders (MSD) Prevention Series, contains examples of worksheets, surveys and hazard identification tools that the workplace parties can use to help them in their MSD prevention efforts. Guidance on MSD risk assessment methods is also included. To obtain either of the above two documents contact one of Ontario's health and safety organizations (see Resources for contact information).

Section 2: MSD Prevention–A Part of Your Occupational Health and Safety Program

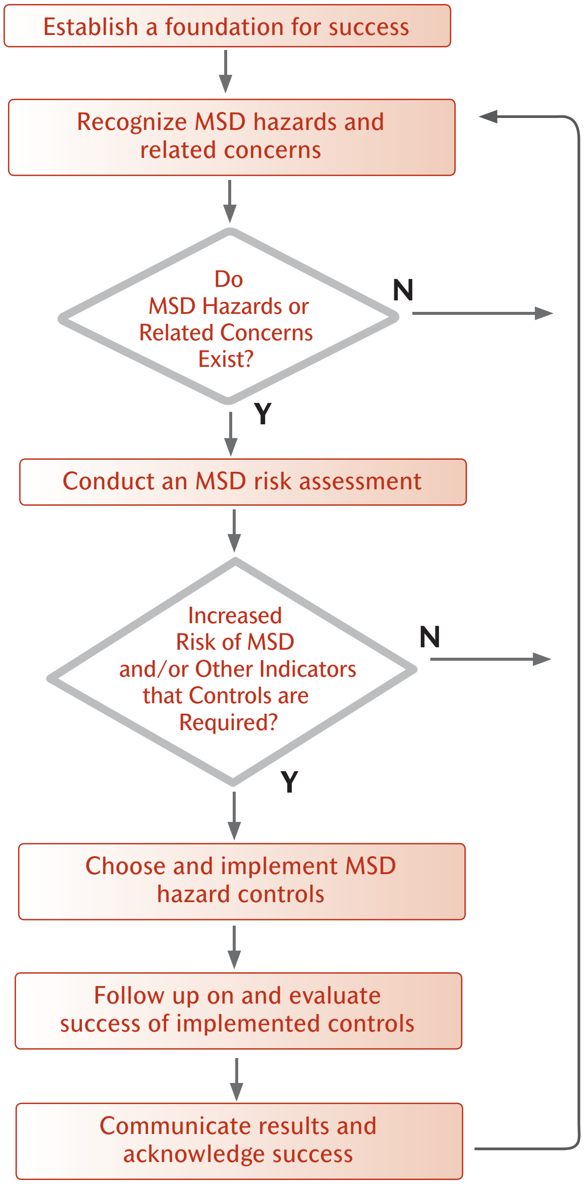


Figure 2.0: Steps in the MSD prevention framework

MSD prevention does not have to be difficult or complex. All you really need is the ability and the will to recognize, assess and control MSD hazards in the same way you would any other hazard in the workplace.

This guideline provides an overview of a recommended MSD prevention framework (see Figure 2.0) that should be familiar to everyone in a workplace such as employers, supervisors, JHSC members, H&S reps and front-line staff. The steps in the framework are the same steps used to deal with any hazard in a workplace. Implementing these steps will help to ensure that MSD hazards are recognized, assessed and, most importantly, controlled, resulting in a reduced risk of MSDs for all workers.

POINT TO REMEMBER

If you have an effective health and safety program, you already have a good foundation for preventing MSDs.

See the **Resource Manual for the MSD Prevention Guideline for Ontario** for more details on how to implement the MSD prevention framework.

Section 3: Establish a Foundation for Success

A number of suggested steps for creating a foundation for a successful MSD prevention program are outlined below. These steps have been shown to be important. However, the elements listed for each step are not all inclusive, and not all elements may be required or applicable in all workplaces. Among the most important steps are management commitment, vision, leadership and worker participation.

See **Section 3 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on how to establish a foundation for success.

Management Commitment to MSD Prevention

Management is encouraged to:

- incorporate MSD prevention activities into their existing health and safety programs
- develop an MSD prevention policy, procedure and/or statement in consultation with the JHSC or H&S rep and communicate it to all workers
- define the roles of employers, managers, supervisors, JHSC or H&S reps, and workers in preventing MSDs
- review reports of MSD hazards and take corrective action
- annually review the MSD prevention aspects of the overall health and safety policy and program in consultation with the JHSC or H&S rep, and
- report on progress of MSD prevention efforts.

POINT TO REMEMBER

Preventing MSDs leads to improved overall business performance. Building a foundation will help to ensure that you get maximum return on your investment.

Establish and Communicate a Process for Identifying and Controlling MSD Hazards

Workplace parties are encouraged to:

- look for MSD hazards during regular workplace inspections
- identify MSD hazards when doing job task analysis
- review reports of MSD concerns and hazards during JHSC meetings
- establish a process for assessing MSD risk
- consider potential MSD hazards when making any change in the workplace
- ensure that all workers are aware of how MSD hazards will be identified and controlled, and
- create an MSD prevention plan that outlines the objectives for, methods to be used in and expectations of any MSD prevention activities implemented in the workplace.

Ensure Worker Participation in the MSD Prevention Process

Workers can play an active role in the MSD prevention process by:

- using their experience and knowledge to recognize and assess MSD hazards and to suggest effective solutions to manage and control them
- participating in training to recognize the symptoms of MSDs and the work-related hazards that might contribute to their development
- participating in training on how to use controls that have been implemented to reduce MSD risk and regularly using these controls (e.g., new equipment, work methods, tools)
- being involved in planning and implementing changes to work tasks or jobs, and
- reporting MSD hazards, pain or discomfort, etc., to management.

Encourage Early Reporting and Bringing Solution Ideas Forward

Managers and supervisors should:

- encourage workers to report signs or symptoms of MSDs as soon as possible
- receive these reports positively and take action to ensure that the workers' pain or discomfort does not get worse, and
- encourage workers to look for ways to reduce MSD hazards, and for better and more productive ways to do the job.

Develop a Culture of Open Communication and Report on MSD Prevention Efforts

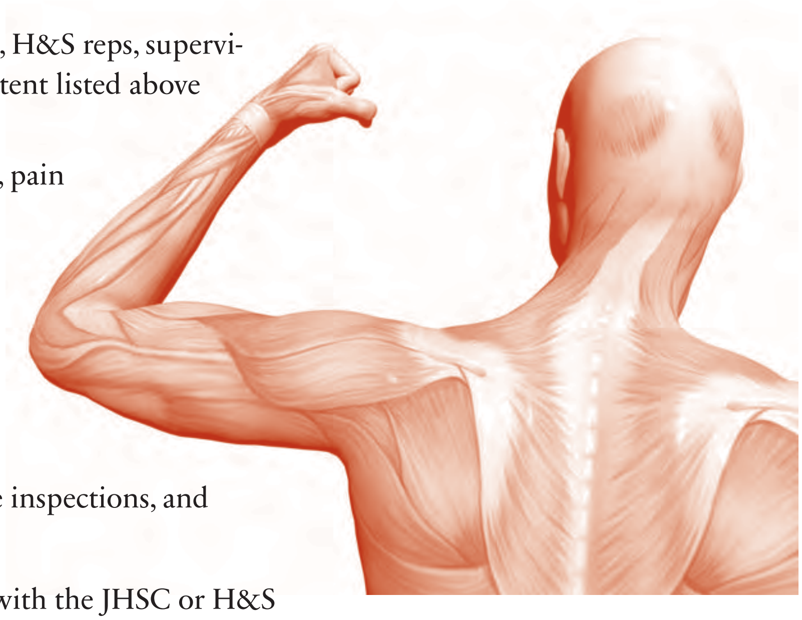
Your MSD prevention program will be more likely to succeed if your workplace culture supports:

- open discussion about the hazards, and
- frequent communication with all workers and the JHSC or H&S rep about MSD prevention efforts.

Provide MSD Prevention Training for All Workers

MSD prevention training for all workers should include:

- the signs and symptoms of MSDs
- how to recognize MSD hazards
- workplace policies and procedures for dealing with concerns related to MSDs, and
- information on the equipment, adjustments and procedures workers need to use or follow to reduce or eliminate their exposure to MSD hazards.



MSD prevention training for JHSC members, H&S reps, supervisors and managers should include all of the content listed above for workers, as well as how to:

- respond when workers report a concern, pain or discomfort
- recognize MSD hazards and use MSD hazard identification tools
- recognize indicators for MSD hazards
- analyze injury and incident reports for MSD trends and issues
- look for MSD hazards during workplace inspections, and
- control MSD hazards in the workplace.

Management is encouraged, in consultation with the JHSC or H&S rep, to identify the best way to provide MSD prevention training for workers, determine the appropriate content for this training and establish a method to evaluate the success of the training.

Planning to Prevent MSDs

The process for choosing and implementing controls for MSD hazards presented above is designed to control hazards that are already present in the workplace, at a job or at a workstation.

The preferred and less expensive option is to prevent MSD hazards in the first place. Efforts should be made to prevent these hazards before introducing a new work process, workstation, tool or piece of equipment into the workplace.

See **Section 3 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on how to plan to prevent MSDs.

Section 4: Understanding MSD Hazards

While not strictly part of the MSD prevention framework, it is important to understand what MSD hazards are before trying to recognize them in the workplace.

Many jobs have MSD hazards – things about the job or the way the job is done that increase the risk of a worker developing an MSD. While a number of things can increase MSD risk, the primary MSD hazards are force, fixed or awkward postures, and repetitions.

Force

Force refers to the amount of effort made by the muscles, and the amount of pressure on body parts as a result of different job demands. All work tasks require workers to use their muscles to exert some level of force. However, when a task requires them to exert a level of force that is too high for any particular muscle, it can damage the muscle or the related tendons, joints and other soft tissue.

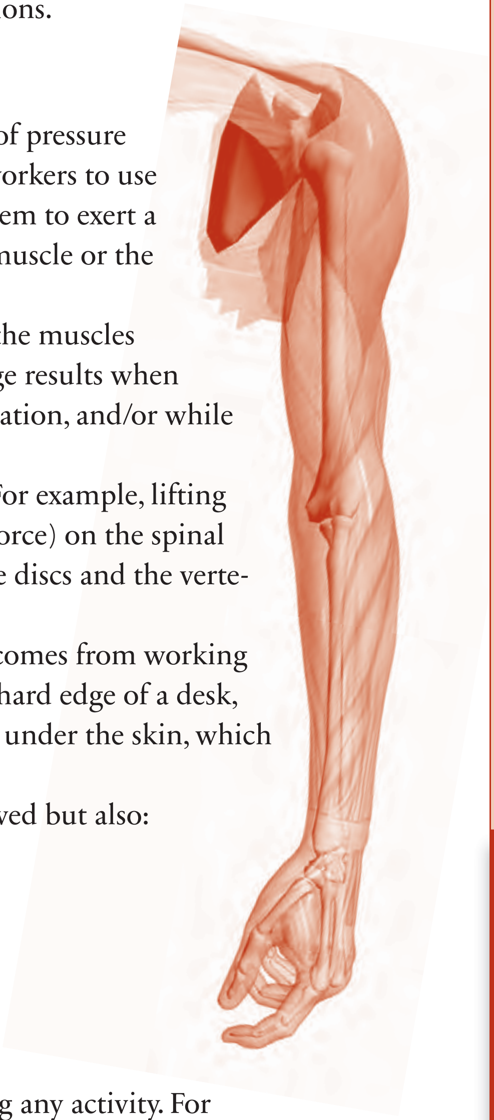
This damage can occur from a single movement or action that requires the muscles to generate a very high level of force. However, more commonly, the damage results when muscles generate moderate to high levels of force repeatedly, for a long duration, and/or while the body is in an awkward posture.

Some job tasks result in high force loads on different parts of the body. For example, lifting a heavy load that is far from the body increases the pressure (compressive force) on the spinal discs and vertebrae in the lower back. This can potentially damage both the discs and the vertebrae.

Another source of force on the body that can potentially cause damage comes from working with hand tools that have hard or sharp edges, resting the forearms on the hard edge of a desk, etc. This force can compress the tendons, muscles, blood vessels and nerves under the skin, which can damage these tissues.

With force, it is important to consider not only how much force is involved but also:

- how long workers need to keep exerting the force
- how many times the force is exerted in a given period of time, and
- the posture used when exerting the force.



Fixed or Awkward Postures

Posture is another name for the position of various parts of the body during any activity. For most joints, a good or "neutral" posture means that the joints are being used near the middle of the full range of motion.

The farther a joint moves towards either end of its range of motion, or the farther away from the neutral posture, the more awkward or poor the posture becomes and the more strain is put on the muscles, tendons and ligaments around the joint. For example, when arms are fully stretched out, the elbow and shoulder joints are at the end of their range of motion. If the worker pulls or lifts repeatedly in this position, there is a higher risk of injury.

With fixed or awkward postures, it is important to consider:

- how long workers need to hold a specific posture (fixed posture)
- how many times an awkward posture is used in a given period of time, and
- the amount of force being exerted when an awkward posture is used.

Repetition

The risk of developing an MSD increases when the same parts of the body are used repeatedly, with few breaks or chances for rest. Highly repetitive tasks can lead to fatigue, tissue damage, and, eventually, pain and discomfort. This can occur even if the level of force is low and the work postures are not very awkward.

With repetitive tasks, it is not only important to consider how repetitive the task is but also:

- how long workers perform the task
- the posture required, and
- the amount of force being used.

Other MSD Hazards and Workplace Factors

Other MSD hazards and workplace factors that should be considered include:

- contact stress
- local or hand/arm vibration
- whole-body vibration
- cold temperatures
- hot work environments
- work organization, and
- work methods.

See **Section 4 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on understanding MSD hazards.

Section 5: Recognize MSD Hazards and Related Concerns

Workplaces are encouraged to set up a process for recognizing jobs with MSD hazards even if no MSDs, worker concerns, or reports of discomfort have been recorded. While this may seem like a great deal of work, identifying and controlling MSD hazards before workers actually report an MSD, e.g. being proactive, can actually save you money, since you avoid all of the cost associated with an MSD related claim.

Workplaces are also encouraged to take advantage of information that they may already collect and review to help recognize jobs with existing MSDs and related concerns (i.e. accident/injury statistics, discomfort surveys, etc). Although this is a more reactive approach, for workplaces just starting, identifying problem jobs or tasks through MSD injuries and concerns may be an excellent starting point. Once MSD injuries and concerns are identified such workplaces may then wish to look at the proactive approaches to help identify the types of MSD hazards present.

Activities that can be used to recognize jobs with MSD Hazards and jobs with MSDs or related concerns are briefly described below.

See **Section 5 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on recognizing MSD hazards and related concerns.

POINT TO REMEMBER

If you already have a process for improving production, quality and/or service levels (e.g., Lean, 5S or Kaizen), make sure that you consider MSD hazards when you look for opportunities to improve and make any changes to any job or workstation.

Recognize Jobs with MSD Hazards

Everyone in the workplace should be trained on how to recognize MSD hazards. This will allow everyone to look for better ways to do their job or identify changes to reduce the risk of MSDs. Possible ways to identify jobs with MSD hazards include:

- using MSD hazard identification tool(s) to document whether MSD hazards are present in each job in the workplace
- encouraging workers to report MSD concerns, signs and symptoms
- asking workers to identify tasks with possible MSD hazards, and
- looking for MSD hazards during workplace inspections.

See the **MSD Prevention Toolbox** for examples of various tools that can be used to help recognize where MSD hazards exist.

POINT TO REMEMBER

Don't wait for reports of MSDs before starting to identify and control MSD hazards.

Recognize Jobs with Known MSDs and Related Concerns

Recognizing jobs with known MSDs and related concerns is a more reactive step involving a review of existing data sources to help identify jobs, tasks and workstations that have a history of MSDs and/or other related concerns (e.g., discomfort, absenteeism)

Possible actions to identify such jobs include:

- reviewing property damage, injury, incident and first aid records to identify departments, work areas, jobs and tasks where workers are reporting MSD-related pain and discomfort
- reviewing accident and incident investigation reports for information that could indicate the presence of MSD hazards
- gathering information and feedback from workers to help identify jobs with high levels of pain, discomfort and or physical demands
- reviewing human resources-related data (e.g., absenteeism, overtime, worker satisfaction) since this data could indicate the presence of MSD hazards, and
- considering production and service-related data because MSD hazards may contribute to sub-standard levels of quality, efficiency, service delivery and production.

See the **MSD Prevention Toolbox** for examples of tools that may help you to collect information and feedback from workers.

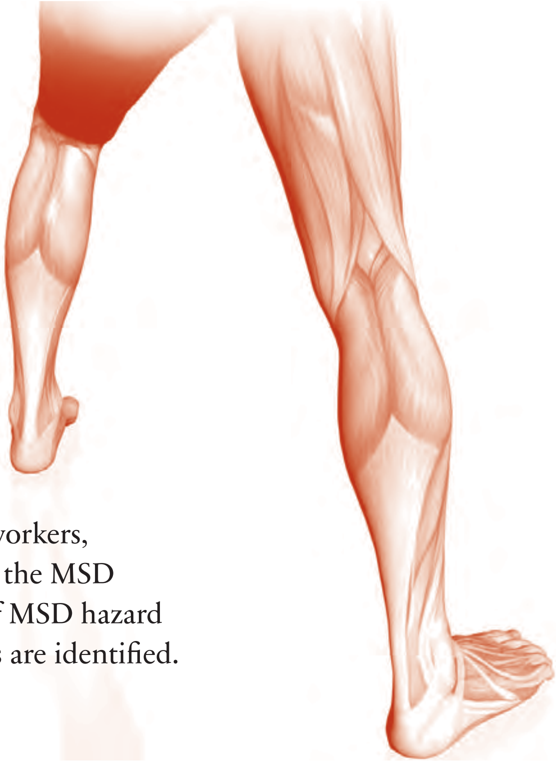
Checking whether MSD Hazards Have Been Recognized

Workplace parties should ask:

- do any jobs or tasks have existing MSDs or other related issues?
- have MSD hazards been recognized for any job or task?

If the answer to either or both of these questions is yes, take action to assess the MSD risk for the workers performing these jobs or tasks. If there is an increased risk of developing an MSD, take steps to implement MSD hazard controls.

Section 6: Conduct an MSD Risk Assessment



This section outlines a 2-step risk assessment process:

- a simple assessment used when the root causes of the MSD hazard appear to be obvious, and
- a more in-depth assessment for more complex MSD hazards and issues.

See **Section 6 of the MSD Resource Manual for the MSD Prevention Guideline for Ontario** for more information on conducting an MSD risk assessment.

A Simple MSD Risk Assessment

A simple risk assessment relies on the opinions and experiences of workers, supervisors, maintenance personnel, etc., to assess the risk related to the MSD hazards of a job, task, workstation, etc. However, using some type of MSD hazard identification tool can help to ensure that less obvious MSD hazards are identified.

Use an MSD Hazard Identification Tool (HIT)

As even the most experienced workers can fail to recognize some important MSD hazards, workplaces are encouraged to use some type of MSD HIT to make sure that all MSD hazards are identified and not just those that are the most obvious. This step is recommended if an MSD HIT was not used in the MSD hazard recognition step.

See the **MSD Prevention Toolbox** for an example of a HIT.

Review Hazards with Appropriate Workers

Meet with appropriate workers, including a JHSC member or H&S rep, to review:

- summarized data relating to reports of pain and discomfort
- worker concerns
- type and number of MSD reports of the job or task
- concerns related to absenteeism and/or production levels, and
- the findings from the MSD hazard identification tool(s).

Discuss Job Demands with Appropriate Workers

Have the workers discuss their job tasks and demands. Where possible, it may help to use:

- a written job procedure as a guide or a description of the physical demands of the job, and
- photographs and video recordings of the workstation, job tasks, etc.

Encourage the workers to focus on the parts of the job that they consider difficult or demanding. If workers are expressing concerns about pain and discomfort related to the job, ask them which actions or activities they believe are contributing to their pain and discomfort. Share the results of these discussions with the JHSC or H&S rep.

Is Further Action Required?

This is a decision point. Before moving on, a decision should be made about whether further action is required. No further action may be required when this job or task has identified MSD hazards but:

- there is no history of workers reporting MSDs or expressing concerns about pain and discomfort, and
- workers and the JHSC or H&S rep don't feel that the current job demands are a concern.

However, the workplace should continue to monitor such a job or task. A more in-depth risk assessment may be called for if workers begin to express concerns about job demands, report pain or discomfort, and/or report MSDs.

Reach Agreement on MSD Hazards

This is a decision point. Is there agreement on what MSD hazards are present on the job or task? If yes, move on to identifying root causes of the MSD hazards. If not, a more in-depth risk assessment will probably be required.

Identify the Root Causes of the MSD Hazards

For each of the agreed-upon MSD hazards, have the workers brainstorm or discuss the root causes of the hazard. Look at all of the factors that could cause the hazard. These factors are process, equipment, materials, environment and human (PEMEH).

See the **MSD Prevention Toolbox** for a brainstorming tool that can be used to help identify root causes of MSD hazards.

Reach Agreement on the Root Causes of the MSD Hazards

This is another decision point. If there is agreement about the root causes, it may not be necessary to do a more in-depth risk assessment. With no agreement, an in-depth assessment to identify the root causes will likely be required.

An In-depth MSD Risk Assessment

You should move on to a more in-depth risk assessment if:

- the MSD hazards are not clearly understood, or
- there is no agreement on the root cause(s) of these hazards.

This level of MSD risk assessment requires more experience, training and knowledge to complete. If a workplace does not have anyone with this knowledge and experience, it may be necessary to bring in a qualified individual.

See the **Resource Manual for the MSD Prevention Guideline for Ontario** for more information and guidance on in-depth MSD risk assessments.

Is the Risk of MSD Increased?

If an in-depth risk assessment indicates that the MSD risk for workers is increased, take steps to select and implement controls for MSD hazards.

If there is no indication that the job or task has an increased risk of MSD, and there is no history of MSDs or reports of pain or discomfort for the job or task, no further action may be required. However, the workplace should continue to monitor the job or task.

If the in-depth risk assessment indicates that the risk of MSD for a job is acceptable but the job or task has a history of MSDs and/or reports of pain or discomfort, the workplace should consider:

- whether the risk assessment methods used were appropriate, considering the MSD hazards identified and/or MSDs reported
- whether accommodations to address individual needs are necessary or possible, and
- whether other factors that were not addressed during the risk assessment may be contributing to the development of MSDs.

Section 7: Choose and Implement MSD Hazard Controls

The process for choosing and implementing controls for MSD hazards is described below. See **Section 7 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on choosing and implementing MSD hazard controls.

POINT TO REMEMBER

Identifying the root cause(s) of an MSD hazard is key to finding effective controls.

Understand Control Approaches for MSD Hazards

Controls should be designed to eliminate a worker's exposure to the identified MSD hazards where possible. Where this is not possible, exposures to MSD hazards should be minimized to acceptable levels or to the greatest extent possible. For example:

- engineering controls reduce or eliminate the worker's exposure to MSD hazards by modifying the work or workplace
- administrative controls reduce a worker's exposure to MSD hazards by developing specific policies and procedures; they may also include:
  - efforts to develop and train workers to use work methods that reduce the risk of MSDs, and
  - changes to how the work is organized, etc.
- personal protective equipment (PPE) cannot effectively control most MSD hazards; some exceptions include:
  - well-designed "anti-vibration" gloves
  - kneepads for kneeling work, and
  - shock-absorbing insoles.

In general, engineering controls are better than administrative controls because:

- when they are implemented correctly, they address the MSD hazards at their source
- they rely less on workers to follow safe work practices and not to make errors, and
- they are often the most cost-effective solutions in the long term because they tend to fix the problems completely and do not require ongoing administrative efforts and costs.

See the **MSD Prevention Toolbox** for some practical examples of the different types of MSD hazard controls.

Involve Appropriate Workers

Make sure that workers who do the job or task are part of the control selection team. Others who should be involved include appropriate JHSC members, maintenance, supervisory and engineering staff.

Review Identified Hazards and Discuss Priority Issues

Review the identified MSD hazards and risk assessment results. Discuss the situation with the workers to determine the hazards that are the highest priority for control. In many cases, the hazards with the greatest risk will be the highest priority. However, the workers' experience and knowledge of the job may suggest that a hazard with less risk is a higher priority. This can happen when the hazard leads to increased frustration, work having to be re-done, jam-ups, etc.

Brainstorm Control Options and Ideas

Generate options and ideas to control exposure to the prioritized MSD hazards. A variety of techniques can be used to come up with a list of potential controls. Begin by brainstorming as many control options and ideas as the team can think of.

See the **MSD Prevention Toolbox** for a brainstorming tool that may help identify options and ideas for MSD hazard controls.

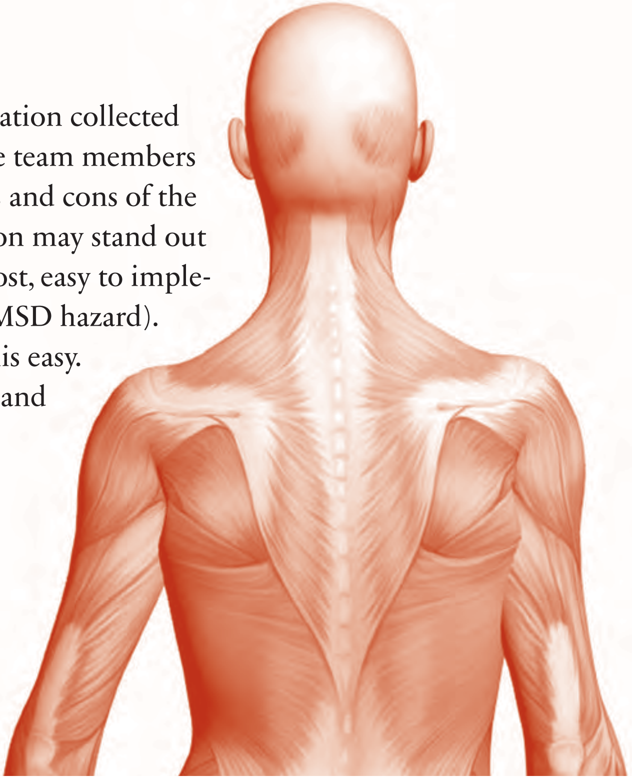
Review and Investigate Control Options and Ideas

After listing MSD hazard control options and ideas, take the time to review and investigate them. One option may stand out to everyone involved as the best. If this occurs and everyone agrees, further review may not be needed. However, a thorough review may help to avoid missing a better but less obvious solution.

Choose Your Preferred Control Option(s)

POINT TO REMEMBER

Simple, low-cost changes (e.g., changes in working height) can make a big difference. In addition, they are usually practical and easy to implement.



Compile all of the information collected in a format that allows the team members to easily compare the pros and cons of the various options. One option may stand out as the best (i.e., it is low-cost, easy to implement and eliminates the MSD hazard). However, it is often not this easy. If no one control stands out, use a process for ranking and weighting the various review factors.

Implement Your Preferred Control Option(s)

How you implement your preferred control is very important. Ensure that all of the workers who will be affected by the control know about the proposed change. These workers also need to be trained to use the control effectively and efficiently.

Immediately after a control is implemented, check to make sure that it is working as expected and there are no surprises. Check that:

- the expectations of the workers involved in the project have been met
- the correct solution was installed and it was installed correctly
- all appropriate workers have been trained on how to use the control
- all workers can demonstrate how and when to use the control
- the concerns of maintenance personnel are addressed
- up- and downstream processes have been reviewed to ensure that no new hazards have been introduced, and
- initial feedback of workers is documented.

Section 8: Follow up on and Evaluate the Success of Implemented Controls

The recommended steps for evaluating all MSD prevention projects are described below. See **Section 8 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on following up on and evaluating success of implemented controls.

Evaluate the Process

As soon as possible after implementing a control, ask those who worked on the solution(s) to provide:

- feedback on how well the process worked, and
- suggestions on how to improve the process.

Evaluate the Control

To evaluate the success of MSD hazard controls more formally, allow some time to pass. This will ensure that:

- any initial "bugs" with the control are corrected
- workers and supervisors have been trained on how to use the control, and
- all workers have had a chance to use and get used to the control.

POINT TO REMEMBER

Sometimes an evaluation suggests that the MSD hazard control is not fully successful. If this is the case, you may not have properly identified all of the MSD hazards. Return to Section 5 (Recognize MSD hazards and related concerns).

Shortly after implementing the control, you should:

- observe workers to see whether they are using the controls and using them correctly
- use the MSD hazard identification tool(s) to verify that the hazards continue to be controlled and that no new hazards have been introduced, and
- ask all appropriate workers for their feedback on the control.

Document the information collected during this evaluation and report back to all appropriate workers and the JHSC or H&S rep. If concerns are noted, ask the project team to discuss them and suggest ways to alleviate them.

A more formal and in-depth evaluation should be done once the finalized control has been in use for a period of time (e.g., 3–6 months). By this time, the workers should have a very good idea of how the control works and the positives or negatives associated with its use.

During this evaluation, consider:

- using a formal survey to gather workers' opinions on the control
- asking workers for suggestions to improve the control
- surveying other appropriate workers about the control (e.g., these would include maintenance, production, engineering, quality, supervisors), and
- collecting production and quality data.

If concerns are identified, bring the project team together to discuss and suggest new ways to correct the identified issues.

See **MSD Prevention Toolbox** for an example of a survey that can be used to collect workers' opinions of the controls.

Do an Ongoing Review and Evaluation

Continue to review all the usual reports to look for problems or improvements on the job or in the work area where the control was implemented. Remember that MSDs may continue to be reported even after a control has been successfully implemented because new cases can result from exposures to hazards before the control was installed.

Section 9: Communicate Results and Acknowledge Success

Good communication is important in preventing MSDs. Even well designed and implemented controls can be less successful than they should be if the communication is poor. The important communication steps to consider for all MSD prevention projects are outlined below.

- keep all staff up to date on progress
- acknowledge all workers involved in the process
- communicate the results of the evaluation, and
- celebrate successes

See **Section 9 of the Resource Manual for the MSD Prevention Guideline for Ontario** for more information on communicating results and acknowledging success.

Resources

Ontario Health and Safety Associations (http://www.preventiondynamics.com)

Construction Safety Association of Ontario
Phone: (416) 674-2726
1-800-781-2726
http://www.csao.org

Education Safety Association of Ontario
Phone: (416) 250-8005
1-877-732-3726
http://www.esao.on.ca

Electrical & Utilities Safety Association
Phone: (905) 625-0100
1-800-263-5024
http://www.eusa.on.ca

Farm Safety Association
Phone: (519) 823-5600
1-800-361-8855
http://www.farmsafety.ca

Industrial Accident Prevention Association
Phone: (905) 614-4272
1-800-406-4272
http://www.iapa.ca

Mines and Aggregates Safety and Health Association
Phone: (705) 474-7233
http://www.masha.on.ca

Municipal Health and Safety Association
Phone: (905) 890-2040
1-866-275-0045
http://www.mhsao.com

Occupational Health Clinics for Ontario Workers Toronto Clinic
Phone: (416) 510-8713
1-888-596-3800
http://www.ohcow.on.ca

Ontario Forestry Safe Workplace Association
Phone: (705) 474-7233
http://www.ofswa.on.ca

Ontario Safety Association for Community and Healthcare
Phone: (416) 250-7444
1-877-250-7444
http://www.osach.ca

Ontario Service Safety Alliance
Phone: (905) 602-0674
1-800-525-2468
http://www.ossa.com

Pulp & Paper Health and Safety Association
Phone: (705) 474-7233
http://www.pphsa.on.ca

Transportation Health and Safety Association of Ontario
Phone: (416) 242-4771
1-800-263-5016
http://www.thsao.on.ca

Workers Health and Safety Centre (WHSC)
Phone: (416) 441-1939
1-888-869-7950
http://www.whsc.on.ca

Ontario Resources

Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD)
http://www.cre-msd.uwaterloo.ca/

Institute for Work and Health
http://www.iwh.on.ca

Ministry of Labour
http://www.labour.gov.on.ca/

Prevention Practices Database
http://www.preventionpractices.com

Workplace Safety and Insurance Board
http://www.wsib.on.ca

Canada Resources

Canadian Centre for Occupational Health and Safety
http://www.ccohs.ca/oshanswers

WorkSafe BC
http://www.worksafebc.com

International Resources

European Agency for Safety and Health
http://europe.osha.eu.int

Health and Safety Executive (HSE)
http://www.hse.gov.uk

National Institute for Occupational Safety and Health
http://www.cdc.gov/niosh/

US Department of Labor, Occupational Safety and Health Administration (OSHA)
http://www.osha.gov

Professional Ergonomics Associations

Association of Canadian Ergonomists
http://www.ace-ergocanada.ca

Ergonomics Society
http://www.ergonomics.org.uk

Human Factors and Ergonomics Society
http://www.hfes.org

International Ergonomics Association (IEA)
http://www.iea.cc

Other Professional Associations

Canadian Association of Occupational Therapists
http://www.caot.ca

Canadian Chiropractic Association
http://www.ccachiro.org

Canadian Kinesiology Alliance
http://www.cka.ca/

Canadian Occupational Health Nurses Association
http://www.cohna-aciist.ca

Canadian Physiotherapy Association
http://www.physiotherapy.ca

College of Chiropractors of Ontario
http://www.cco.on.ca

Occupational Hygiene Association of Ontario
http://www.ohao.org

Ontario Kinesiology Association
http://www.oka.on.ca/

Ontario Occupational Health Nurses Association
http://www.oohna.on.ca

Ontario Physiotherapy Association
http://www.opa.on.ca

Ontario Society for Occupational Therapists
http://www.osot.on.ca

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Hagbert M, Silverstein, B., Wells R, et al. 1995. Work Related Musculoskeletal Disorders (WMSDs): A Reference Book for Prevention. Bristol PA: Taylor & Francis

Health and Safety Executive. 2002. Upper Limb Disorders in the Workplace. United Kingdom (www.hsebooks.com)

National Research Council, 1999. Work-related Musculoskeletal Disorders. National Academy of Sciences. Washington, DC: National Academy Press

NIOSH. 1997. A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorders of the Neck, Upper Extremity and Low Back (http://www.cdc.gov/niosh/docs/97-141/)

NIOSH. 1997. Elements of an Ergonomics Program (www.cdc.gov)

Occupational Health and Safety Council of Ontario, 2007. Occupational Health and Safety Council of Ontario's MSD Prevention Series. Part 2: Resource Manual for the MSD Prevention Guideline for Ontario. (WSIB Form Number: 5158A).

Occupational Health and Safety Council of Ontario, 2007. Occupational Health and Safety Council of Ontario's MSD Prevention Series. Part 3: MSD Prevention Toolbox. (WSIB Form Number: 5159A).

Review Process

The MSD Prevention Guideline for Ontario (the Guideline) will be regularly reviewed and modified in order to provide Ontario workplaces with information on new research findings, assessment methods, control approaches, etc. The review process is described below:

1) The Guideline will be formally reviewed by a technical committee appointed by OHSCO every five (5) years from the date of publication. The committee will consider all received requests for modifications and the current state of research related to MSD prevention. The technical committee will make a recommendation to OHSCO to re-affirm or update the Guideline.
2) If the recommendation is to update the Guideline, the technical committee will meet to consider the specific changes to be made.
3) The recommended changes will be presented to OSHCO for approval. Once approved by OHSCO the recommended changes will be distributed to external stakeholders for comment.
4) After the comment period, the technical committee will meet to review all comments received and submit a final version of the updated Guideline to OSHCO.
5) An early review of the Guideline may be considered if information regarding new and well-supported research findings is received, and if the new research findings suggest that information in the Guideline is not providing Ontario workplaces with a reasonable approach to MSD prevention.
6) The Chair of OHSCO will ensure that all comments or requests for modifications are reviewed on an annual basis.
7) All requests for changes or modifications to the Guideline should be sent to:

By Canada Post:
Chair of OHSCO
c/o Branch Secretary
Best Practices Branch
Prevention Division
11th Floor, WSIB
200 Front Street W.
Toronto, ON, M5V 3J1

By Email: prevention@wsib.on.ca

Please put "MSD Prevention Guideline c/o Best Practices Branch" in the e-mail's subject field.

PREVENTION GUIDELINE

Occupational Health and Safety Council of Ontario (OHSCO)
MUSCULOSKELETAL DISORDERS PREVENTION SERIES

PART 2:

Resource Manual for the MSD Prevention Guideline for Ontario

MSD
MUSCULOSKELETAL DISORDERS

RESOURCE MANUAL

Disclaimer

The material contained in this manual is for information and reference purposes only and not intended as legal or professional advice. The adoption of the practices described in this manual may not meet the needs, requirements or obligations of individual workplaces.
Use, reproduction and duplication of this manual is recommended and encouraged.

5158A (02/07)

PART 2:

Resource Manual for the MSD Prevention Guideline for Ontario

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MSD
MUSCULOSKELETAL DISORDERS

Acknowledgements

This document, the Resource Manual for the MSD Prevention Guideline for Ontario, is part 2 of the Occupational Health and Safety Council of Ontario's Musculoskeletal Disorders (MSD) Prevention Series. It was developed in partnership with the members of the Occupational Health and Safety Council of Ontario (OHSCO), with the support of the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD), and in consultation with representatives from Ontario's labour organizations, employer associations and individual employers and workers.

Supporting organizations include:

- Construction Safety Association of Ontario
- Education Safety Association of Ontario
- Electrical & Utilities Safety Association
- Farm Safety Association
- Industrial Accident Prevention Association
- Institute for Work & Health
- Mines and Aggregates Safety and Health Association
- Municipal Health and Safety Association
- Occupational Health Clinics for Ontario Workers
- Ontario Forestry Safe Workplace Association
- Ontario Ministry of Labour
- Ontario Safety Association for Community and Healthcare
- Ontario Service Safety Alliance
- Pulp and Paper Health and Safety Association
- Transportation Health and Safety Association of Ontario
- Workers Health and Safety Centre
- Workplace Safety and Insurance Board (Ontario)

The support and participation of everyone who contributed to the development of this manual and its related documents is greatly appreciated. Graphics in this manual were created by the Canadian Centre for Occupational Health and Safety (www.ccohs.ca).

Scope of the Resource Manual

The Resource Manual for the MSD Prevention Guideline for Ontario is being made available through the partners of the Ontario health and safety system. Its primary purpose is to provide Ontario's employers and workers with more detailed information and advice on how to implement the generic framework for preventing musculoskeletal disorders that is described in the MSD Prevention Guideline for Ontario, part 1 of OHSCO's MSD Prevention Series.

A wide variety of health and safety experts and associations, employers, employer associations and unions were consulted in developing this manual. Experience in other jurisdictions was considered, as were the opinions and advice of international experts.

This manual refers to a number of tools, worksheets and surveys that can be used to help workplaces in their MSD prevention efforts. Examples of tools that may be useful can be found in the MSD Prevention Toolbox, part 3 of OHSCO's MSD Prevention Series. To obtain Part 1 or Part 3 of OHSCO's MSD Prevention Series contact one of Ontario's health and safety organizations (see Appendix for contact information).

The MSD prevention framework presented in the MSD Prevention Guideline for Ontario and the implementation steps described in this manual are consistent with best practices and effective approaches based on current information and experience. The framework and the specific implementation steps represent one way of addressing MSDs in a workplace. Other MSD prevention processes and programs that include worker training and involvement and a process to recognize, assess and control MSD hazards (including those that may have been established through a collective agreement) may be equally effective. Some of the implementation steps described in this manual may not be applicable to all workplaces.

The MSD prevention framework and the implementation steps described in this manual are consistent with the requirements for an effective health and safety program. Therefore, workplace MSD prevention efforts can and should be fully integrated into an existing health and safety program where possible and practical.

For workplaces that already have an MSD prevention program in place, this manual may be helpful when considering whether existing program elements can be modified or improved.

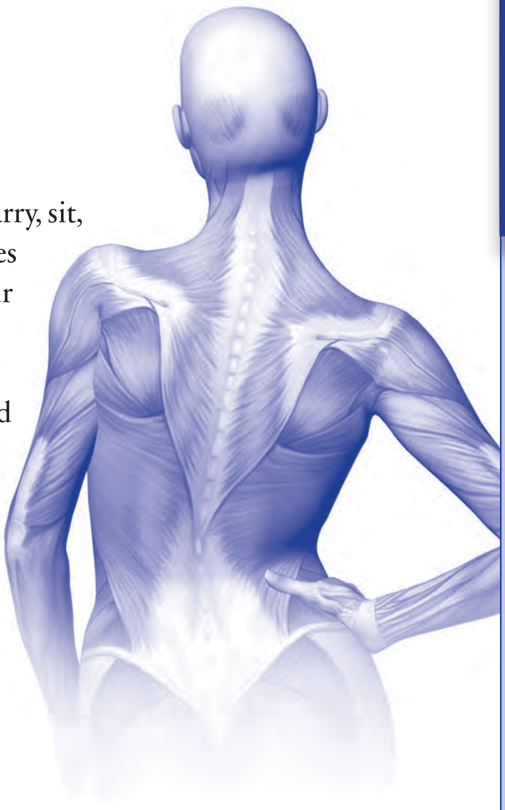
For workplaces that do not have an existing MSD prevention program, this manual will help when implementing an effective MSD prevention framework and/or integrating MSD prevention into the existing health and safety program.

The information in this manual is generic and not targeted at any specific type of workplace, industry sector or work task. Although the particular hazards, jobs and tasks present in different workplaces will vary, the hazards that can lead to MSD are the same for all workplaces.

The MSD Prevention Guideline for Ontario and this manual:

- do not describe all elements of an effective health and safety management system that should be implemented in all workplaces
- do not cover all of the legislated workplace health and safety requirements
- do not specifically apply to Early and Safe Return-to-Work programs
- do not address issues related to personal wellness, fitness, diet or lifestyle, and
- do not describe the full scope of workplace ergonomics.

Section 1: Introduction



Every day we use our muscles, tendons, ligaments and joints to lift, carry, sit, stand, walk, move and work in a variety of ways. However, sometimes these tasks or the way we do them can put too much demand on our bodies, causing pain and discomfort. In addition, it may lead to a more serious injury called a musculoskeletal disorder (MSD).

MSDs are the number one type of work-related lost-time injury reported to the Workplace Safety and Insurance Board (WSIB) in Ontario. They:

- cause pain and suffering for thousands of workers every year, and
- cost Ontario's workplaces hundreds of millions of dollars due to worker absence and lost productivity.

MSDs are strongly linked to known risk factors or hazards in the workplace.

Now is the time to take action on MSD hazards!

The Purpose of the Guideline and the Resource Manual

The MSD Prevention Guideline for Ontario describes a recommended framework for MSD prevention. This resource manual provides more detailed information and advice on how to implement that framework to prevent MSDs. Where possible, the framework can and should be integrated into your existing health and safety program and other business activities.

This manual also provides general information about MSDs, medical diagnoses that are classified as MSDs and why MSDs are a prevention priority for Ontario's health and safety system. Key workplace hazards that have been related to the development of MSDs are described with examples. While any work can expose people to MSD hazards, the hazards only become a problem when:

- the hazard level is too high
- the frequency of exposure to the hazard is too high, and/or
- the length of exposure to the hazard is too long.

Guidance is provided for doing an MSD risk assessment and for selecting and implementing controls to minimize the risk of MSD.

Target Audience for the Guideline

The MSD prevention guideline and this manual are intended for:

- workplace parties involved in health and safety, including:
  - managers
  - supervisors
  - Joint Health and Safety Committee (JHSC) members
  - health and safety representatives (H&S reps)
  - representatives of workplace union(s)
  - health and safety professionals, and
  - workers.
- unions, employer associations, health and safety professionals, health and safety associations, ergonomists, and others who may find the information useful when helping workplaces with MSD prevention.

What are Musculoskeletal Disorders?

MSD is an umbrella term for a number of injuries and disorders of the muscles, tendons, nerves, etc. Other terms that mean the same as MSD include:

- repetitive strain injury (RSI)
- cumulative trauma disorder (CTD)
- work-related musculoskeletal disorder (WMSD)
- musculoskeletal injury (MSI, MSK)
- occupational overuse syndrome (OOS), and
- sprain and strain.

DEFINITION OF MSD

MSDs are injuries and disorders of the musculoskeletal system. They may be caused or aggravated by various hazards or risk factors in the workplace.

The musculoskeletal system includes:

- muscles, tendons and tendon sheathes
- nerves
- bursa
- blood vessels
- joints/spinal discs, and
- ligaments.

MSDs do not include musculoskeletal injuries or disorders that are the direct result of a fall, struck by or against, caught in or on, vehicle collision, violence, etc.

Many body parts can be affected by MSDs. The back is the most common, but the shoulders, neck, elbows, hands and wrists are also frequently involved. MSD-related pain and discomfort have also been reported in the hips, knees, legs and feet.

A number of medical diagnoses are covered by the term MSD, including:

- back pain (many specific diagnoses)
- carpal tunnel syndrome (wrist/hand)
- epicondylitis (tennis or golfer's elbow)
- muscle strain
- rotator cuff disorder or syndrome (shoulder)
- tension neck syndrome
- tendonitis (anywhere in the body), and
- tenosynovitis (anywhere in the body).

While different body parts can be affected by these disorders, the symptoms of MSDs are similar no matter where they occur. The symptoms generally include:

- pain with or without movement
- swelling and tenderness
- reduced range of motion and/or stiffness, and
- tingling and/or numbness in nerve-related injuries or disorders.

Why are MSDs a Problem?

MSDs are a problem because:

- they can affect every aspect of a worker's life, and
- they are costly for workplaces.

MSDs are the number one type of lost-time claim reported to the WSIB, resulting in major direct and indirect costs for Ontario employers. From 1996 to 2004, the WSIB approved more than 382,000 MSD-related lost-time claims. These claims represented almost 27 million lost-time days from work and direct costs of more than $3.3 billion.

Ontario's employers are estimated to have paid more than $12 billion in direct and indirect costs for MSD-related lost-time claims reported between 1996 and 2004. Indirect costs include:

- overtime or replacement worker wages
- equipment modifications
- administration
- retraining, and
- lost productivity and reduced quality.

MSD FACTS

In Ontario, MSDs account for:

- 42% of all lost-time claims
- 42% of all lost-time claim costs, and
- 50% of all lost-time days.

(Averages for 1996–2004)

These statistics account for only lost-time claims. They underestimate the true size of the MSD problem in Ontario workplaces. Many

people continue to work in pain and discomfort. They may not file a WSIB claim but take personal sick time to go for medical help or until the pain subsides. Workers in pain are also likely to be less productive and their work quality may decrease.

Why do MSDs Occur in the Workplace?

The human body is an amazing machine. It can do a huge variety of difficult, complex and unique physical and mental tasks. In fact, human beings have to do many tasks because machines and technology cannot match our ability to think, reason, make decisions, feel, be precise and make judgements.

However, the human body is also limited in what it can do. MSDs occur where the *demands of the job exceed the capabilities* of the person doing the job.

Each person in a workplace is unique. This diversity in human beings shows up in many ways, including our:

- size and shape
- strength and endurance
- flexibility
- hearing
- eyesight
- knowledge and experience
- education, and
- skill.

These differences exist regardless of gender, age or ethnic group. Therefore, just because one person can perform a job task without suffering an MSD, it does not mean that everyone will be able to. Jobs should be designed for a variety of workers. They should take into account what we know about the variation in workers' size, strength, endurance, etc. If this is not done, some workers will have a greater risk of developing MSDs than others.

There is a strong link between exposure to certain physical factors or hazards in a workplace and the development of an MSD. There is also evidence that certain work organization factors are related to an increased risk of MSDs. These factors include:

- perceptions of high job demands or workloads
- monotonous job tasks
- perceptions of low job control
- a lack of clarity about job worth, importance or expectations
- low job satisfaction, and
- perceptions of low social support.

While these issues should be considered, they are beyond the scope of this manual. Therefore, methods for evaluating and controlling them are not addressed here. However, some of the elements presented in the framework may help to reduce the negative effects of certain work organization factors.

Does Ontario's *Occupational Health and Safety Act* Address MSDs?

POINT TO REMEMBER

Controlling MSD hazards in a workplace is not only the right thing to do; **it is the law.**

The Occupational Health and Safety Act requires employers to:

- ensure that workers are made aware of the hazards associated with their jobs and workplaces
- implement controls to reduce the risk of injury due to these hazards, and
- take every reasonable precaution in the circumstances to protect a worker.

MSD hazards must be treated the same as any other workplace hazard. This means that they need to be:

- recognized and identified
- assessed, and
- controlled.

All parties in a workplace have a role to play in preventing MSDs in the workplace. See **Section 3: Establish a Foundation for Success** for more information.

Is MSD Prevention Good for Ontario's Businesses and Employers?

An effective approach to MSD prevention can help employers compete in today's global marketplace. Preventing MSDs helps employers to:

- reduce costs
- increase productivity
- improve the quality of their products and services, and
- stimulate innovation.

The argument for preventing MSDs is persuasive even if you consider only the direct costs, let alone the costs when people are working in pain and discomfort or are absent. Some suggest that the costs associated with working in pain are much higher than those related to absenteeism due to MSDs. For MSD-related lost-time WSIB claims, time and money must be spent investigating, assessing and controlling the MSD hazards associated with a job task. Most likely, one or more jobs will have to be modified to accommodate injured workers.

In contrast, an effective MSD prevention program helps employers to retain their skilled and knowledgeable workers. This is particularly significant with an aging workforce. A well-implemented MSD prevention program is an opportunity to consider how the jobs are done. The resulting changes not only reduce the workers' exposure to MSD hazards but also help to improve productivity and quality by finding better, smarter and more efficient ways to do the job.

A good MSD prevention program allows tasks to be done with less stress and strain. This may improve customer service, both internally and externally, and allow greater innovation in work processes and procedures.

See the **MSD Prevention Toolbox** for information on the cost–benefit of implementing MSD prevention strategies.

ERGONOMICS IS GOOD BUSINESS

"Ergonomic programs can substantially reduce workers' compensation costs, with savings of up to 60%–80% over a 4- to 5-year period."

— US General Accounting Office 1997

"Older workers have lower non-fatal injury rates. However, when they get hurt, they need more time off. Job characteristics such as high stress, repetitiveness and high physical demand are statistically related to early retirement."

— In Kowalski-Trakofler et al., 2005

"The ceiling lift project [at St. Joseph's General Hospital, Comox, BC] resulted in a 40% reduction in total claims cost, [an] 82% reduction in lift/transfer costs, [and an] 83% reduction in lost [time] hours [related to lift/transfer injuries]"

— Occupational Health & Safety Agency for Healthcare in BC 2002

What Comes Next?

Now is the time to take action. This resource manual provides details on how to integrate MSD prevention into your occupational health and safety program through the involvement of all the workplace parties: employers, supervisors, health and safety staff, workers, JHSC members or the health and safety representative and unions.

Section 2: MSD Prevention – *Part of Your Occupational Health and Safety Program*

MSD prevention does not have to be difficult or complex. All you really need is the knowledge and will to recognize, assess and control MSD hazards in the same way you would any other hazard in the workplace.

Figure 2.0 shows the steps in a framework to prevent MSDs. These steps should be familiar to you, since they are the same ones used when dealing with any hazard or health and safety issue. This section briefly describes each step. Sections 3 to 9 provide more information as well as tools, worksheets and other similar resources for implementing these steps.

POINT TO REMEMBER

If you have an effective health and safety program, you already have a good foundation for preventing MSDs.

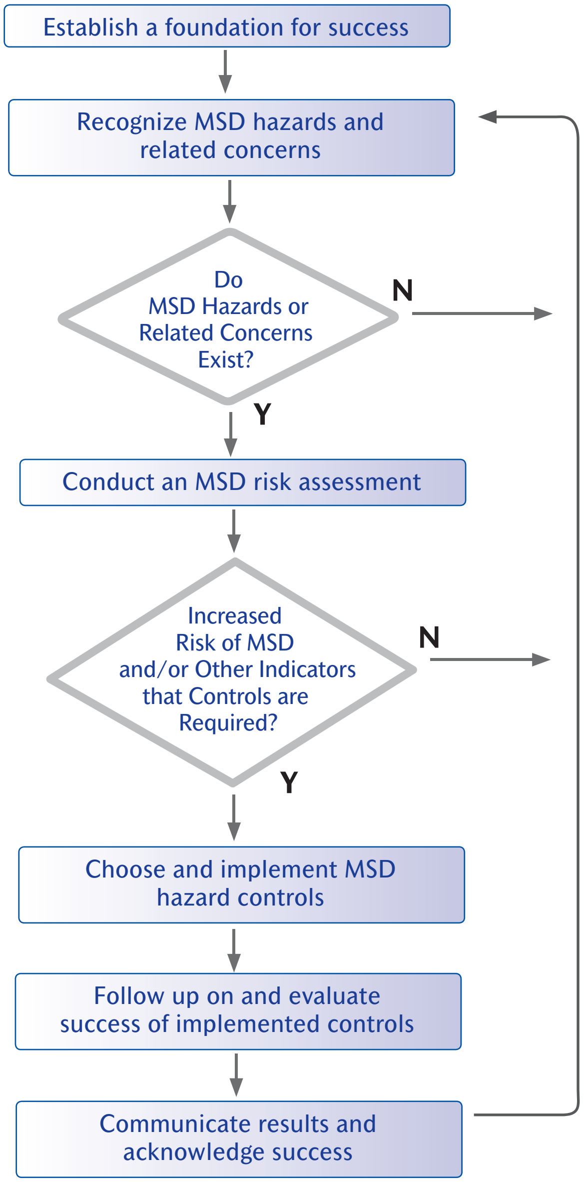


Figure 2.0: Steps in the MSD prevention framework

Steps in Implementing the MSD Prevention Framework

Establish a foundation for success (Section 3)

The essential keys to prevent MSDs in the workplace are:

- management commitment and support
- a documented MSD prevention process that is communicated to all workplace parties
- worker participation in the prevention process, and
- training on MSD prevention for all workplace parties.

Understand MSD Hazards (Section 4)

While not strictly part of the MSD prevention framework, it is important to understand what MSD hazards are before trying to recognize them in the workplace. Known workplace MSD hazards include:

- force
- fixed or awkward posture
- repetition
- contact stress
- vibration
- temperature
- work organization, and
- work methods.

Recognize MSD hazards and related concerns (Section 5)

Workplaces are encouraged to set up a process for recognizing jobs with MSD hazards even if no MSDs, worker concerns, or reports of discomfort have been recorded. This can be done by asking workers, during workplace inspections or with a formal hazard identification tool.

On the other hand, workplaces already have a great deal of information that can help them to recognize jobs that likely have MSD hazards. A regular review of accident/injury data, accident investigation reports, human resources related data, and production and/or service-related data can identify those jobs where MSDs already exist or where MSD hazards are causing other problems. Asking workers to fill out discomfort surveys is another excellent way to collect information that can help to identify jobs that need further attention.

Conduct an MSD risk assessment (Section 6)

Risk assessment methods allow you to make a simple or, if required, an in-depth assessment of the level of risk to the workers who perform jobs with recognized MSD hazards.

Choose and implement MSD hazard controls (Section 7)

The goal of the MSD prevention program is to implement controls for the MSD hazards when workers are at an increased risk of developing MSDs. A variety of approaches, suggestions and ideas can be used to reduce the risk for workers.

Follow up on and Evaluate the Success of Implemented Controls (Section 8)

Implementing controls for MSD hazards is not the end of the MSD prevention process. The processes of identifying hazards and introducing controls and the success of these controls should be evaluated.

Communicate results and acknowledge success (Section 9)

Communication tools are important for keeping everyone involved in the program up to date: the controls, results and successes of the MSD prevention efforts need to be publicized.

Go Back to Recognize MSD Hazards and Related Concerns (Section 5)

MSD prevention is an ongoing process. After implementing controls for MSD hazards, go back and look for other opportunities for improvement. Repeat the steps with other priority jobs or identify new jobs that require action.

Section 3: Establish a Foundation for Success

The key steps in establishing a foundation for successful MSD prevention are shown in Figure 3.0. Among the most important steps are management commitment and worker participation.

POINT TO REMEMBER

Preventing MSDs not only reduces worker pain and suffering, it also leads to improved overall business performance. Building a foundation will help to ensure that you get maximum return on your investment.

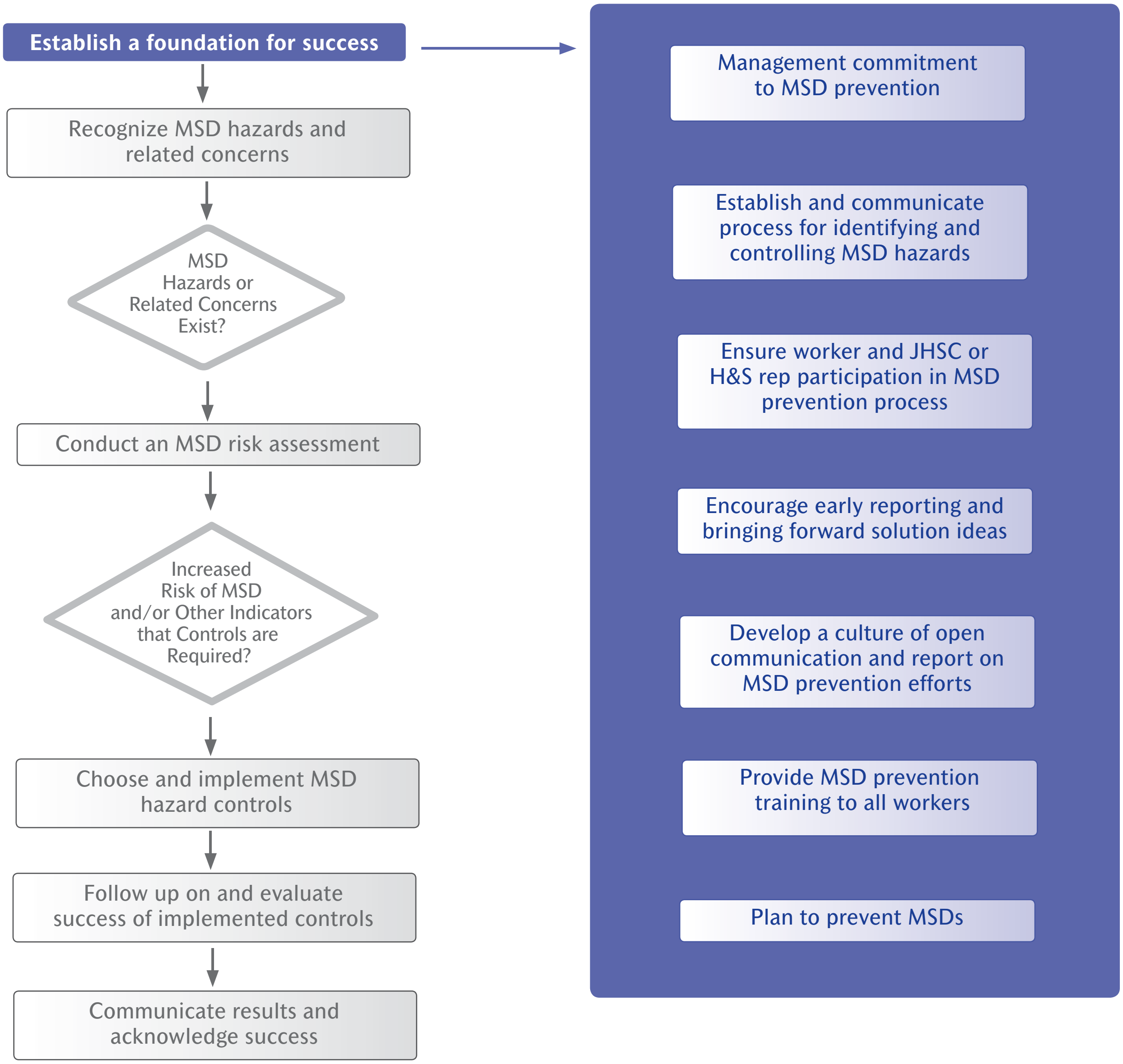


Figure 3.0: Establish a foundation for success

Look at the checklist below. Do you already have a solid foundation for MSD prevention? If not, see the information following the checklist for more details on establishing or improving your foundation for success.

DO YOU ALREADY HAVE A FOUNDATION FOR SUCCESS?

☑ Are owners, employers, managers and front-line supervisors aware that they must do everything reasonable in the circumstances to protect their workers from MSD hazards?

☑ Have all managers, front-line supervisors and workers been trained to recognize MSD hazards?

☑ Is there a well-communicated process for workers to report problems that could lead to MSDs?

☑ Are workers encouraged by the employer and their supervisors to report problems that could lead to MSDs?

☑ Are front-line supervisors looking out for conditions or work practices that could lead to MSDs?

☑ Have all workers been informed of MSD hazards related to their work and how to avoid them?

☑ Do monthly inspections by the employer and/or JHSC look for MSD hazards (e.g., awkward postures, excessive force, high rates of repetition)?

☑ Are reports of MSD-related pain or discomfort investigated to the same standard as other safety hazards?

☑ Are workers provided with and trained how to use equipment that helps to reduce the risk of MSDs?

☑ Are reports of MSD-related pain and discomfort and any implemented controls or solutions recorded and kept?

☑ Are injury or first aid statistics reviewed each month for trends that need to be investigated to prevent MSDs in your workplace?

Management Commitment to MSD Prevention

Commitment begins with the chief executive officer and the senior managers and is critical for any successful MSD prevention effort. It needs to be clearly communicated and visibly demonstrated. Effective management commitment to MSD prevention can be shown by:

- integrating MSD prevention into existing health and safety activities and business processes
- developing an MSD prevention policy, procedure or statement, in conjunction with the JHSC or H&S rep
- communicating this policy, procedure or statement to all workers
- defining the roles of employers, managers, supervisors, JHSC or H&S reps, and workers in preventing MSDs (See **MSD Prevention Roles**)

- integrating MSD prevention into everyone's day-to-day work
- working with the JHSC or H&S rep to ensure that work tasks and processes are designed to control MSD hazards
- encouraging open discussion and learning from mistakes and successes
- reviewing reports of MSD hazards and taking corrective action, and
- reporting on progress of MSD prevention efforts.

See the **MSD Prevention Toolbox** for:

- the "5-steps" to managing MSD prevention and
- a sample MSD prevention policy, procedure and program

MSD PREVENTION ROLES

Ontario's *Occupational Health and Safety Act* is based on the internal responsibility system. This means everyone has a role to play in maintaining a healthy and safe workplace. Employers, supervisors, workers and the JHSC or the H&S rep must work together to prevent injuries and illnesses. Some suggested MSD prevention roles are listed below.

Employers and managers should:

- incorporate MSD prevention into their health and safety policy and program
- review the health and safety program to include or strengthen MSD prevention activities
- make sure that workers and JHSC members or the H&S rep are trained how to recognize, assess and eliminate or control MSD hazards
- ensure that supervisors know what to do if they recognize MSD hazards or if a worker raises a concern
- ensure that MSD hazards related to poor design of tools, equipment, workstations or work practices are identified and any associated risks are controlled
- make sure that new equipment is designed and installed to reduce exposure to MSD hazards, and
- ensure that workers have the equipment and training they need to reduce their exposure to MSD hazards.

Supervisors should:

- ensure that everyone under their supervision is aware of MSD hazards on the job and is trained to do his or her job safely
- look for MSD hazards during workplace inspections, job task analyses and discussions with workers, and when reviewing injury reports
- reinforce proper working techniques and use of equipment and personal protective equipment (PPE)
- encourage and support workers taking scheduled breaks
- check that workers have adjusted their workstations to suit themselves and their work, and provide help as needed
- support workers when they have questions or concerns
- be aware of MSD warning signs and indicators, and
- take action on reported MSD hazards and concerns, and follow up with workers.

See page 14 for Worker and JHSC/H&S rep roles

MSD PREVENTION ROLES

Workers should:

- report MSD hazards and concerns to their supervisors
- take scheduled breaks and take advantage of opportunities to change postures or relax muscles
- move around and occasionally change positions
- go to their supervisors with questions and concerns or to ask for additional training
- offer suggestions to improve working conditions to their supervisor, health and safety rep or the JHSC
- be aware of symptoms of MSDs and report them early if they occur
- ensure that they understand the information and instructions provided
- use proper working techniques
- use the equipment and tools provided to reduce exposure to MSD hazards, and
- know how to make adjustments to the workstation to suit themselves and the work they do, and to ask for help as needed.

JHSC members and health & safety reps should:

- get training on recognizing, assessing and controlling MSD hazards
- ensure that MSD hazards are included on inspection checklists
- actively look for MSD hazards
- discuss MSD-related concerns at JHSC meetings and with the employer and workers
- review training records to ensure that everyone in the workplace has received training on how to do their jobs safely and how to identify the MSD hazards in the workplace, and
- make recommendations to the employer on how to eliminate, control or reduce exposure to MSD hazards.

Establish and Communicate a Process for Identifying and Controlling MSD Hazards

To identify and control MSD hazards efficiently, processes and activities that target these hazards need to be established.

Some activities to consider include:

- creating an MSD Prevention Plan that outlines the objectives for, methods to be used in and expectations of any MSD prevention activities implemented in the workplace
- making all workers aware of how MSD hazards will be identified and controlled
- communicating the role of all workplace parties in MSD prevention efforts
- looking for MSD hazards during regular workplace inspections
- identifying MSD hazards when doing job task analysis
- reviewing reports of MSD concerns during JHSC meetings
- establishing a process for MSD risk assessment

- looking for MSD hazards when:
  - planning for or implementing new production processes
  - purchasing and installing new equipment, and
  - making changes to existing work processes.
- evaluating and reporting on the lessons learned from MSD prevention efforts.

Ensure Worker Participation in the MSD Prevention Process

Workers have first-hand knowledge of their tasks and how the design of their workstation, tools, equipment, etc., influences the way they do their jobs. They know when they are in pain and discomfort and usually have a good understanding of the causes. Workers also have very good practical ideas for reducing their exposure to MSD hazards.

You can ensure that workers take active roles in the MSD prevention process by:

- using their experience and knowledge to recognize and assess MSD hazards and to suggest effective solutions to manage and control them
- training them to recognize the signs and symptoms of MSDs and the work-related hazards that might contribute to them
- providing instruction on and support for the use of controls that have been implemented to reduce MSD risk (e.g., new equipment, work methods, tools)
- ensuring that they are involved in planning and implementing any change to the work task or job, and
- encouraging them to report MSD concerns to management and supporting them when they do.

Encourage Early Reporting and Bringing Solution Ideas Forward

To encourage early reporting of possible MSD hazards:

- employers should develop and communicate a process for workers to report problems that could lead to MSDs
- all managers and supervisors in a company should encourage all workers to report signs or symptoms of MSDs as soon as possible, and
- management needs to receive these reports positively and take action to ensure that the workers’ pain or discomfort does not get worse.

Managers and supervisors should encourage workers to look for ways to reduce MSD hazards and bring forward ideas to improve the design or organization of a job, task, workstation, etc. These ideas may lead to fewer MSD hazards and better, more productive ways to do the job.

For innovation and creativity to flourish, you need to:

- be ready to learn from mistakes, and
- continue to encourage and recognize those who bring forward ideas for improvement.

Develop a Culture of Open Communication and Report on MSD Prevention Efforts

Your MSD prevention program will be more likely to succeed if your workplace culture supports open discussion about the hazards, and frequent communication with all workers about prevention efforts.

Such communication reinforces management's commitment to MSD prevention, and lets workers know that action is being taken to reduce MSD hazards.

Provide MSD Prevention Training to All Workers

Everyone in the workplace should receive training on MSD prevention. This will help all workers, supervisors and managers to understand and carry out their roles effectively.

MSD prevention training for workers should include:

- the signs and symptoms of MSDs
- how to report a concern in the workplace
- how to recognize MSD hazards
- who should receive reports of MSD hazards
- workplace policies and procedures for dealing with concerns related to MSDs, and
- what equipment, adjustments and procedures workers need to use or follow to reduce or eliminate their exposure to MSD hazards.

MSD prevention training for JHSC members, health and safety reps, supervisors and managers should include all of the content listed above for workers, plus:

- how to respond when workers report a concern, pain or discomfort
- how to recognize MSD hazards and use MSD hazard identification tools
- how to recognize indicators for MSD hazards
- how to analyze injury and incident reports for MSD trends and issues
- how to look for MSD hazards during workplace inspections, and
- how to eliminate or control MSD hazards in the workplace.

POINT TO REMEMBER

Train the workers who are directly involved in MSD prevention on how to use MSD hazard identification tools. This will allow them to be more involved in the MSD prevention activities that are related to their jobs.

Planning to Prevent MSDs

The process for choosing and implementing controls for MSD hazards presented above is designed to control hazards that are already present in the workplace, at a job or at a workstation.

It is better to prevent MSD hazards from existing in the first place. It is important to think about preventing these hazards before introducing a new work process, workstation, tool or piece of equipment into the workplace.

MSD hazards can often be eliminated at the planning, design, purchasing and installation stages. In most cases, it is less expensive to design MSD hazards out at the start than to add controls to manage them afterwards.

Planning Stage

You can help to eliminate MSD hazards while you are planning any new project, expansion, process or product line. Discuss how a new product, machine or tool is likely to affect workers. This process helps to focus attention on the need to ensure that MSD hazards are considered and addressed during the design stage.

Design Stage

The design stage involves architects, engineers, industrial designers and many others. They all should be aware of MSD hazards and how to eliminate them during this stage of the project. For example, it may be possible to avoid MSD hazards by considering:

- how the worker(s) will use and interact with the design
- the materials being used or produced, and
- how the design will operate and be maintained.

POINT TO REMEMBER

Preventing MSD hazards is less expensive and more effective than trying to control them later.

Steps to consider in the design stage include:

- ensuring that in-house engineers, maintenance personnel and designers are trained to address MSD hazards
- developing in-house design processes and standards that address MSD hazards at the design stage
- where practical, using mock-ups of new designs or testing different design options
- considering how the design will be used by all workers, whether they will work at or around it or be responsible for maintaining it, and
- liaising with other designers, manufacturers and suppliers to stay aware of new technology and alternative materials that will eliminate or reduce MSD hazards.

Purchasing Stage

Many workplaces purchase their equipment or workstations from a supplier and do little or no in-house design. These workplaces should consider establishing a review process that looks for MSD hazards when workstations, equipment, tools, materials, etc., are purchased for use by workers in the workplace.

This review process will be more effective if in-house purchasing department workers are trained how to consider MSD hazards or have access to someone who is. Any engineering or design specifications provided to the purchasing department should highlight factors that are important for MSD prevention. Finally, workplaces should consider developing in-house purchasing standards for frequently purchased items (e.g., tools, gloves, chairs, furniture) to ensure that MSD-related factors are considered in the purchasing process.

Other points to consider include:

- encouraging purchasers to make choices that minimize or eliminate MSD risk to the workers, even if they are slightly more expensive, and
- before introducing a new item, considering whether it is possible and practical to do one or more trials to:
    - evaluate its use, and
    - evaluate whether workers will be exposed to any MSD hazards during its use.

Installation Stage

A good design is one where the exposure to MSD hazards is minimized. However, it can be ruined if it isn't installed correctly. For example:

- if the installers put a component in a slightly different location (e.g., to cut costs on wiring), the new location may lead to awkward work postures for workers, or
- if the pieces of equipment in the new work area are put closer together to save space, this can lead to problems for both workers and maintenance staff.

If company workers are installing equipment, ensure that these workers have appropriate training on how to prevent MSD hazards and are given instructions that note any key issues that need to be considered during the installation. If an outside contractor is doing the installation, it is important to let the contractors know of key issues that need to be considered during the installation. Regular inspections and checks by workplace parties during the installation phase will help to ensure that equipment is being installed in a way that eliminates or reduces exposure to any MSD hazards.

Section 4: Understand MSD Hazards

Before moving on to "Recognize MSD Hazards and Related Concerns", it is important to understand what MSD hazards are.

Many jobs have MSD hazards that come from the job itself or the way it is done. These hazards increase the risk of developing an MSD.

Although a number of factors can increase MSD risk, the key hazards are:

- force
- fixed or awkward postures, and
- repetition.

POINT TO REMEMBER

For each job or task, look at all of the MSD hazards together. These hazards always interact. Therefore, it is important to consider how they interact to understand the MSD risk to the workers doing the job.

Force

Force is the amount of effort exerted by your muscles. All work tasks require the worker to exert some force. However, when a task requires a level of force that is too high for any particular muscle, it can damage the muscle or the related tendons, joints and other soft tissues.

You have to consider how much force is being exerted or how much weight is being handled. In addition, think about:

- how long you need to keep exerting it
- how many times you need to exert it in a given period, and
- the posture you are in when exerting the force.

Activities that often involve high force requirements include:

- lifting, lowering and carrying
- pushing or pulling, and
- gripping and manipulating objects.

In addition, don't forget: exerting a force (even at a low level) for a long time without a break (to rest and recover) can lead to pain and discomfort.

POINT TO REMEMBER

The MSD risk associated with force increases as:

- the amount of force required increases
- the posture used gets more awkward
- the number and/or speed of repetitions increases, or
- the length of time the force is exerted between breaks increases.

Fixed or Awkward Postures

Posture is another term for the position of your various body parts during any activity. For most joints, good posture is near the middle of the full range of motion. This is called the "neutral" posture.

POINT TO REMEMBER

The risk associated with awkward postures increases as:

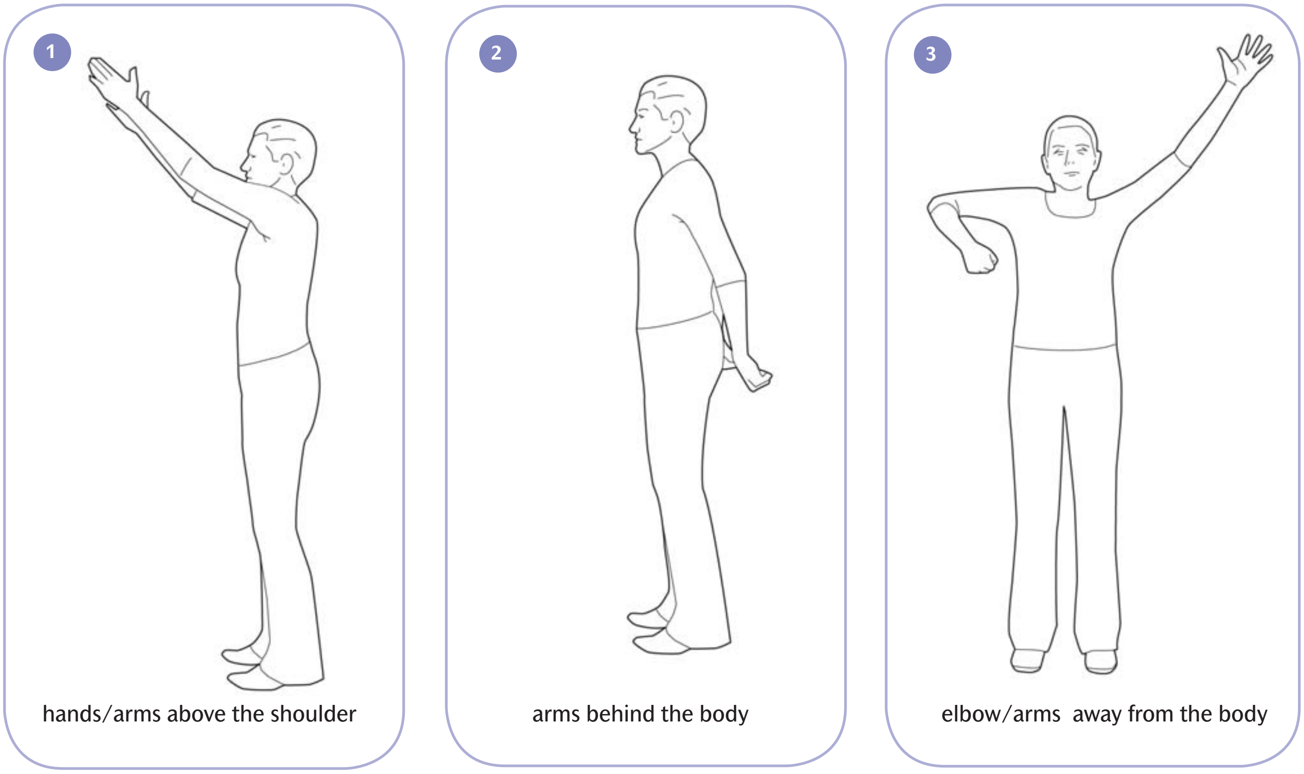
- the joints move farther away from a neutral posture
- the muscles exert higher levels of force
- the number of times the posture is adopted increases, and
- the length of time the posture is held increases.

The farther a joint moves towards either end of its range of motion (i.e., the farther away from neutral), the more awkward the posture becomes. This puts more strain on the muscles, tendons and ligaments around the joint.

When you hold an awkward posture for a long time (i.e., if the posture is fixed), you may begin to feel pain and discomfort. This happens when the muscles get tired because lack of movement keeps them from getting enough blood flow to keep them supplied with energy.

Figures 4.1 to 4.7 show some common awkward postures.

Awkward shoulder postures



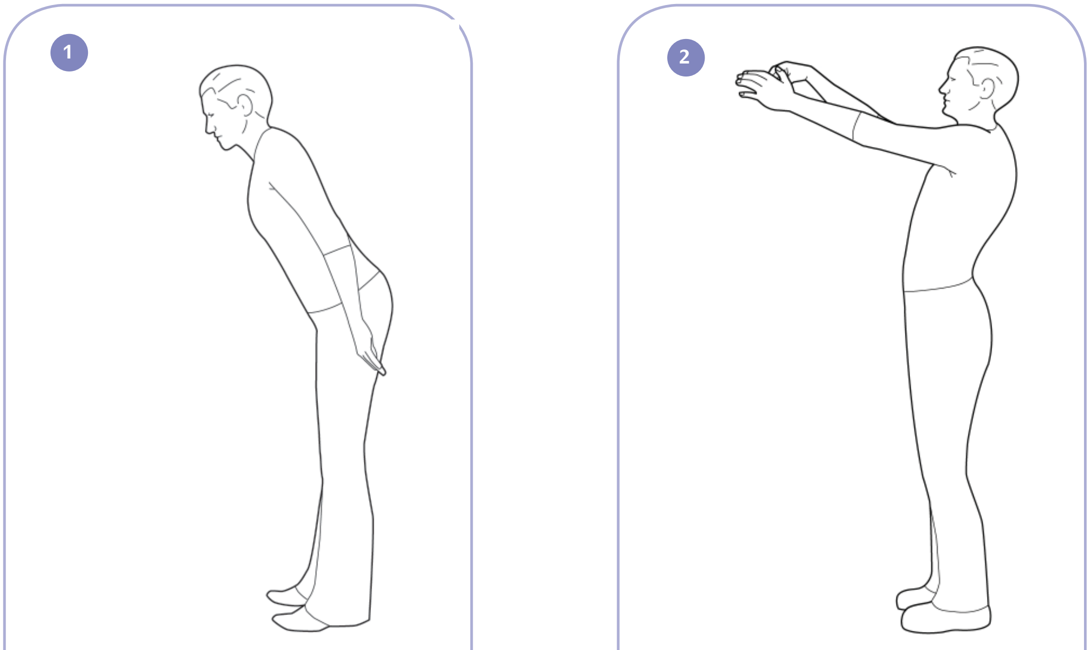
hands/arms above the shoulder

arms behind the body

elbow/arms away from the body

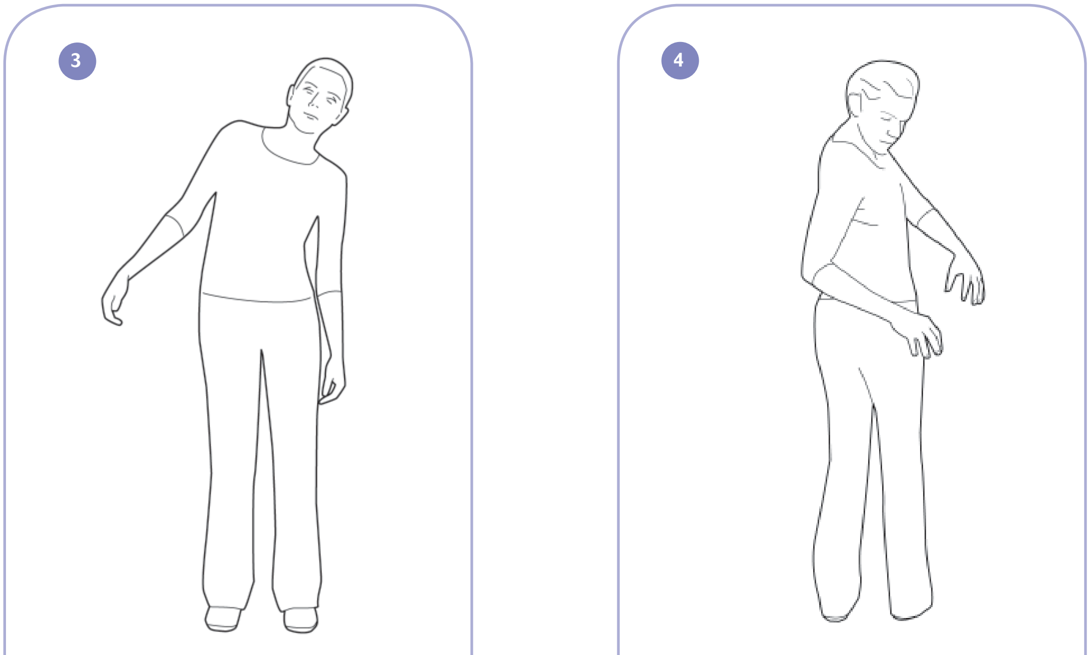
Figure 4.1: Awkward shoulder postures

Awkward back postures



Bending the back/trunk forward

Bending the back/trunk backward

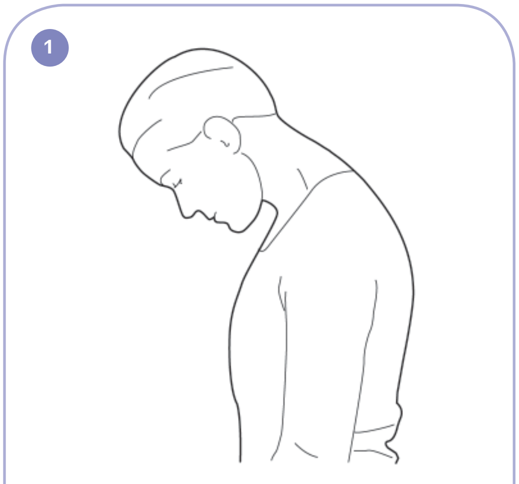


Bending the back/trunk to one side

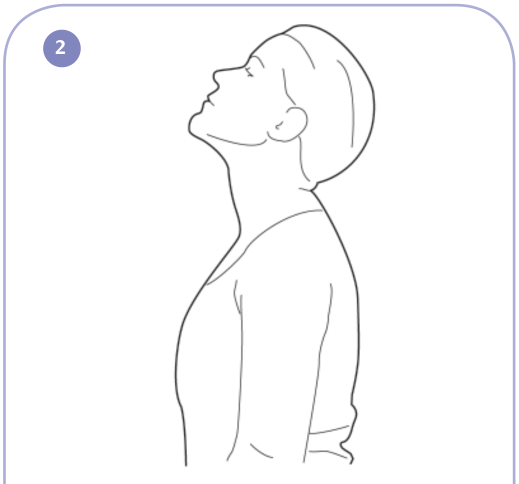
Twisting back/trunk

Figure 4.2: Awkward back postures

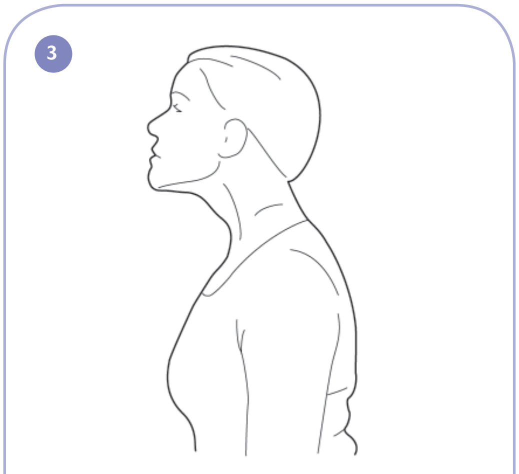
Awkward neck postures



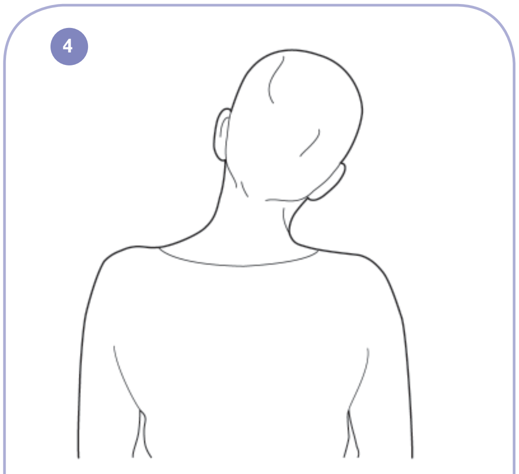
Bending the neck down



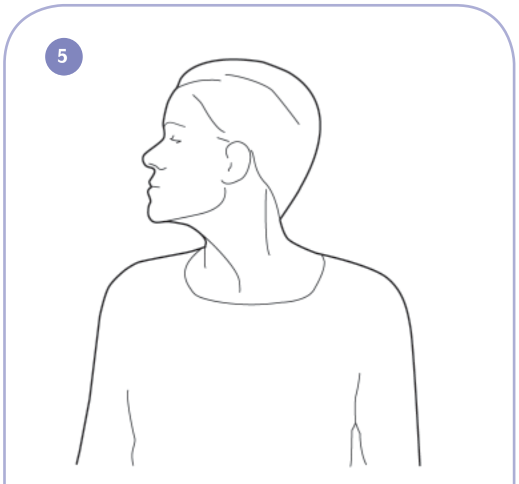
Bending the neck up/back



Bending the neck down with chin up/out



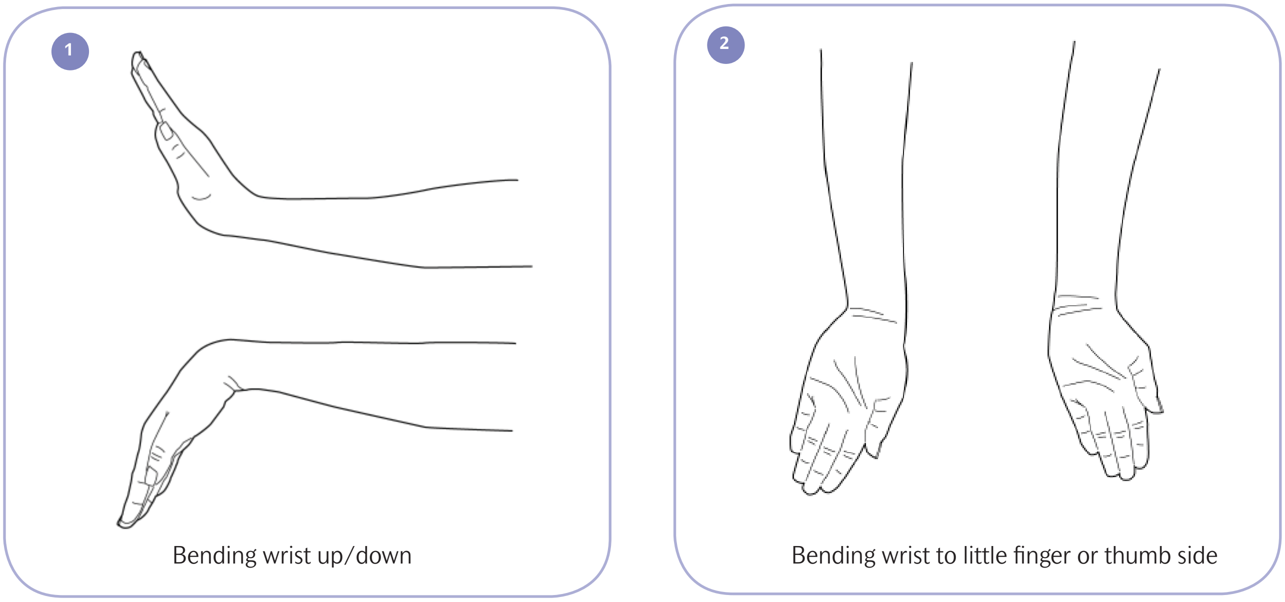
Bending the neck to one side



Twisting the neck

Figure 4.3: Awkward neck postures

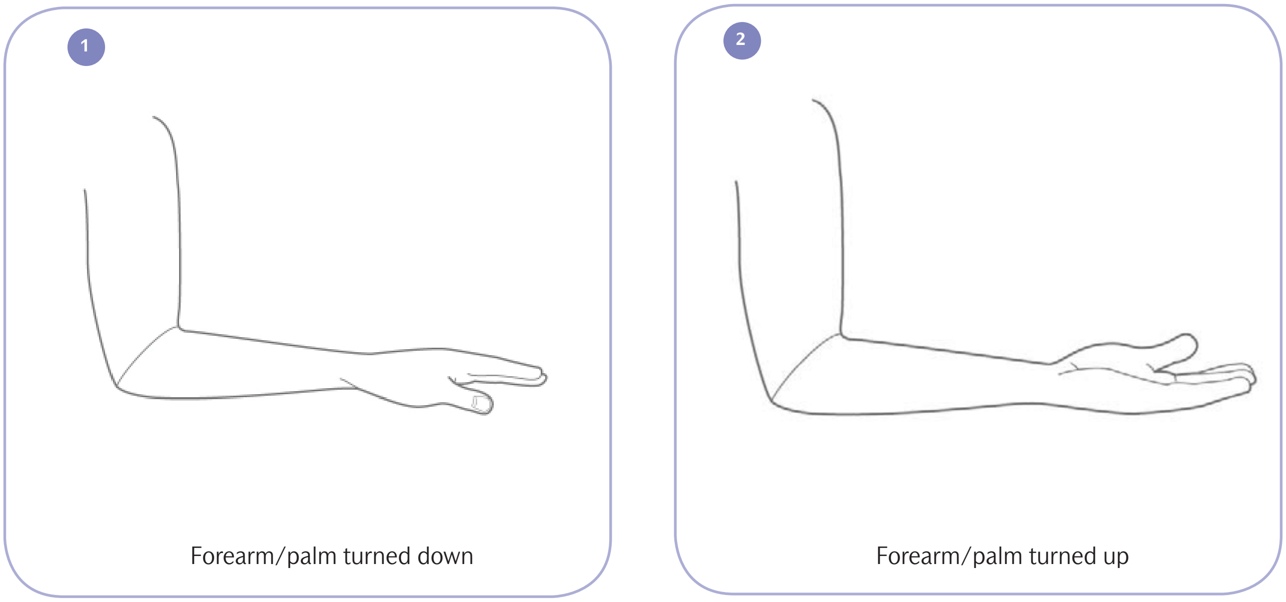
Awkward wrist postures



Bending wrist up/down

Bending wrist to little finger or thumb side

Figure 4.4: Awkward wrist postures



Forearm/palm turned down

Forearm/palm turned up

Figure 4.5: Awkward elbow/forearm postures

Figure 4.6: Kneeling

Figure 4.7: Squatting

EXAMPLES OF TASKS THAT REQUIRE AWKWARD POSTURES

Tasks that require awkward postures include:

- leaning sideways to reach into a low drawer while sitting
- bending down to work at a low level
- keyboarding on a desk that is too high
- reaching over your head (e.g., when painting a ceiling)
- reaching for objects behind your back
- bending your wrist when moving objects or keyboarding
- bending your neck down (e.g., looking at small components in poor light), and
- twisting your neck to view documents or the computer monitor.

In addition, don't forget: even if you use near-neutral postures, you can feel pain and discomfort if you stay in the same posture for too long.

Gripping

The type of grip that is used affects the level of MSD risk. Figures 4.8 and 4.9 show several types of grips workers may have to use.

Ideally, all forceful gripping of objects and tools should be done with a power grip (see Figure 4.8). Such a grip allows the greatest force to be exerted with the least strain on your hand, wrist and forearm muscles.

Moderate force pinch grips have a higher risk of injury than moderate- and even high-force power grips. However, it may be impossible to do some jobs without using a pinch grip, such as when precision is required. In these cases, it is important to reduce the amount of force required as much as possible.

The risk when using a pinch grip can be low if a low level of force is used, but it increases as:

- the level of force exerted increases
- the length of time you need to hold the pinch grip increases, and
- the number and speed of pinch grips increase.

Most desirable grip

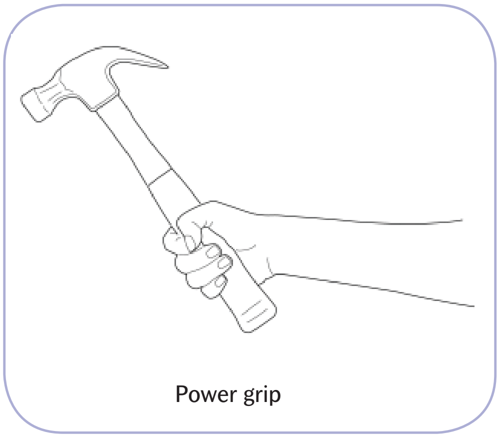


Figure 4.8: Most desirable grip

Undesirable pinch grips

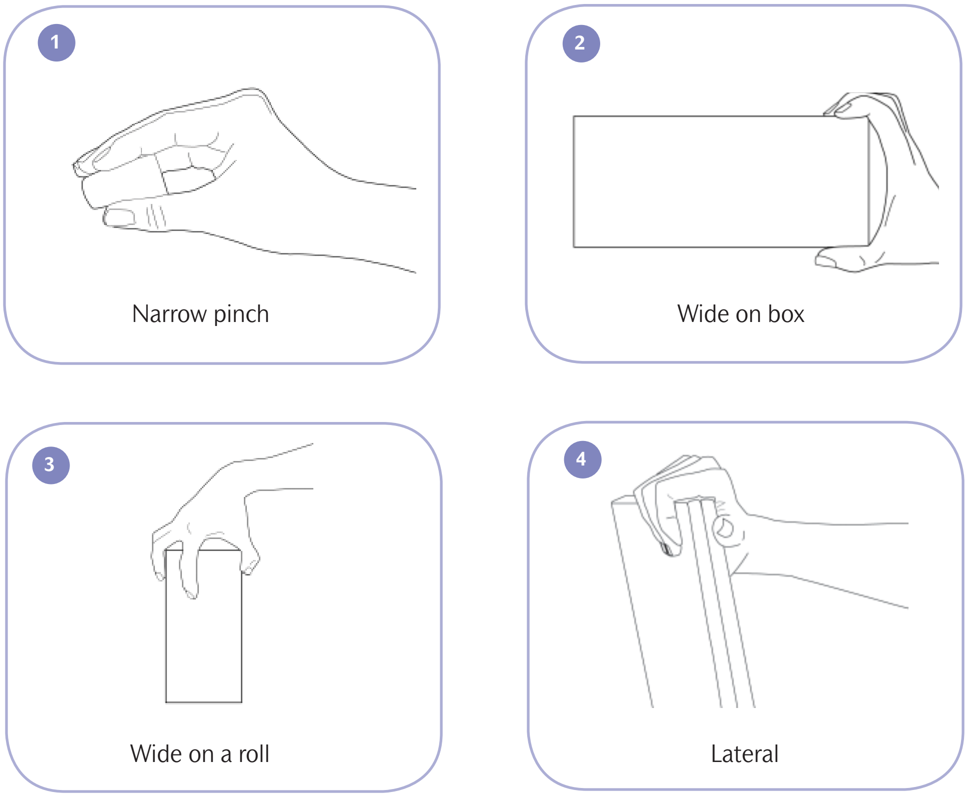


Figure 4.9: Undesirable pinch grips

FACTORS THAT INCREASE THE RISK OF MSD WHEN GRIPPING

Examples of factors that increase the risk of MSD when gripping include:

- handles or items that are too large or small
- objects that are slippery or irregularly shaped
- vibrating tools or objects
- heavy or bulky gloves, and
- cold hands.

Repetition

The risk of developing an MSD increases when you use the same muscles, tendons, joints, etc. repeatedly, with few breaks or chances for rest. Highly repetitive tasks can cause muscle fatigue, damage to other tissues, and, eventually, pain and discomfort. This can occur even if the level of force exerted is low and the work postures are satisfactory.

The MSD risk increases if the repetitive action also requires high force and/or an awkward posture.

In addition, don't forget: doing any task for too long without taking a break can also lead to pain and discomfort.

POINT TO REMEMBER

The MSD risk associated with repetition increases as:

- the number or speed of actions required increases
- the muscles being used have to exert higher levels of force
- the joints of the body move farther away from the neutral position, and
- the length of time the task is done without a break increases.

Contact Stress or Pressure and Repeated Impacts

Contact stress happens when contact between a body part (e.g., elbow, wrist) and a hard or sharp object puts pressure on the skin and the underlying tissues. The pressure can damage the skin and, over time, muscles, tendons and nerves. It may also compress and possibly damage blood vessels. Repeated impacts occur when using a body part to hit an object.

Examples of contact stress or pressure include:

- using hand tools with short handles that dig into your hand
- resting your wrist or elbow on the sharp edge of a work surface
- kneeling on a hard or uneven surface, and
- using your palm, foot or knee as a hammer.

Local or Hand/Arm Vibration

Vibration from hand tools and work pieces affects your hands. Depending on the level and frequency of the vibration and how long the vibrating tool is used, the vibration can contribute to nerve and circulation problems in your hands and fingers. Other factors to consider are how tightly the tool is gripped and whether your hands are cold.

Whole-body Vibration

If you stand, sit or lie on a surface that vibrates, the vibration can be transmitted to your entire body. Whole-body vibration exposure can contribute to back pain and performance problems. Whole-body vibration issues are most common with vehicle operators who drive off-road or over rough surfaces.

The risk of MSD due to whole-body vibration depends on:

- the level and frequency of the vibration
- the length of exposure to the vibration, and
- whether awkward postures of the back or neck are required during vibration exposure.

Cold Temperatures

Working in cold temperatures can increase your risk of MSD. This occurs because:

- your muscles do not work as efficiently when cold
- the flexibility of your muscles and tendons may be reduced if they are cold
- blood circulation in your hands and arms is reduced, and
- your sense of touch is decreased when your hands and fingers are cold.

All these situations can lead to increased effort and put more strain on the muscles and tendons. Cold can be an issue when the air temperature is low, or when working with cold objects. Examples include hand tools that have cold metal handles, pneumatic tools that direct cold exhaust onto fingers or hands, and frozen or refrigerated food.

Hot Work Environments

Working in a hot or humid environment puts more strain on your entire body by increasing body temperature and dehydration. This is mainly a concern for heat stress or heat stroke, but can also lead to increased muscle fatigue and errors in how work is done. Increased rest time is required to allow the muscles to recover and to maintain body temperature.

Work Organization

Work organization refers to the way a job is organized. Work organization factors relevant to MSD risk include:

- staffing levels
- workload schedule and job pacing
- monotonous tasks
- communication and feedback, and
- how much control workers have over how they do their jobs.

Evidence suggests that the rate of MSDs increases when:

- workers perceive their workload to be high
- communication is poor
- workers don't receive appropriate feedback, and
- workers feel they have little or no control over how they do their jobs.

Work Methods

Work method refers to the way a job is done (e.g., technique). Factors affecting work method include:

- physical and mental demands
- training
- feedback, and
- supervision.

Workers need to know how to do a job safely. They need to be trained to perform a job so that exposures to MSD hazards are minimized.

POINT TO REMEMBER

If a job is poorly designed and has a high level of MSD hazards, training probably isn't going to be enough to prevent exposure to MSD hazards and the resulting pain and discomfort.

Section 5: Recognize MSD Hazards and Related Concerns

This section provides information about how to recognize jobs with MSD hazards and jobs with existing MSDs and/or related concerns. Guidance is also provided on how to select and prioritize jobs for an MSD risk assessment (see Figure 5.0).

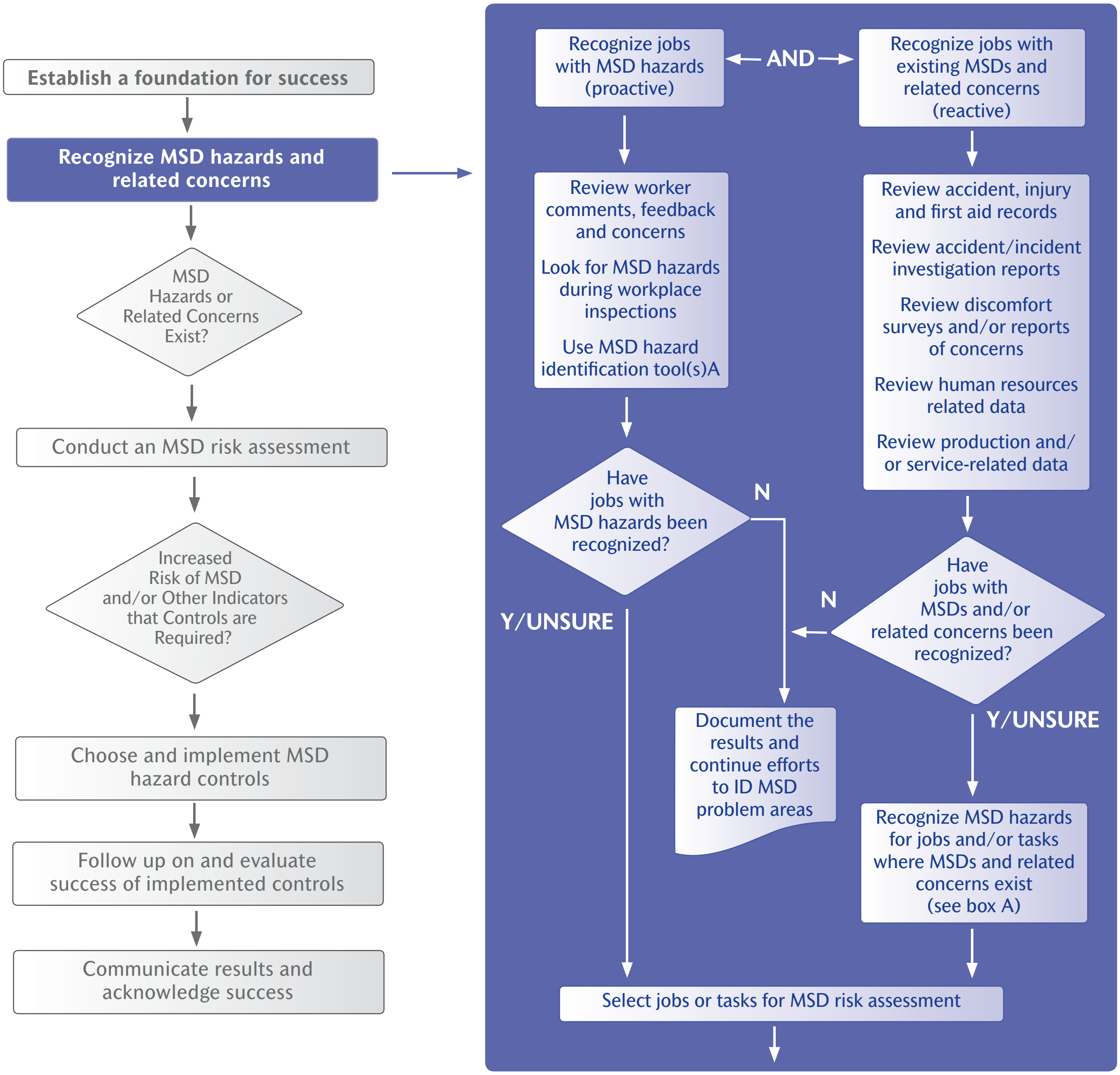


Figure 5.0: Recognize MSD hazards and related concerns

As shown in Figure 5.0, recognizing MSD hazards and related concerns should, ideally, be both proactive and reactive. Workplaces are encouraged to look for MSD hazards, even if the job or task has no history of MSDs, worker concerns, or reports of discomfort. While this may seem like a great deal of work, identifying and controlling MSD hazards before workers actually report an MSD, e.g. being proactive, can actually save you money, since you avoid all of the costs associated with an MSD related claim (administration, investigation, accommodation, overtime, possible WSIB surcharges, etc.)

Along with a proactive approach to MSD prevention workplaces should already be reviewing their accident/injury statistics and other sources of information on a regular basis. This review is done to identify jobs with existing MSDs and related concerns. The best thing about this reactive approach is that most workplaces already collect and review much of this information.

Again, workplaces should look to use both proactive and reactive approaches to help them identify jobs where MSD hazards exist. However, it is understood that when a workplace is just beginning their MSD prevention effort that they will want to focus on those jobs where MSDs have already occurred. And for many workplaces this is a good place to start; addressing jobs with MSDs first and then implementing a proactive MSD hazard identification process.

Recognize Jobs with MSD Hazards

In order to be most effective at recognizing jobs with MSD hazards, everyone in the workplace should be trained on how to recognize MSD hazards. This allows everyone to look for better ways to do their job or to identify changes that reduce the risk of MSDs.

Figure 5.1 shows three suggested activities that can be used to recognize jobs with MSD hazards. While all of these activities are valuable when looking for jobs with MSD hazards, some workplaces may decide to use only one or two of them before moving on to risk assessment and/or implementation of MSD hazard controls.

POINT TO REMEMBER

Use of MSD hazard identification tool(s), such as the example provided in the MSD Prevention Toolbox, is encouraged because they help to document the hazard identification process and may reveal MSD hazards that are not recognized by workers or during inspections!

Figure 5.1: Recognize MSD Hazards

Review Worker Comments, Feedback and Concerns

Workers should be a key source of information about job demands and MSD hazards. Many workplaces keep track of worker concerns and comments about job demands, tool and equipment design, workstation layouts, etc. This information may be gathered:

- during shift or crew meetings and noted in the supervisor's shift log
- during quality and production meetings
- through a worker suggestion box, or
- through direct reports to the supervisor, JHSC member or H&S rep, of on-site medical staff.

More formal methods can also be used to gather information directly from workers. Various types of surveys have been developed that can be used to gather information about:

- job demands and tasks that workers find difficult
- pain and discomfort, and
- general concerns related to workstations, tools or jobs and tasks.

The surveys help identify MSD hazards and how they relate to different job tasks and requirements.

See the **MSD Prevention Toolbox** for examples of a perceived exertion survey and a general worker feedback survey. Guidance on how to use these surveys is also provided.

Look for MSD Hazards during Workplace Inspections

Workplace inspections are an excellent opportunity to identify and report on MSD hazards in the workplace. While members of the JHSC typically do regular workplace inspections, managers, supervisors and/or workers often do additional inspections or workplace reviews. Anyone who does inspections should be trained to recognize MSD hazards.

Inspection forms and reports should be designed to prompt those doing the inspection to look for MSD hazards, and make it easy for them to record any that are identified.

See the **MSD Prevention Toolbox** for sample questions that can be included on a general workplace health and safety inspection form.

Use MSD Hazard Identification Tools (HITs)

The use of a formal MSD HIT or checklist is encouraged. These tools are useful for documenting the MSD hazard identification process. They can also reveal MSD hazards that are not identified by workers or during regular inspections.

MSD HITs are designed to screen jobs to find the ones likely to pose an increased risk of developing MSDs. They can be used:

- when the cause(s) of worker pain and discomfort are not easily recognized,
- to help ensure that common MSD hazards are not overlooked, and
- as part of a comprehensive, proactive review of MSD hazards in a workplace.

When an MSD HIT indicates that MSD hazards exist at a job or task, a more thorough risk assessment may be needed to determine whether workers performing the job or task are at an increased risk for MSDs.

POINT TO REMEMBER

Sometimes MSD hazards are not immediately obvious when watching a worker doing his/her job. Indicators of MSD-related problems include:

- reporting discomfort and/or soreness
- taking frequent breaks due to fatigue
- shaking or rubbing arms, hands, shoulders, or back due to discomfort
- making modifications to the workstations or equipment (e.g., padding tools/sharp edges)
- wearing protective products (e.g., wrist supports, back/tennis elbow braces)

These indicators are often easy to see and should trigger further action to identify if MSD hazards exist.

POINT TO REMEMBER

Ask a trained person for help if you have any questions about why, when or how to use any of the MSD HITs.

See the **MSD Prevention Toolbox** for examples of MSD HITs and guidance on how to use them. Information on who can help workplaces prevent MSDs is also provided.

Checking whether MSD Hazards Have Been Recognized

This is a decision point. If no MSD hazards have been recognized, you should document the work done so far, including the results from the MSD HITs, to show your due diligence.

If, however, MSD hazards have been recognized you should consider which jobs and/or tasks should be targeted for further action. To do this it is often useful to review other data related to the job and/or task MSD, e.g. the history of reported MSDs. Even if no MSDs have occurred other information, such as discomfort surveys results and/or production and service-related data, can be used to help select jobs for further action.

See 'Choosing Jobs and Tasks for Further Action' at the end of this section for more information on factors to consider when prioritizing jobs and/or tasks for MSD risk assessment.

See **Section 6: Conduct an MSD Risk Assessment** for more information.

Recognize Jobs with Known MSDs and Related Concerns

Figure 5.2 shows a number of recommended activities that are useful for recognizing jobs with existing MSDs and related concerns. Workplaces may decide to use one or more of these activities to help them identify jobs that have a history of reported MSDs and/or other concerns that can indicate that MSD hazards are present.

Figure 5.2: Recognize jobs with MSDs and related concerns

If jobs and/or tasks have a history of MSDs or other related concerns, workplaces should consider using the proactive activities described above to help them identify what MSD hazards are potentially causing the identified concerns.

POINT TO REMEMBER

Don't wait for reports of MSDs in your workplace before you start to identify and control MSD hazards.

Review Accident, Incident, Injury and First Aid Records

You should review your accident, incident, injury and first aid records regularly. Use these records to identify the departments, work areas, jobs and tasks implicated in these events. They show you the departments or jobs of workers who are reporting pain and discomfort or making MSD-related claims. Consider jobs with a history of MSD claims a priority for action.

However, remember that these records tell you about what has happened in the past. They do not predict what will happen in the future. For example, as you make changes through your MSD prevention activities, you will find that such information becomes less helpful.

Review Accident and Incident Investigation Reports

Pay attention to accident and incident investigation reports:

- investigate reports of muscle pain and discomfort and all MSD-related claims as you would any other injury or incident report

- make sure that those who are responsible for incident investigations are trained how to recognize MSD hazards, and
- design your investigation process to ask questions about and identify these hazards.

By reviewing these investigation reports regularly, you should be able to identify which jobs have MSD hazards, and which hazards are causing MSD claims.

Worker Suggestions and Reports of Concerns

Workers' reports and suggestions can help to identify actual and potential MSD hazards. All workers in the workplace should be:

- trained to identify and encouraged to report MSD hazards whenever they see them (e.g., in their own job, in any other job in the workplace), and
- aware of indicators that MSD hazards exist even if the hazards are not immediately obvious.

Workplaces are encouraged to document reports from workers about:

- pain and discomfort
- design of tools, equipment, workstations, etc.
- physically difficult or tiring tasks, and
- suggested changes or improvements to reduce exposure to MSD hazards.

Supervisors' Inspection Reports and Shift Notes

Supervisors can play a key role in helping to identify jobs, work tasks and workstations with MSD hazards. They should be looking for MSD hazards at all times, and especially when doing any type of inspection.

All supervisors should:

- be aware of indicators that MSD hazards exist even if the hazards are not immediately obvious
- document the presence of these indicators and speak to the workers about possible causes
- listen to, investigate, follow up on and document:
    - worker concerns about the design of a workstation, tools and a job or task, and
    - reports of pain and discomfort in workers.
- be trained to recognize and report on MSD hazards, and
- notify workers and the JSHC or H&S rep when MSD hazards are identified.

Review Discomfort Survey Results

Discomfort surveys are an excellent way to collect information about worker discomfort. These surveys are generally filled in anonymously and are not used to collect information about individual workers. Rather, they can provide managers, supervisors and the JHSC or H&S rep with excellent information about the overall level of discomfort being experienced by workers in a particular area or department.

See the **MSD Prevention Toolbox** for an example of a discomfort survey. Guidance on how to use this survey is also provided.

Human Resources-related Data

Your human resources department has data that can help you to pinpoint where MSD hazards might exist. For example, look for:

- jobs, work areas or departments that have higher than normal rates of overtime or absenteeism:
  - absenteeism may increase when workers who are experiencing pain and discomfort take time off work but may not make an official report, and
  - more overtime might be worked because workers are less productive or they are off due to pain and discomfort, requiring other workers to fill in for them.
- data related to worker satisfaction such as:
  - jobs that are difficult to fill because of high physical demands, and
  - suggestions for improvements made by the workers.

Production- and Service-related Data

Reviewing production- and service-related data can help to identify jobs that have MSD hazards. Such jobs may also have sub-standard levels of efficiency, service delivery and production. Workers may also consider them to:

- be process bottlenecks
- have poor quality results, and
- have a higher incidence of errors.

Identifying and controlling these MSD hazards will help to improve the overall operational performance of the job, work area or department.

POINT TO REMEMBER

If you already have a process for improving production, quality and/or service levels (e.g., Lean, 5S, Kaizen), make sure that you consider MSD hazards when you:

- look for opportunities to improve, and
- make any changes to any job or workstation.

Checking whether Jobs with MSDs and/or Related Concerns Have Been Recognized

This is a decision point. If there are no jobs and/or tasks with a history of MSDs, and if no other related concerns have been recognized, you should document the work done so far to show your due diligence.

If, however, some jobs and/or tasks do have a history of MSDs, or other related concerns have been recognized you should take steps to identify any MSD hazards associated with these jobs and/or tasks. The 'proactive' activities described in the first part of this section can help you do that. It is important to remember that it is sometimes difficult to identify the root cause of an MSD or other concerns. So, even if no MSD hazards are identified when talking to workers, during inspections or using a formal MSD hazard identification tool, jobs with a history of MSDs should be considered for further action.

See **Section 6: Conduct an MSD Risk Assessment** for more information.

Choosing Jobs and Tasks for Further Action

The information and data you have collected and reviewed will help you to select the jobs and tasks that are a priority for further action. Each workplace has to decide how to choose which jobs and tasks are a priority.

Generally speaking, jobs and tasks that might be considered to be a higher priority for further action include those that have:

- MSDs present
- recognized MSD hazards
- reports of worker discomfort or concerns
- reports of concerns by supervisors or the JHSC
- higher than average rates of overtime, absenteeism, worker dissatisfaction, etc., and/or
- productivity and/or quality problems.

See the **MSD Prevention Toolbox** for a sample prioritization method and worksheet.

If you have recognized MSD hazards or related concerns, move on to **Section 6: Conduct an MSD Risk Assessment.**

Section 6: Conduct an MSD Risk Assessment

Once jobs with MSD hazards have been identified, you need a clear understanding of the job elements or workstation-design factors that are creating these hazards.

The risk assessment process (see Figure 6.0) can help to define the source of the MSD hazards problem clearly, which in turn allows for solutions that target the root cause of the problem. Using this process can help you to:

- prevent similar MSD-related problems in the future, and
- ensure that solutions don't create new and unexpected problems.

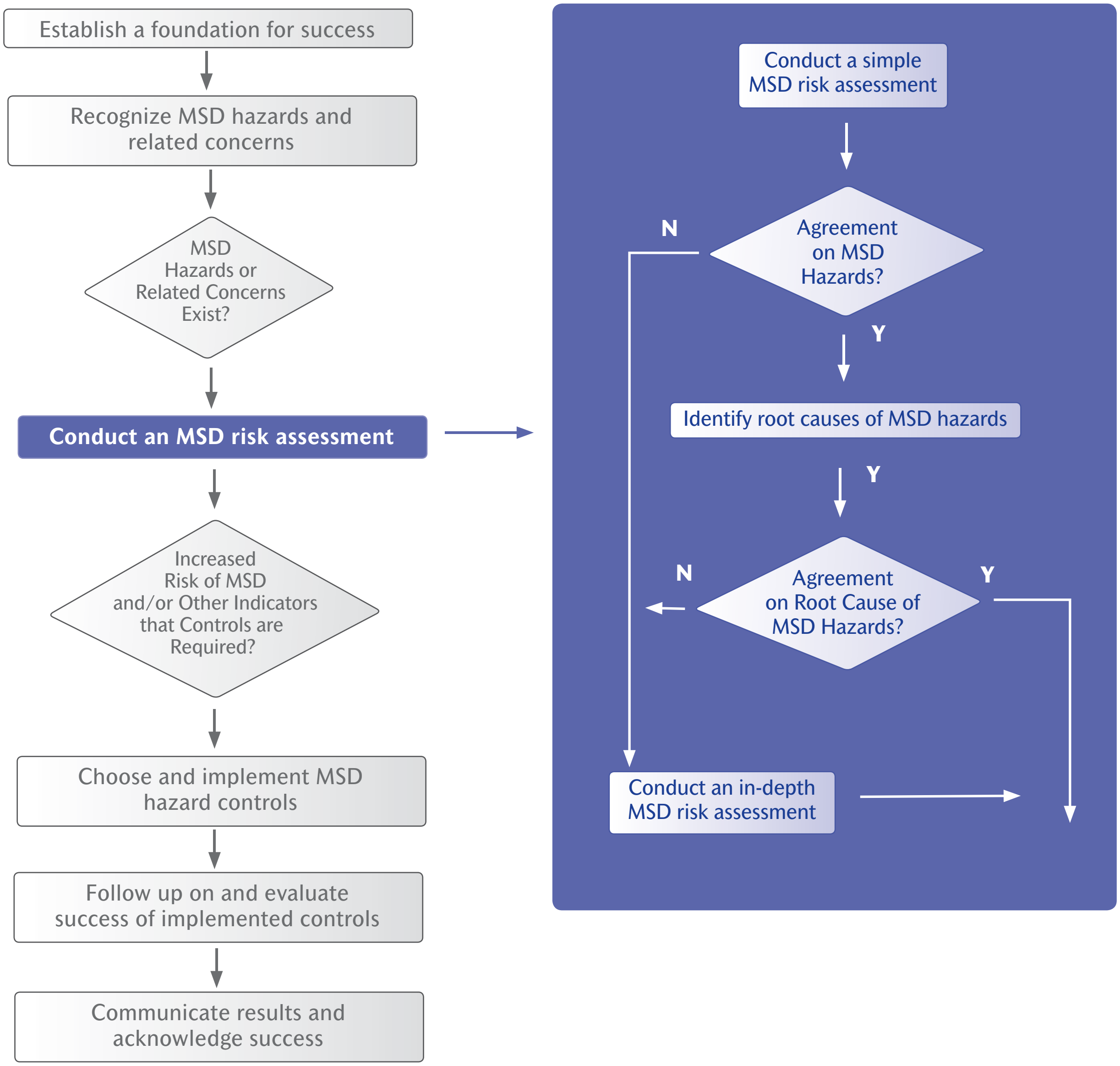


Figure 6.0: Conduct an MSD Risk Assessment

Solving MSD problems does not have to be difficult or complicated. Many problems are obvious once you start looking for them, and their solutions can be just as obvious. When there is agreement on the root causes of the obvious MSD hazards, further risk assessment may not be required. At that point it may make sense to move on to choosing a control for the identified hazards. If the root causes do not appear to be obvious, an in-depth risk assessment may be called for.

This section describes 2 related assessment approaches:

- a simple risk assessment approach, and
- a more in-depth, quantitative risk assessment.

A Simple MSD Risk Assessment

A simple risk assessment is largely based on workers' opinions and experiences to assess the risk related to the MSD hazards of a job, task, workstation, etc.

This approach is effective if:

- the MSD hazards are very clearly understood, and
- there is agreement on the root cause of these hazards.

The people doing a job often know which aspects of it:

- cause them the most pain and discomfort, and
- are most demanding and difficult.

They likely know what the MSD hazards are and what causes them; and they may have a clear idea of one or more solutions that can help to reduce or solve the associated problems.

However, because even the most experienced worker can fail to recognize some important MSD hazards, workplaces are encouraged to use an MSD hazard identification tool to make sure that all MSD hazards are identified and not just those that are the most obvious.

Figure 6.1 shows the steps you should take for this initial, simple risk assessment.

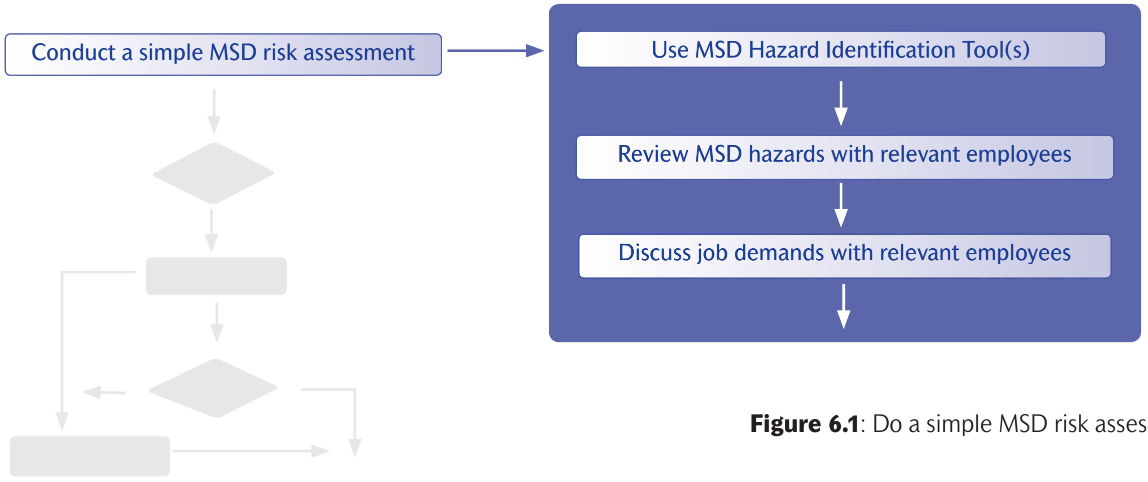


Figure 6.1: Do a simple MSD risk assessment

Use MSD Hazard Identification Tool(s)

If an MSD HIT was not used in the MSD hazard recognition step, it is recommended that the workplace use a HIT to help ensure that any MSD hazards not recognized by the workers are documented. See the **MSD Prevention Toolbox** for an example of a HIT.

Review Hazards with Appropriate Workers

Hold a meeting with workers who work on a specific job. Try to have both very experienced and inexperienced workers at this meeting. Newer workers may see and recognize issues that more experienced workers have become used to.

You should also invite the supervisors responsible for the job and a JHSC member or the H&S rep to the meeting. It may help to include representatives from maintenance, engineering and human resources.

At this meeting, workers should review all the available information including:

- a summary of reports of pain and discomfort
- an overview of worker concerns
- the type and number of MSD-related claims for the job or task
- concerns related to absenteeism and production levels, and
- the findings from the MSD HITs.

Discuss Job Demands with Appropriate Workers

Have the workers discuss their job tasks and demands that relate to the identified MSD hazards. Where possible, it may help to use:

- a written job procedure as a guide or a description of the physical demands of the job, and
- photographs and video recordings of the workstation, job tasks, etc.

NOTE

This discussion will be more useful if the workers have been trained on how to see and identify MSD hazards. If your workers have not had such training, consider providing it before you begin.

Encourage the workers to focus on the parts of the job that are physically difficult or contribute to their discomfort or pain. For each step in the job, ask the workers which actions or activities most likely contribute to the MSD problems.

Is Further Action Required?

This is a decision point. Before moving on, a decision should be made about whether further action is required.

No further action may be required for this job or task:

- if it has identified hazards but:
  - ❍ there is no history of workers reporting MSDs, or expressing concerns about pain and discomfort, and

- workers and the JHSC or H&S rep don't feel that the current job demands are a concern.

However, the workplace should continue to monitor the job or task. A more in-depth risk assessment may be called for if workers begin to express concerns about job demands, report pain or discomfort, and/or report MSDs.

POINT TO REMEMBER

If everyone agrees on the MSD hazards and their root causes, it may not be necessary to do an in-depth risk assessment. Instead, start to choose and implement MSD hazard controls.

Reach Agreement on MSD Hazards

This is a decision point. Once you have a list of job related activities or actions that are probably causing the MSD problems, or will likely do so in the future, check whether the workers at the meeting agree that these are the key hazards.

If there is no agreement, you will probably need to do a more in-depth assessment (see below).

Identify the Root Causes of the MSD Hazards

For each of the agreed-up hazards, have the workers brainstorm or discuss the root cause(s) of the hazard. Look at all the factors that can cause the hazard. Do this by considering if the hazard is related to process, equipment, materials, environment or human (PEMEH) aspects of the job.

See the **MSD Prevention Toolbox** for Tips for Eliminating and Controlling MSD hazards using PEMEH categories and Eliminating and Controlling MSD Hazards – Developing Solutions Worksheet Example to document potential controls.

Reach Agreement on the Root Causes of the MSD Hazards

This is another decision point. After you have determined the root causes of the hazards, check whether everyone believes that these are the true causes.

If there is agreement, it may not be necessary to do a more in-depth risk assessment. You can go to **Section 7: Choose and Implement MSD Hazard Controls**. If there is no agreement, you may need to do a more in-depth assessment (see below).

An In-depth MSD Risk Assessment

You should move on to a more in-depth, quantitative risk assessment if:

- the MSD hazards are not clearly understood, or
- there is no agreement on the root cause of these hazards.

The suggested steps for an in-depth MSD risk assessment are listed in Figure 6.2.

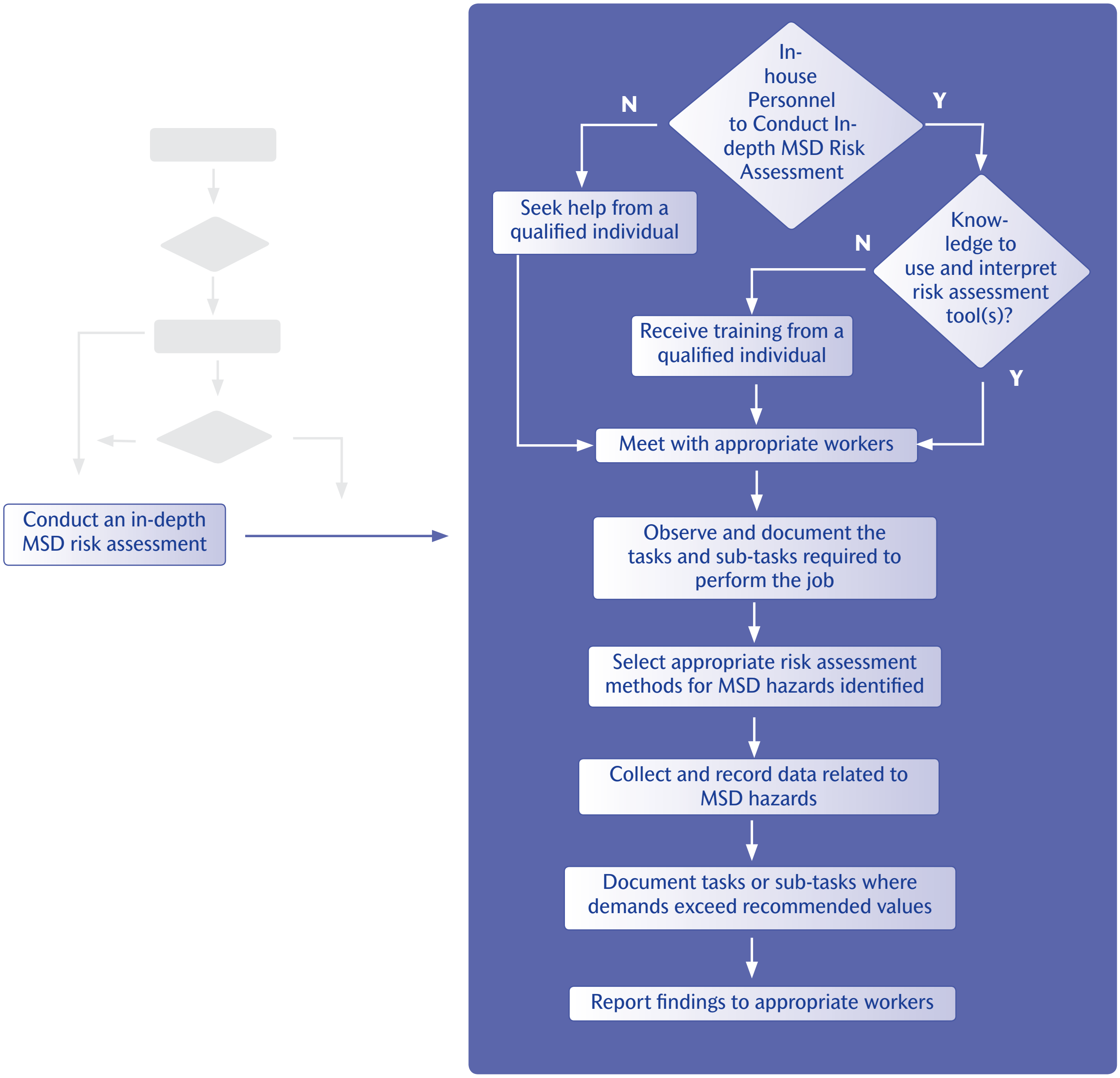


Figure 6.2: In-depth MSD risk assessment

Decide Who Should do the In-depth Risk Assessment

Here is another decision point. Once you decide to do a more in-depth, quantitative MSD risk assessment, you need to consider whether to:

- do it in-house, or
- get help from a qualified person from outside your organization.

This level of risk assessment requires more experience, training and knowledge. You may find that it is less costly and more efficient to seek help from a qualified person from outside the workplace.

If you decide to do the risk assessment in-house, it is important that those doing it be trained on how to use and interpret the risk assessment tools.

See the **MSD Prevention Toolbox** for information on things to consider when selecting a person to help you with your MSD prevention efforts.

Meet with the Appropriate Workers, Supervisors and Managers

Before doing a quantitative MSD risk assessment, you should meet with the workers who do the job or task being assessed. A member of the JHSC or the H&S rep should also be at this meeting. The workers need to know that:

- an assessment is going to be done
- why this is happening, and
- how the results of the assessment will be used.

Supervisors and managers for the work area or department should also be at this meeting. They should:

- show that they support the risk assessment process, and
- make a commitment to any changes needed to control the identified MSD risks.

Observe and Document the Tasks and Sub-tasks Required to do the Job

To find the root cause of an MSD hazard, you need a detailed understanding of how the job is done and all of the tasks and sub-tasks involved.

This is called a task analysis and description. It involves reviewing all of the tasks and the safe work or standard operating procedures that are part of the job. You must work closely with experienced workers to observe and document all of their tasks and sub-tasks, including those related to:

- equipment breakdowns, jams, shutdown and start-up, cleaning or maintenance, and
- non-routine but predictable tasks caused by schedule changes, seasonal variations and customer demands, etc.

If it is practical and allowed, make video recordings of tasks being performed. The video images can be slowed down and paused to help better identify work postures and used to show others job tasks where MSD hazards might exist. Other ideas to consider include:

- making a sketch of the work area or workstation to show movement paths of a worker, reaches, distances, heights, etc., and
- using existing documents such as job descriptions and procedures, standard operating procedures and physical demands descriptions to look for areas of concern.

POINT TO REMEMBER

If in-house staff have not been trained how to use and interpret the results of an MSD risk assessment method, get help from a qualified person.

Select Appropriate Risk Assessment Method

Once you have a good idea of all the tasks involved in the job, you should select an appropriate risk assessment method that reflects the MSD hazards identified. Various assessment methods are available to evaluate the MSD risk, and it is important to select one that is appropriate for the specific type of MSD hazard and for the job or task being evaluated. For example, the Lifting Equation of the National Institute for Occupational Safety and Health (NIOSH) can be used to evaluate lifting and lowering tasks, but not the demands on the hands, wrists and/or arms due to repetitive assembly-line tasks.

See the **MSD Prevention Toolbox**, for guidance on selecting appropriate risk assessment tools.

No matter which method you decide to use, ensure that those using it have adequate training before applying it in the workplace. Some methods are relatively easy to use. With a little training, anyone in the workplace can learn to use and apply them. Other methods are more complex. They require sophisticated understanding of their uses, limitations and interpretation of findings. Such methods require a much higher level of training to learn their use and practical experience and guidance in interpreting their findings.

POINT TO REMEMBER

Identifying the root cause of an MSD hazard is key to choosing effective controls.

Collect Data Related to the Hazards

To assess the risk for MSDs you will need data about the demands of the job or task. The data needed will depend on the risk assessment method(s) selected in the previous step. Each risk assessment method will require specific data and information about the type of hazard being assessed.

MSD risk assessment methods may require you to collect some or all of the following data:

- the dimensions of the work area, including distances of required reaches
- load weight, size and location (for both picking up and putting down) for any lifting, lowering and carrying (whole body, 1- or 2-handed)
- forces used for any pushing, pulling, grasping, etc.
- work postures required (e.g., bending, reaching, twisting)
- the frequency of physical efforts (i.e., the number of times per minute, hour or shift)
- length of time a force is exerted or a posture is held
- production and service demands (i.e., per minute, hour or shift)
- contact stresses, local or whole-body vibration, work organization factors and work methods
- shift schedules and organization (i.e., length of shift, rotation, and number and length of breaks)
- environmental factors (e.g., noise, light, temperature, floor surface), and
- other information (e.g., required PPE, number of staff doing the task, types of assistive devices provided, drawings of the work area layout).

Digital photographs of key tasks can be used to document specific hazards and issues.

Document Tasks or Sub-tasks where Demands Exceed Recommended Values

The risk assessment should allow you to determine which of the identified MSD hazards exceed recommended values. For each task and sub-task, you should document:

- the MSD hazards associated with it
- any measures that help to define or describe the hazard
- which tool you used to assess the risk, and
- the results of the risk assessment.

You should then highlight any tasks and sub-tasks where the risk associated with the MSD hazard exceeds acceptable levels.

Note: workplaces are encouraged to establish 'standards' for what will be considered acceptable levels. These standards should be developed in consultation with the JHSC or H&S rep. and, if applicable, workplace union representatives. Workplace parties should seek the assistance of a qualified individual if they do not have the knowledge or experience to establish these standards.

Report the Findings to Appropriate Workers, Supervisors, Managers and the JHSC or H&S representative

Create a report detailing the MSD risk assessment process and present the findings to the appropriate workers, supervisors, managers and JHSC or H&S rep. Highlight all tasks and sub-tasks that have an increased risk of MSD and discuss what further action, if any, needs to be taken.

Is the Risk of MSD Increased?

Steps should be taken to select and implement controls for MSD hazards when:

- everyone agrees that the job or task exposes the workers to an increased risk of injury, or
- an in-depth risk assessment indicates that the MSD risk for workers is increased.

No further action may be required when:

- there is no indication that the job or task has an increased risk of MSD, and
- there is no history of MSD or reports of pain or discomfort for the job or task.

However, the workplace should continue to monitor the job or task.

If the in-depth risk assessment indicates that the risk of MSD for a job is acceptable but the job or task has a history of MSDs and/or reports of pain or discomfort, the workplace should consider:

- reviewing the risk assessment methods used to ensure that appropriate methods were chosen for the MSD hazards identified and/or reported MSDs
- whether accommodations to address individual needs are necessary or possible, and

- whether factors that were not addressed during the risk assessment may be contributing to the development of MSDs.

If the Risk of MSD is Increased, Identify Potential MSD Hazard Controls

Identifying potential controls for MSD hazards is not technically part of the MSD risk assessment process. It is included here as a reminder that risk assessment is only a means to an end, not the end.

The risk assessment provides you with greater understanding of the MSD hazards for a job and the level of risk associated with these hazards. But the reason for doing the risk assessment is to gain the information you need to take the next step. That step is making changes and modifications in the design of the job, tools, equipment, workstation, work organization, environment, etc. These changes are intended to reduce or eliminate the risk of MSD for the workers doing the job.

See **Section 7: Choose and Implement MSD Hazard Controls** for:

- more information on how to choose and implement controls for MSD hazards, and
- examples of control strategies for different MSD hazards.

See the **MSD Prevention Toolbox** for:

- a worksheet to help identify root causes for MSD hazards
- information on things to consider when selecting a person to help you with your MSD prevention efforts
- guidance on MSD risk assessment methods, including which methods are appropriate for which tasks and jobs, and where to find more information on these methods, and
- principles for choosing an MSD risk assessment method.

Section 7: Choose and Implement MSD Hazard Controls

POINT TO REMEMBER

Identifying the root cause of an MSD hazard is key to choosing effective controls.

You have identified and assessed the risks due to MSD hazards in your workplace. You did this so that you can put effective controls in place that decrease or eliminate workers' exposure to those hazards. The process for choosing and implementing controls for MSD hazards is outlined in Figure 7.0.

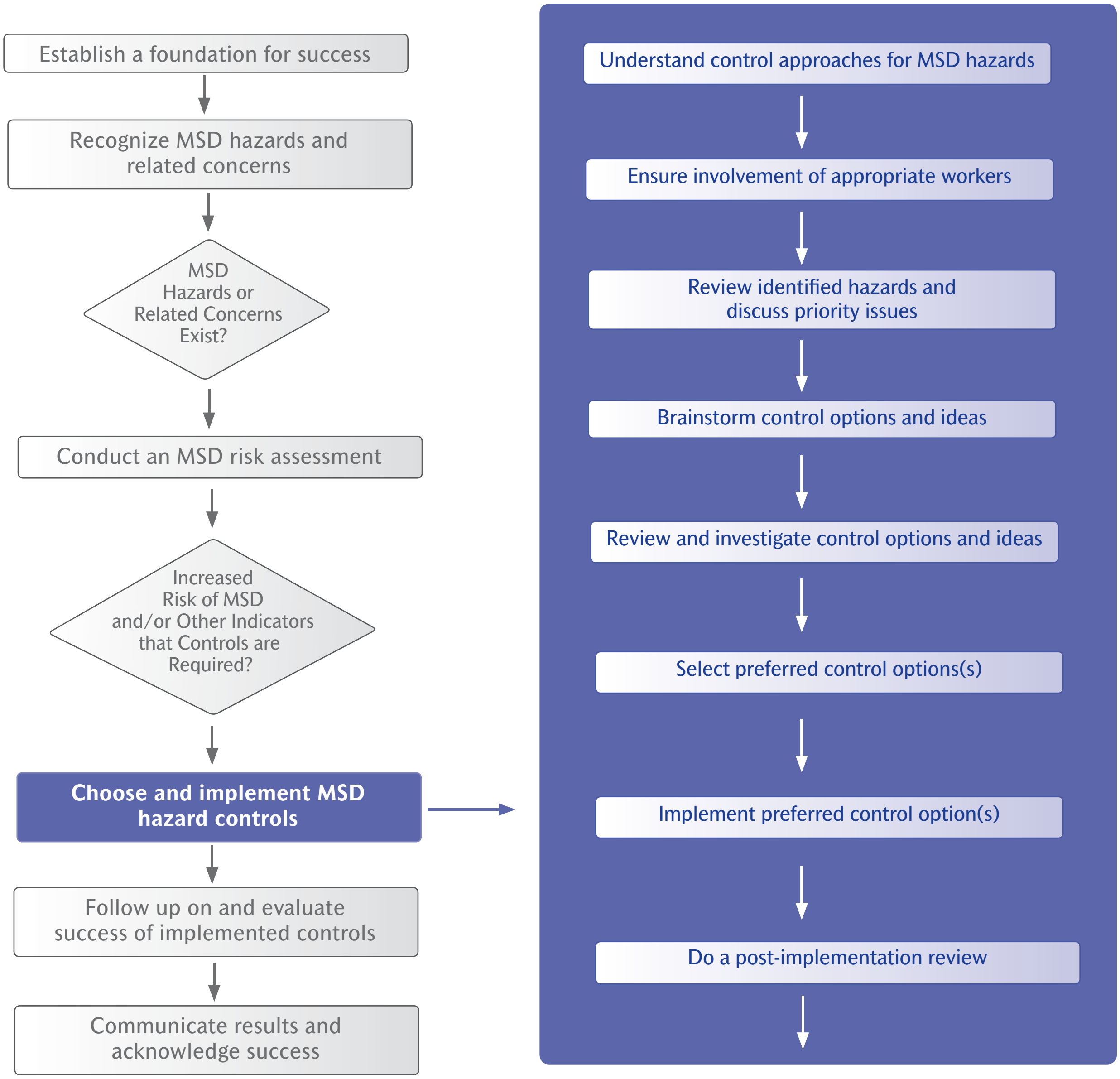


Figure 7.0: Choose and implement MSD hazard controls.

Effective controls for MSD hazards do not have to be elaborate or expensive. Often a simple change in a work process, workstation or tool is effective. If a more complex change is needed, it may be possible to implement it in stages. For example, you may be able to:

- make small changes to the design of a workstation or piece of equipment over time, and/or
- include changes to the way the job is organized or staffed until all the other controls are in place.

When the development or implementation of an MSD hazard control is going to be delayed, it is important to consider interim controls. These may not be the preferred or best solution, but they can reduce the risk in the short term.

Make sure that controls for MSD hazards do not create new hazards. You need to consider both the workers handling the controls and those who have to work in and around them (e.g., maintenance personnel, cleaners, suppliers).

The remainder of this section provides information about:

- the types of controls that can reduce workers' exposure to MSD hazards, and
- how to select and implement these controls.

Understand Control Approaches for MSD Hazards

Ideally, controls should be designed to eliminate a worker's exposure to the identified MSD hazards. There are 2 main controls for MSD hazards: engineering controls and administrative controls. In addition, you can use a combination of these types of controls.

Engineering Controls

Engineering controls reduce or eliminate the worker's exposure to MSD hazards by modifying the work or workplace. They include:

- modifying workstations
- providing new tools or equipment to reduce demands
- changing the tools or equipment used to do the work, and
- modifying the production process.

Specific examples of engineering control ideas and concepts include:

- changing the way materials, parts, people and products are transported (e.g., using mechanical assist devices to eliminate heavy lifting and carrying)
- changing the process or product to reduce exposure to MSD hazards (e.g., reorienting or redesigning equipment parts, workstatations or work areas to allow for easier access
- modifying containers, carts, bins or stands to improve work postures (e.g., cutting the sides out of deep bins, providing height-adjustable bin inserts)
- changing the design and/or layout of a workstation (e.g., using height-adjustable tables, relocating tools, materials or other items to reduce reaching)

- changing the way parts, tools, equipment and materials are manipulated (e.g., using fixtures to hold work pieces, suspending tools to reduce the weight and allow easier access)
- changing tool designs (e.g., "pistol" grips for knives to improve wrist postures, full hand squeeze-actuated triggers to replace finger-actuated triggers)
- changing materials and fasteners (e.g., lighter-weight materials to reduce lifting loads, Robertson screws instead of slotted screws)
- changing the layout of the work environment (e.g., removing physical and visual obstructions that cause awkward postures or static exertions), and
- adjusting the speed of production machines, conveyors, etc., to reduce repetitive motion risks and give workers more control of the work process.

Engineering controls are preferred over administrative controls because:

- when they are implemented correctly, they address the MSD hazards at their source
- they rely less on workers to choose safe work practices and not make errors, and
- they are often the most cost-effective solutions in the long term, because they tend to fix the problems at the source and do not require ongoing administrative efforts and costs.

POINT TO REMEMBER

The effectiveness of an engineering control is often specific to the task or workplace. Therefore, all controls and solutions should be carefully considered in terms of the specific job, task and work process.

Administrative Controls

Administrative controls are designed to reduce exposure of workers to MSD hazards by developing specific policies and procedures, changing work schedules, adjusting staffing levels, etc. They may also include efforts to develop and train workers to use work methods that reduce the risk of MSD.

Administrative controls change the way work is done. They do not change the physical work environment. Administrative controls do not eliminate hazards, but they can greatly reduce the risk of MSDs. For example, administrative controls can help until engineering controls can be adopted, and when engineering controls cannot be used for technical reasons.

POINT TO REMEMBER

Administrative controls may seem to cost less than engineering controls. However, their costs actually can be much higher in the long run!

In some cases, a combination of administrative and engineering controls provides the best solution.

Examples of administrative control ideas and concepts include:

- establishing policies and procedures about:
  - appropriate tool or equipment use
  - regular tool or equipment inspection, and
  - maintenance.
- rotating workers through several jobs with different physical demands to reduce the stress on limbs and body regions (job rotation)
- broadening or varying the job content (job enlargement)

- training workers to support job rotation and job enlargement strategies
- implementing appropriate work-hardening procedures for new workers
- scheduling more breaks to allow rest and recovery
- reducing shift length or the amount of overtime allowed
- training workers to recognize MSD hazards and to use work practices that can ease the demands or burden of tasks
- changing a lifting task from a 1-person lift to a 2-person lift
- training workers to use good body mechanics and adopt neutral work postures
- training workers to use good manual handling methods and techniques
- encouraging workers to rest muscles, relax and change their posture during brief pauses in the work cycle, and
- implementing warm-up and stretching exercises.

Administrative controls do not eliminate hazards. Therefore, management must ensure that the controls' practices and policies are followed. This may involve:

- developing weekly job-rotation schedules
- adjusting levels of staffing based on workload
- continuously training workers to allow job enlargement, and
- providing ongoing training and education.

Personal Protective Equipment (PPE)

Providing the workers with PPE cannot effectively control most MSD hazards. Some products may be useful for treatment or rehabilitation, but are of little or no benefit for MSD prevention. The following products are **not** recommended or effective at preventing MSDs:

- back belts, and
- wrist supports and splints.

These products do not reduce the risk of injury to workers. In some cases, they may increase it. There are some exceptions. Equipment that has been shown to be effective includes:

- well-designed "anti-vibration" gloves
- kneepads for kneeling work, and
- shock-absorbing insoles.

Involve Appropriate Workers

It is important to have all workers involved in MSD prevention efforts. This is especially relevant during discussions of hazard control ideas and options, and the process used to choose which control(s) to implement.

Make sure that employees who work at the job that is being improved are part of the control selection team. Others who should be involved include appropriate maintenance, supervisory and engineering staff, and member(s) of the JHSC or the H&S rep.

Review Identified Hazards and Discuss Priority Issues

The team considering which controls to implement needs a clear understanding of:

- the MSD hazards that exist for a job, and
- the results of any risk assessment methods used.

Review the identified MSD hazards and risk assessment results. Discuss the situation with the workers to determine which hazards are the highest priority for control. In most cases, the hazards with greatest risk will be seen as the high priorities for control. However, a hazard with less risk may be considered a higher priority if it leads to more frustration, work having to be re-done, jam-ups, etc.

Brainstorm Control Options and Ideas

Once the MSD hazards have been prioritized, it is time to generate options and ideas to effectively control exposure to them. A variety of techniques can be used to come up with a list of control options. Brainstorming is useful to identify as many options and ideas as the team can think of. Be open to innovative and unusual control options and ideas suggested by the team. Using or building on these ideas can often lead to better and more productive solutions for your workplace. The PEMEH categories (process, equipment, materials, environment, and human) can also be used when considering possible MSD hazard controls.

See the **MSD Prevention Toolbox** for Tips for Eliminating and Controlling MSD hazards using PEMEH categories and Eliminating and Controlling MSD Hazards – Developing Solutions Worksheet Example to document potential controls.

Techniques for identifying MSD hazard control options and ideas include:

- talking to staff who do similar work in other companies
- talking to suppliers of equipment and materials
- looking at catalogues, brochures, etc.
- contacting one of Ontario's health and safety associations (see Appendix)
- talking to labour organizations and/or employer associations
- attending trade shows and conferences
- searching the Internet, and
- posting questions on Internet safety discussion groups.

POINT TO REMEMBER

Consider a number of possible solutions. Consider testing several solutions on a small scale before deciding on which one to implement.

Review and Investigate Control Options and Ideas

After listing MSD hazard control options and ideas, take the time to review and investigate them. One control option may stand out to everyone involved as the best. If this occurs and everyone agrees, further review may not be needed. However, choosing what seems to be the obvious (i.e., often the easiest) option may lead to problems later on. Alternatively, it may cause you to miss a much better but less obvious option.

Before starting the review process, list the control options and ideas and assign one or more staff members to be responsible for reviewing each one. They will then bring their findings back to the rest of the team.

For each option and idea, consider and document some or all of the following:

- the likelihood that the control will eliminate or significantly reduce exposure to the hazard
- the effect of the control on other parts of the work process (both up- and downstream)
- any new issues or hazards the control might introduce at the workstation or in other areas of the workplace
- the cost to implement, use and maintain the control
- the practicality of the control:
  - is it easy to do, in use elsewhere, purchased off-the-shelf?
  - is significant design or redesign required?
- the effect of the control on productivity and/or quality
- the need to train workers
- the feelings and concerns expressed by appropriate workers, and
- other information:
  - from suppliers and manufacturers
  - from employers who have already implemented the control, and
  - in case studies or research papers.

All of these sources of information can be used to help identify which of the control options and ideas you should consider using. Once you have narrowed down the list, consider:

- using one or more of the ideas on a trial basis to evaluate its success, and
- creating a mock-up or prototype of a new workstation or work area layout to test how it will help reduce the workers' exposure to hazards.

Choose Your Preferred Control Option(s)

After reviewing your MSD hazard control options and ideas, you need to choose one control or a combination. This can be difficult if you have a large number of options and ideas to consider.

Compile all of the collected information in a format that allows the team members to easily compare the pros and cons of the various options. One option may stand out as the best (i.e., it is low cost, easy to implement and eliminates the MSD hazard). However, it is often not this easy. A process for ranking and weighting the various review factors should be considered if a decision between different controls must be made.

Implement Your Preferred Control Option(s)

How you implement your preferred control is very important. Check that all of the workers who will be affected by the control know about the change. They need to know:

- what will happen
- why it is happening
- when it will happen, and
- what it will mean for them, in terms of new work methods, etc.

POINT TO REMEMBER

Simple, low-cost changes (e.g., changes in working height) can make a big difference. In addition, they are usually easy to implement.

The workers need to receive any training necessary to use the control effectively and efficiently. When you are installing a new control, it is important to:

- install the control correctly
- ensure that no new hazards are introduced
- consider whether a break-in period is needed to allow workers to get used to the control before the process speed or production expectations return to normal.

Do a Post-implementation Review

Immediately after a control is implemented, you should check to make sure that it is working as you expected and there are no surprises. Check that:

- the expectations of the workers involved in the project have been met
- the chosen solution was installed correctly
- all appropriate workers have been trained on how to use the control
- all appropriate workers can demonstrate how and when to use the control
- the concerns of maintenance personnel are addressed
- up- and downstream processes have been reviewed to ensure that no hazards or negative issues have been introduced
- no new hazards or concerns have been introduced, and
- initial feedback of appropriate workers is documented.

See the **MSD Prevention Toolbox** for:

- Eliminating/Controlling MSD Risks – Developing Solutions Worksheet
- Tips for Eliminating and Controlling MSD Hazards
- Questions to Consider When Choosing MSD Hazard Controls.

Section 8: Follow up on and Evaluate the Success of Implemented Controls

The post-implementation review is the first step in a good evaluation of any MSD prevention project. You should do this review as soon as possible after a control has been installed or implemented. Figure 8.0 shows the steps recommended to evaluate all MSD prevention projects.

POINT TO REMEMBER

Sometimes an evaluation suggests that the MSD hazard control is not fully successful. In this case, you may not have properly identified all of the MSD hazards. Return to Section 5 (Recognize MSD Hazards and Related Concerns).

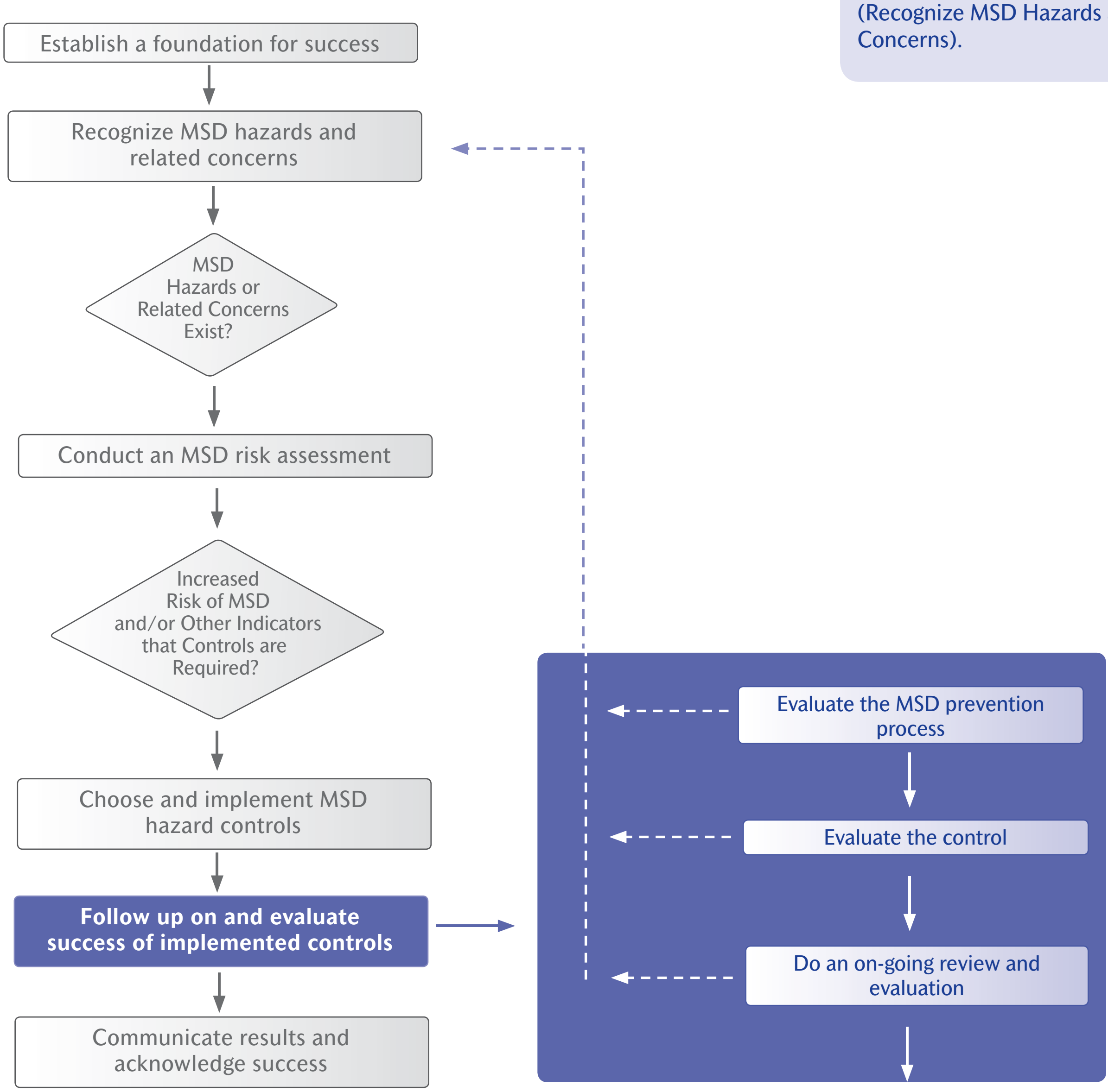


Figure 8.0: Follow up on and evaluate the success of implemented controls

Evaluate the Process

This part of the evaluation focuses on how well the MSD prevention process worked to control MSD hazards on a particular job or in a particular work area.

As soon as possible after implementing a control, you should ask the team that worked on the solution(s) to provide feedback on how well the process worked, and suggestions on how to improve the process.

Consider asking each team member the following:

- did you fully understand the purpose of the project?
- did you fully understand your role in the project?
- do you think that you received adequate training to take an active part in the project?
- did you feel that you had enough time to properly take part in this project?
- were the HITs easy to use and appropriate for this project?
- were the risk assessment methods used easy to understand and appropriate for this project?
- do you feel that you were given an opportunity to express your concerns and opinions?
- is your overall opinion of the MSD prevention project positive, neutral or negative?
- is there anything you think should be done differently to improve the process used in future MSD prevention projects?

Evaluate the Control

To evaluate the success of MSD hazard controls more formally, allow some time to pass. This will ensure that any small "bugs" with the control are corrected, and all workers have had a chance to use and adjust to the control.

Shortly after implementing the control, you should:

- observe and ask the workers and supervisors directly whether they are using the control and using it correctly
- use the MSD HITs to verify that the hazards continue to be controlled and that no new hazards have been introduced
- ask all appropriate workers for their feedback on the control:
  - ❍ is it easy to use?
  - ❍ does it make the task easier and less demanding?
  - ❍ does it speed up or slow down production?
  - ❍ is it reliable and easy to maintain?
  - ❍ are there any concerns or problems with the control?
  - ❍ has it led to any new problems?

Document the information collected during this evaluation and report it back to all appropriate workers. If concerns are noted, ask the project team to discuss them and suggest ways to alleviate them.

A more formal and in-depth evaluation should be done once the finalized control has been in use for a while (e.g., 3–6 months). By this time, the workers should have a very good idea of how the control works and the positive or negative things associated with its use.

During this evaluation, you should consider:

- using a formal survey to gather workers' opinions on the control
- asking workers for suggestions to improve the control
- surveying other appropriate workers about the control (e.g., maintenance, production, engineering, quality, supervisors), and
- collecting production and quality data.

See **MSD Prevention Toolbox** for an example of a survey that can be used to collect workers' opinions of the controls.

You could also re-use some of the surveys used during the hazard identification step (see **Section 5: Recognize MSD Hazards and Related Concerns**):

- postural discomfort
- workload or MSD hazard perception, and
- MSD HITs.

POINT TO REMEMBER

Which survey, checklist, HITs, etc., did you use during the initial assessment of the job or task? Use the same tool to evaluate it after implementing the control. This will allow you to compare the results.

Compare the information or data collected with what you found before the control was installed.

Bring the project team together to discuss and suggest new ways to correct any identified issues.

Do an Ongoing Review and Evaluation

Continue to review all the usual reports to look for problems or improvements on the job or in the work area where the control was implemented. Include regular JHSC or H&S rep inspection reports, and accident, injury, first aid, absenteeism, overtime, production and/or quality reports. This information is normally reviewed by the JHSC, the occupational health nurse, human resources, production and/or quality personnel.

Remember that MSDs may continue to be reported even after a control has been successfully implemented. Since it takes time to develop an MSD, new cases can result from exposures to hazards before the control was installed. Effective controls will prevent new MSD cases from starting and reduce the reports of signs and symptoms. Depending on the type of work done, the number of cases may not really drop until 1 to 2 years after a control has been implemented.

Section 9: Communicate Results and Acknowledge Success

Good communication is important in preventing MSDs. Even well designed and implemented controls can be less successful than they should be if the communication is poor. Figure 9.0 outlines the key communication steps to consider for all such projects.

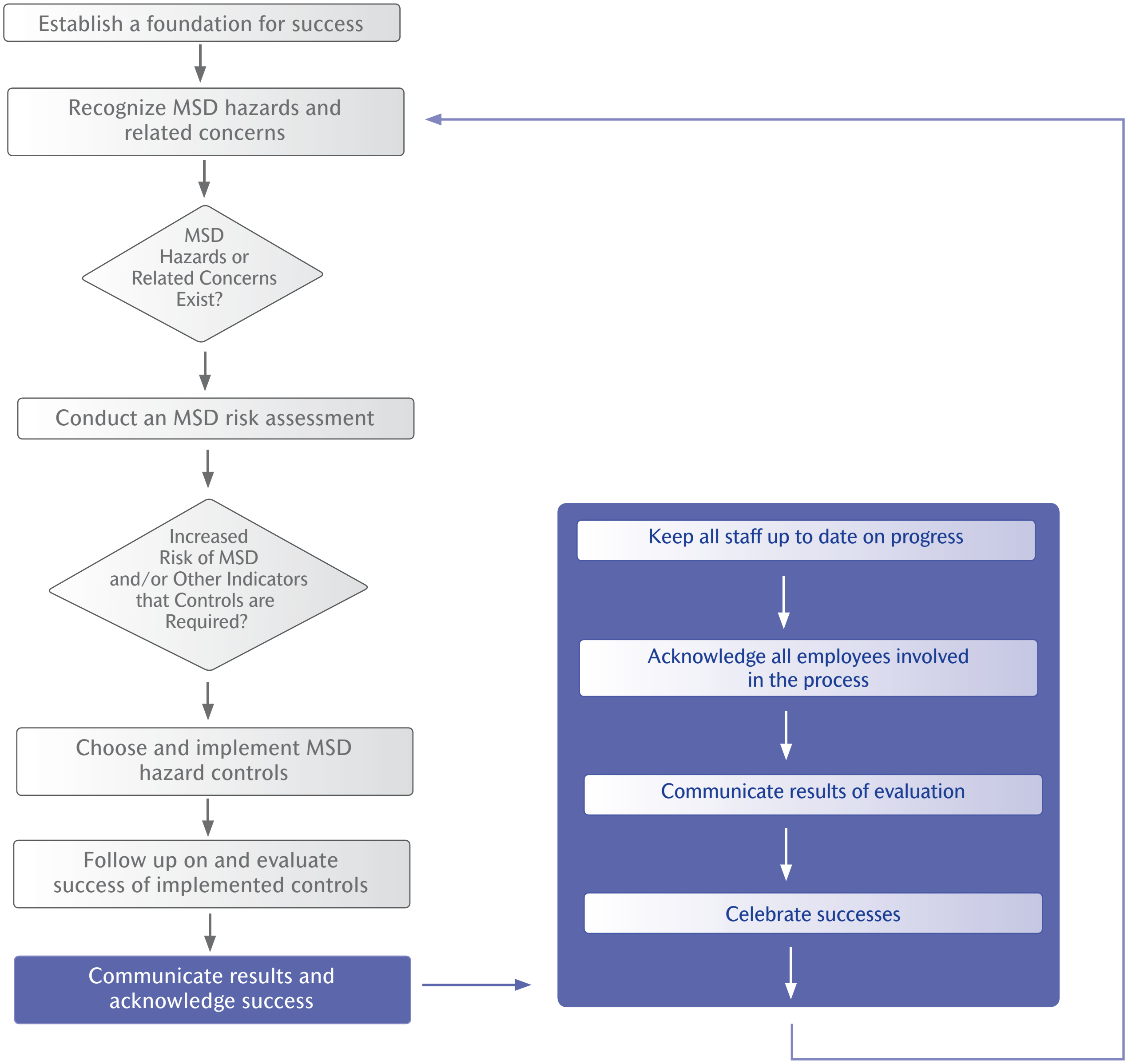


Figure 9.0: Communicate results and acknowledge successes

Keep All Workers Up to Date on Progress

Update all workers on the MSD prevention projects going on in the workplace. This will:

- show that MSD prevention is a priority for the workplace, and that real steps to address these hazards are being taken, and
- help to address any concerns of workers.

While all workers should be kept up to date, it is particularly important to ensure that the workers directly affected by the controls receive detailed information about how their jobs or work areas are affected. These workers may need more frequent and detailed updates to help manage their questions and concerns.

You can easily update workers by:

- discussing specific projects at regular crew or departmental meetings
- posting expected project timelines on departmental or work area bulletin boards
- posting updates on these bulletin boards and health and safety bulletin boards
- putting updates into workplace newsletters
- reviewing progress at JHSC and senior management meetings, and
- sending a broadcast email out to all workers.

Acknowledge Everyone Involved in the Process

When communicating information about any MSD prevention project, acknowledge everyone who was involved in the process. This recognition:

- shows these people that their participation and hard work are appreciated
- reinforces the commitment to MSD prevention, and
- motivates others to get involved in such efforts.

No matter how you recognize individuals for their work on MSD prevention, remember that:

- ideally, the recognition should be public and personal, and
- it can also be included and recorded in regular performance appraisals.

Communicate the Results of the Evaluation

After implementing and evaluating a control, you should let workers know the results of this evaluation. We suggest that you report the findings from all the evaluations.

When the outcome is successful, communicating the results of an evaluation reminds everyone that:

- changes have been made
- the workers' risk of MSD has been greatly reduced, and

- the success resulted from workers at all levels and departments working together to solve identified problems.

Letting workers know when a control is not considered successful is less easy but just as important. These outcomes should be acknowledged as learning opportunities. In addition, you can:

- indicate that you intend to continue looking for an effective control until success is found
- recognize the people who are working on the project, and
- offer continued support and resources to allow them to find a solution that will be a success.

Celebrate Successes

When a control does reduce exposure to MSD hazards and, possibly, improves other business performance measures, it is time to celebrate this success. The celebration can start by communicating the results of the evaluation (above). However, consider having a special celebration for your successful efforts. This will help to generate motivation and support for future MSD prevention efforts at all levels of the organization.

Appendices

MSD Prevention Glossary, Abbreviations and Acronyms

Resources

Selected Bibliography

Review Process

MSD Prevention Glossary, Abbreviations and Acronyms

Term	Definition
Administrative control	Work practices, work methods, policies and procedures established to reduce exposure to a work-related hazard (e.g., scheduling more breaks, job rotation, job enlargement).
Awkward posture	Any fixed or constrained body position that overloads muscles, tendons or joints. Generally, the more a joint deviates from the neutral position the more the posture is considered to be “awkward” and the greater the risk of injury.
Centre for Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD)	Funded by the WSIB of Ontario and the University of Waterloo, CRE-MSD conducts research to improve the understanding of and prevention of work-related musculoskeletal disorders.
Contact stress	Exposure of a body part to a hard or sharp surface or edge on a workstation or a hand tool (e.g., leaning forearms against the sharp edge of a desk).
Duration	The length of time a person performs a task or is exposed to a specific hazard without a rest period. Also, the amount of time during a shift a task is performed (e.g., 2 hours per shift).
Dynamic muscle work	Use of muscles to generate a force that causes the length of the muscle to change during the activity, resulting in motion around a joint.
Ergonomics	The scientific discipline concerned with understanding interactions between humans and other elements of a system (tools, equipment, products, tasks, environment) to optimize human well-being and overall system performance.
Force	The amount of effort exerted by your muscles.
Hazard	Any source of potential damage, harm or adverse health effects on something or someone under certain conditions at work.
Hazard identification tool (HIT)	A tool used to help identify MSD hazards in the workplace.
Health and safety representative (H&S reps)	A worker selected by the workers to represent them with the employer to resolve health and safety issues. They are required in workplaces with 5–19 workers.
Human (as used in the PEMEH process)	A human factor that can lead to an increased risk for workers performing specific jobs or tasks. To reduce the risk of MSD it is important to consider decisions made by humans, at all levels. For example, these decisions can result in: ■ poor workstation design ■ poor work organization ■ inadequate staffing levels ■ inadequate training, supervision and coaching ■ increased production pressures ■ differences in work methods or techniques ■ inappropriate responses to reports of MSD-related concerns, and ■ inconsistent use of equipment or controls that help to reduce MSD risk.

Internal responsibility system (IRS)	A health and safety philosophy based on the principle that every individual in the workplace is responsible for health and safety.
Institute for Work and Health (IWH)	An independent, not-for-profit research organization established in 1990 by the WSIB of Ontario. The Institute's mission is to research and promote: new ways to prevent workplace disability, improved treatment and optimal recovery and safe return to work
Joint health and safety committee (JHSC)	A forum where employer and worker representatives meet to identify and evaluate hazards and make recommendations to the employer on how to resolve them. A JHSC is legally required in most workplaces with 20 or more workers. Depending on the size of the workplace, at least 1 worker member and 1 management representative must receive additional training to become the "certified" members.
Musculoskeletal disorder (MSD)	Injuries and disorders of the musculoskeletal system. They may be caused or aggravated by various risk factors in the workplace. The musculoskeletal system includes muscles, tendons, tendon sheathes, nerves, bursa, blood vessels, joints and ligaments. MSDs do not include musculoskeletal injuries or disorders that are the direct result of a sudden, single event involving an external source (e.g., fall, vehicle accident, violence).
MSD-related concerns	Issues or concerns that may be related to MSD hazards and MSDs even if no formal reports of musculoskeletal disorders have been received from workers. These include: ▪ unreported pain and discomfort ▪ absenteeism due to unreported MSDs, and ▪ lower productivity and quality due to poor workplace design, high job demands or worker pain and discomfort, etc.
National Institute for Occupational Safety and Health	The federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness in the United States.
Neutral posture	The body position that minimizes stresses on the body. Typically the neutral posture will be near the mid-range of any joint's range of motion
Occupational Health and Safety Council of Ontario (OHSCO)	A group made up of senior representatives from the Ontario Ministry of Labour, WSIB, the Institute for Work & Health and all of Ontario's health and safety associations.
Process, equipment, materials, environment and human (PEMEH)	One way of categorizing the causes of hazards and/or looking at possible control options.
Personal protective equipment (PPE)	Hazard controls implemented at the worker such as head, eye or hearing protection.
Repetition	The number of similar exertions, actions or tasks performed in a specified amount of time.
Risk	The chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard. It may also apply to situations with property or equipment loss.

Risk assessment	The in-depth examination of the hazard once it has been identified. It involves measurement and assessment of the exposure variables to quantify the probability that exposure to the hazard will result in an MSD. Exposure variables include frequency, duration and magnitude.
Root cause	Underlying cause; an identified reason for the presence of a defect or problem. It is the most basic reason, which, if eliminated, would prevent recurrence.
Static work	A task where the worker needs to generate force in the muscles but there is no movement of the limbs or body.
Training	Any activity, session, event, etc., designed to provide information and/or instruction to workers and to verify that workers have understood and are able to use the information and/or instruction. Examples include: ■ crew meeting sessions ■ safety talks ■ computer-based learning ■ on-the-job demonstration(s) ■ leader-led in-class sessions, and ■ the provision of written materials with follow-up to ensure understanding, etc.
Workplace parties	Persons who have a role to play in ensuring health and safety in a workplace. They include: ■ employer ■ managers ■ supervisors ■ workers ■ JHSC or H&S rep, and ■ where applicable, the union(s) representing workers in the workplace.
Workplace Safety and Insurance Board (WSIB)	An agency of the Ontario provincial government dedicated to the prevention of all workplace injuries, illnesses and fatalities. It oversees Ontario's workplace safety education and training system and administers Ontario's no-fault workplace insurance for employers and their workers.

Resources

Ontario Health and Safety Associations
(http://www.preventiondynamics.com)

Construction Safety Association of Ontario
PHONE: (416) 674-2726
1-800-781-2726
http://www.csao.org

Education Safety Association of Ontario
PHONE: (416) 250-8005
1-877-732-3726
http://www.esao.on.ca

Electrical & Utilities Safety Association
PHONE: (905) 625-0100
1-800-263-5024
http://www.eusa.on.ca

Farm Safety Association
PHONE: (519) 823-5600
1-800-361-8855
http://www.farmsafety.ca

Industrial Accident Prevention Association
PHONE: (905) 614-4272
1-800-406-4272
http://www.iapa.ca

Mines and Aggregates Safety and Health Association
PHONE: (705) 474-7233
http://www.masha.on.ca

Municipal Health and Safety Association
PHONE: (905) 890-2040
1-866-275-0045
http://www.mhsao.com

Occupational Health Clinics for Ontario Workers
Toronto Clinic
PHONE: (416) 510-8713
1-888-596-3800
http://www.ohcow.on.ca

Ontario Forestry Safe Workplace Association
PHONE: (705) 474-7233
http://www.ofswa.on.ca

Ontario Safety Association for Community and Healthcare
PHONE: (416) 250-7444
1-877-250-7444
http://www.osach.ca

Ontario Service Safety Alliance
PHONE: (905) 602-0674
1-800-525-2468
http://www.ossa.com

Pulp & Paper Health and Safety Association
PHONE: (705) 474-7233
http://www.pphsa.on.ca

Transportation Health and Safety Association of Ontario
PHONE: (416) 242-4771
1-800-263-5016
http://www.thsao.on.ca

Workers Health and Safety Centre (WHSC)
PHONE: (416) 441-1939
1-888-869-7950
http://www.whsc.on.ca

Ontario Resources

Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD)
http://www.cre-msd.uwaterloo.ca/

Institute for Work and Health (IWH)
http://www.iwh.on.ca/

Ministry of Labour
http://www.labour.gov.on.ca/

Prevention Practices Database
http://www.preventionpractices.com/

Workplace Safety and Insurance Board
http://www.wsib.on.ca

Canada Resources

Canadian Centre for Occupational Health and Safety
http://www.ccohs.ca/oshanswers

WorkSafe BC
http://www.worksafebc.com

International Resources

European Agency for Safety and Health
http://europe.osha.eu.int

Health and Safety Executive (HSE)
http://www.hse.gov.uk

National Institute for Occupational Safety and Health
http://www.cdc.gov/niosh/

US Department of Labor, Occupational Safety and Health Administration (OSHA)
http://www.osha.gov

Professional Ergonomics Associations

Association of Canadian Ergonomists
http://www.ace-ergocanada.ca

Ergonomics Society
http://www.ergonomics.org.uk

Human Factors and Ergonomics Society
http://www.hfes.org

International Ergonomics Association (IEA)
http://www.iea.cc

Other Professional Associations

Canadian Association of Occupational Therapists
http://www.caot.ca

Canadian Chiropractic Association
http://www.ccachiro.org

Canadian Kinesiology Alliance
http://www.cka.ca/

Canadian Occupational Health Nurses Association
http://www.cohna-aciist.ca

Canadian Physiotherapy Association
http://www.physiotherapy.ca

College of Chiropractors of Ontario
http://www.cco.on.ca

Occupational Hygiene Association of Ontario
http://www.ohao.org

Ontario Kinesiology Association
http://http://www.oka.on.ca/

Ontario Occupational Health Nurses Association
http://www.oohna.on.ca

Ontario Physiotherapy Association
http://www.opa.on.ca

Ontario Society for Occupational Therapists
http://www.osot.on.ca

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Review Process

The Resource Manual for the MSD Prevention Guideline for Ontario (the Manual) will be regularly reviewed and modified in order to provide Ontario workplaces with information on new research findings, assessment methods, control approaches, etc. The review process is described below:

1) The Manual will be formally reviewed by a technical committee appointed by OHSCO every five (5) years from the date of publication. The committee will consider all received requests for modifications and the current state of research related to MSD prevention. The technical committee will make a recommendation to OHSCO to re-affirm or update the Manual.

2) If the recommendation is to update the Manual, the technical committee will meet to consider the specific changes to be made.

3) The recommended changes will be presented to OSHCO for approval. Once approved by OHSCO the recommended changes will be distributed to external stakeholders for comment.

4) After the comment period, the technical committee will meet to review all comments received and submit a final version of the updated Manual to OSHCO.

5) An early review of the Manual may be considered if information regarding new and well-supported research findings is received, and if the new research findings suggest that information in the Manual is not providing Ontario workplaces with a reasonable approach to MSD prevention.

6) The Chair of OHSCO will ensure that all comments or requests for modifications are reviewed on an annual basis.

7) All requests for changes or modifications to the Manual should be sent to:

By Canada Post: Chair of OHSCO
c/o Branch Secretary
Best Practices Branch
Prevention Division
11th Floor, WSIB
200 Front Street W.
Toronto, ON, M5V 3J1

By Email: prevention@wsib.on.ca

Please put "MSD Prevention Guideline c/o Best Practices Branch" in the e-mail's subject field.

RESOURCE MANUAL