A statistical model to estimate shoulder recovery time in highly repetitive work

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Abstract; Work related muscle-skeletal disorders (WMSD) have a huge impact in manufacturing industry. Global economy increases demand for goods manufactured on production lines, requiring day to day improved efficiencies, thus exposing workers to some WMSD risk factors. Recovery time for local muscular fatigue has been a control method to prevent such disorders. This work aims to present a statistical model to calculate recovery time considering personal and occupational variables instead of those biomechanical variables used in most of current models.

Practitioner Summary: This statistical model estimates recovery time within the cycle work in repetitive activities on industrial work, depending on personal and operational variables instead to rely on biomechanical models, thus pretends to made easy to attend the local muscular fatigue and prevent it effect on workers.

Keywords: Recovery time, risk factors, local muscular fatigue, statistical model.

1. Introduction

The twentieth century can be described, in the industrial environment, as the mass production growth and consolidation century, and automotive industry has been the engine of industrial economy, Womack et al (1992), names it “the industry of industries”. One important industry characteristic is the large number of people employed for assembly operations and by its component supplying associated companies.

To highlight the importance of automotive industry in job creation, a report by the International Labor Organization (ILO, 2000) using the example of France industry, establishes the relation of jobs created; the auto industry held 313,000 workers, with an extended impact on 773,000 jobs in the manufacturing industry. Even affected by economic crisis, automobile production keeps growing. Table 1.1 shows worldwide annual vehicle production. By 2013 there were 87,249,845 new manufactured vehicles all over the world, employing around ten million people (the figure corresponds to 39 countries). The International Organization of Motor Vehicle Manufacturer (OICA, 2014) estimated at 5\% the automotive industry participation in worldwide job creation. These data shows the magnitude of the manufacturing industry and its importance to the economy of countries.

Mexico is part of this scenario, with an annual production of 3,052,395 vehicles in 2013 and employing more than 140,000 direct jobs, ranking among the top productive countries. Using the OICA ratio, the estimated population employed by this industry has increased to 2.5 million people.

The automotive industry offers a glimpse to employment and manufacturing in general. This industry is relevant for study, as many of its tasks are done by hands as the main element implying displacement of upper extremities to generate assembling movements and to reach materials and tools.

Technology and industrialization progress has not stalled, Kumar (2001) mentions the influence of such processes in humans, as none of the body systems was meant to withstand occupational stress. Power demand, repetition activities or positions adopted during extended periods of stress on human physiological systems, is inherently unnatural. It concludes that, based on a complex multivariable system, there are vast opportunities for emergence of unexpected situations.
In an attempt to control this type of injuries, it is essential to understand them. Bernard (1997) refers to this type of damage as a situation related to the rise of industrialization in society, but it is up to the 70’s that these injuries causes were studied using epidemiological methods.

Figure 1.1. Worldwide production of vehicles. Source: International Organization of Motor Vehicle Manufacturer (OICA, 2013).

In Britain, Muggleton et al (1999) refers to work-related injuries as typical of the twentieth century and considered as the most frequent type of workplace health problems. For musculoskeletal injuries, those present in upper extremities are the most severe, second to back injuries. The origin of this disorder types is associated with industry demand to increase productivity, while the health services has increased awareness due to the rapid increase of disabilities and their impact on costs, medical care costs, disability pay, lost workdays, employee turnover and absenteeism indirect costs, including labor. It also deteriorates the morale of workers and decreases work quality. Emphasizes importance of prevention and awareness of employers and employees about problems caused by musculoskeletal injuries and the strategies to prevent them.

The European Agency for Safety and Health at Work (2010) report mentions that musculoskeletal injuries (WMSD) are related to repetitive work, identified as a cause in 60% of the cases. 30% of the WMSD are related to the shoulder-neck region. The WMSD can cost from 0.5% to 2% of countries GDP.

According to the Bureau of Labor Statistics (BLS) in 2005, the U.S. lost 1,234,700 work days. In the same study it reported 47,861 shoulder disorders and 92,576 disorders due to repetitive motion, 55% affecting wrist. For 2008, the BLS recorded 29% of injuries in workplaces were diagnosed as WMSD, involving an average of 10 lost days by injury, the incidence rate is 33 cases per 10,000 full-time workers. In South Korea, 82% of occupational injuries are related to the manufacturing industry, Kun et al (2010).

In 2012, the Instituto Mexicano del Seguro Social (IMSS, 2014) of Mexico reported 4,853 work related injuries, from those, 503 were classified as “enthensophaties”, 430 assumed shoulder injuries and 233 carpal tunnel syndrome, with most cases originatinated in industrial and manufacturing companies. In addition, there is a worrying trend in affected woman workers, and around 80% of these disorders were diagnosed in women. In recent years, number of cases is increasing. Female population employed by manufacturing industry, according to INEGI (2013) was 2,660,804 women in such jobs. Mexican government is now introducing a new federal normative focusing on detection of risks of muscle skeletal disorders and the actions to prevent it.
Summarizing, and according to Punnet and Wegman (2004), the WMSD are common in many countries, with significant costs and impact on quality of life. Although not solely caused by work, they constitute a significant proportion of all registered diseases and work-related compensable in many countries. Accurate data of incidence and prevalence of WMSD is difficult to obtain, and official statistics are difficult to compare between countries.

1.1 Fatigue and recuperation time.

Effect of fatigue on human activities has been studied for some time, and Rohmert (1973) has been established as the basic reference on the subject. Law and Avin (2010) refer to sports, exercising, rehabilitation and ergonomics research. In ergonomics, it is important to identify potential mechanisms or causes of injuries affecting workers quality of life and production optimization. Muscle fatigue is one of those processes identified as a potential cause of WMSD, involving task load and duration.

Likewise, Law and Avin (2010) mention endurance time or sustained maximum load (ET: endurance time) as a basic variable to quantify development of muscle fatigue. Intensity and holding time (ET) has been widely recognized as nonlinear. Interpretation of this relationship is used for relatively low-intensity activities that can be developed for long periods of time.

Muscle fatigue can result from static or dynamic work, Price (1990), differentiates these depending on load cycle frequency. Price mentions emergence of local muscle fatigue when moderated energy loads are located in muscle groups.

Fatigue has been associated with physical activity and work is physical activity. Santy and Duwal (2010) found that fatigue occurs when performing either light or heavy duty work. Specific mention of fatigue as a cause of injury is not scientifically proven. However, many researchers believe that a fatigued muscle is more prone to injury. There is a scarcity of fatigue definitions and lack of consensus on the issue. They conclude that fatigue effects can be mitigated more effectively reducing the daily work. Reduction of daily work allows workers time to relieve muscle fatigue.

For fatigue and work design, Wiker et al (1990) found that dominant sustained periodic elevations of upper extremities above shoulder level caused discomfort and fatigue in light manual work and low level effort demands. They mention that work requiring hands elevation above the head should be avoided even in light work.

Development of models to estimate fatigue and recovery times is based on calculation of maximum resistance (MET) based on maximum voluntary contraction (MVC). Several models focus on obtaining the time before fatigue using MET. There are few models aimed at recovery time calculation. Rohmert curves (1973) are used in virtually all models for estimations.

Rohmert (1973) curves to determine the exposure times assume efforts below 15% MVC can be repeated without any restriction, not producing fatigue. This suggests that the light work, for example manual assembly produces no physical fatigue. This assumption motivated the search for fatigue prediction models for these jobs. Mathiassen and Åhsberg (1999) propose a model in addition to the MVC based on age and gender,

\[ \ln T_{lim} = \beta + \beta G + A \ast M + \beta + \beta GA \ast GM + \beta AM \]

Where G is gender, A is age and M is MVC. After final model statistical analysis, \( \ln T_{lim} = 3.704 - 0.097M \). Expressed linearly, the model is; \( T_{lim} = 40,609 \ast e^{-0.097M} \).

In the final expression we notice strength as the significant factor. This text makes a strong criticism of the formula application in the sense Rohmert 15% MVC mentioned in the previous paragraph.

The Rohmert formula appears in Garg et al (2002) noting that the MET calculations are over estimated for % MVC <45% and sub estimated for %MVC > 45%. Abound on 15% MVC arguing that for 5% MVC subjects appear unable to indefinitely sustain effort. The study tested for different shoulder and elbow flexion angles for
different % MVC for MET. The formula used is: \( \text{METime} = 43.44 \times (\% \text{ MVC}) -0.9027 \) and statistical analysis mentioned a coefficient \( r^2 = 0.8824 \).

In the same way, El Ahrache et al (2006) has developed a model to calculate MET for a given percentile. The following equation is proposed:

\[
\text{MET}_{p_{50}} = e^{[\ln \text{MAT}_{\text{mo}} + \text{p}_{50} + \ln(\text{MET}_{\text{MEDIA}} + c \times \text{MET}_{\text{MEDIA}})]}
\]

When applying this equation results represent the maximum time, in minutes, for different values of resistance of % MVC. The model can be generalized to different human body parts. For example, the average time for the 10% MET shoulder MVC is 17.75 minutes. For 15% MVC average time is 9.19 minutes.

In El Ahrache et al (2006), part of its analysis also considered models and Mathiassen and Åhsberg (1999) and Garg et al (2002) model: Sato (1984); \( 0.398 \times \text{fMVC}^{1.29} \) and Rohmert FMVC (1986): \( 0.2995 \times \text{fMVC}^{1.65} \). It has been mentioned that the formulas can be applied to different human joints.

Rose et al (2000) designed the model for the shoulder, and its adaptation is: \( \text{MET} = 20.6 \times e^{-6.04Mn} \), where Mn is the resultant moment in elbow joint. Alternatively proposes a model to calculate task resumption time. This is the rest time period between tasks. This is different to the concept of recovery time. The resume time is given by:

\[
\text{Tr} = 0.0167 \times e^{8.64/(1.46+0.346Mn)} \]

where \( Mn \) is the resultant moment.

López Millán (2013) found a statistical model that estimates recovery time for shoulder, it does not require physical calculations, but some personal and operational variables; gender (0 for women and 1 for men), height (in centimeters), weight (in kilograms), effort time (sustained posture on the shoulder, in seconds), force (usually tools or materials weight). The statistical model is:

\[
\text{RT}=e^{-8.27-2.06 \text{Gender}+0.375 \text{Efforttime}+0.0318 \text{Force}+0.0284 \text{Height}+0.0116 \text{Weight}}
\]

Where RT is recovery time, in seconds, needed by the shoulder to minimize the local fatigue. The point here is that recovery time could be combined with productive time, this is, recovery time is a lapse of time while shoulder is in neutral posture, may be a flexion less than 45 degrees respect the vertical. The model was developed using lineal regression and values for coefficients were \( r=0.972 \) and \( r^2=0.946 \), meaning that there is a small variation percentage unexplained for the model.

Fatigue is a common phenomenon in industrial work and although there is no evidence of relationship with WMSD, it was deemed important in MET studies and maximum endurance time. Most MET models are based on percentages of maximum voluntary contraction % MVC. In reviewed literature only Rose et al (2000) used different concepts. Considering the background, this work aimed to develop a statistical model through a set of variables and their relationship with fatigue and recovery times, in this case, for the shoulder muscle group.


Shoulder recovery time calculation will be made using the statistical model in López Millán (2013). The result on recovery time are based on Rohmert (1973) formula, but the procedure to obtain it is different. There is no need to calculate neither shoulder momentum nor maximum voluntary contraction (MVC), which is not necessary easy to obtain. We just need general data for people, gender, height, weight, effort time and exerted force. Recovery time is calculated as follow:

Obtain data corresponding to each subject; gender (0 for woman or 1 for man), height on centimeters and weight on kilograms. Observe a task and take time, in seconds, for shoulder sustained posture and measure weight (lb) for tool or materials or insertion or force, push or pull. The later can be obtained using a dynamometer.

Substitute each data on the following regression equation:

\[
\text{RT}_{LR} -8.27-2.06 \text{Gender}+0.375 \text{Efforttime}+0.318 \text{Force}+0.0284 \text{Height}+0.0116 \text{Weight}
\]

Once the recovery time for linear regression is calculated, use the result as exponent for \( e \) number. This can be performed with a scientific calculator or using a Microsoft® Excel® function. The final result is expressed in seconds and it means the time lapse the shoulder needs on neutral position for every minute of work.

For instance, consider a woman 164.5 cm tall and 63.5 kg performing a task including a shoulder elevation for 6 seconds with fully extended arm using a 5 lb pneumatic tool. First introduce data on equation 1

\[
\text{RT} = -8.27 -(2.06 \times 0)+(0.375 \times 6)+(0.318 \times 5)+(0.0284 \times 164.5)+(0.0116 \times 63.5)=0.9784 \text{ sec}
\]
Then introduce result from equation 1 as the exponent for the e number:

\[ RT_n = e^{0.9784} \quad \text{or} \quad RT_n = 2.66 \text{ sec.} \]

This means that for every 6 seconds of shoulder elevation carrying a 5 lb tool, there should be 2.66 seconds for recovery time. The recovery time could be within the repetitive task in a minute cycle time but in a shoulder position with an angle lower than 45 degrees to trunk.

The model is sensible to the difference between women and men on recovery time. If data for the last example is used with a gender change, the result is as follow:

\[ RT = -8.27 - (2.06 \times 1) + (0.375 \times 6) + (0.318 \times 5) + (0.0284 \times 164.5) + (0.116 \times 63.5) = -1.081 \text{ sec} \]

Introducing the result from equation 1 as the exponent for the e number:

\[ RT_n = e^{-1.081} \quad \text{or} \quad RT_n = 0.34 \text{ sec.} \] It means there is almost not recovery time necessary for men.

2.1 Model development procedure.

66 records from automotive industry anthropometric database were randomly selected, although the number of measures per record is extensive, they were selected for project model research purposes in correspondence to defined personal variables, these are: age, sex, height and weight. The rest of the variables were defined in the previous section. The sample size is the number of workstations that could be analyzed. 38 workstations were analyzed and some modifications were derived, for example height variation to calculate the shoulder angle, variations in strength or time spent in static postures.

Data was analyzed by multiple lineal regression, after several trials, coefficients were not strong enough to obtain the model, so, assuming the recovery time as lognormal distribution data, different models of response variable transformation were tested. The variable is transformed directly using the natural logarithm provided data to test the new multiple linear regression model. The regression model for transformed data is summarized in the following equation. Under the model variables elimination assumption, the same independent variables were chosen for analyzing the transformed data.

\[ \ln RT = -8.27 - 2.06 \times \text{Gender} + 0.375 \times \text{Effort time} + 0.318 \times \text{Force} + 0.0284 \times \text{Height} + 0.0116 \times \text{Weight} \]

The values for the test were: \( r = 0.972, r^2 = .946 \) and \( r \text{ adjusted} = 942 \). The relationships value between variables is deemed as excellent. Variables explain almost all of the model variation. Of course, it is very difficult to create a perfect model, for this reason a percentage of 5.8% of unexplained variation is highly convenient and leads to the conclusion that model's ability to estimate recovery time is very accurate. Assumptions in the model were verified in detail and tested for conditions of linearity, independence and residual normality.

3. Conclusions.

Risk factors for occurrence of Work Related Muscle-Skeletal Disorders (WRMSD), are well known, such as an awkward posture, basic shoulder elevation, repetition rate for awkward posture and the posture hold time, Bernard et al (1997), Sommerich et al (1993) are in concordance with the risk factors, but they included insufficient recovery time as a risk factor too, especially for long term exposure. Experience has shown the importance of keeping risk factors within control to decrease the rate of disorders and consequently lower the lost days and the cost of injuries.

The statistical model proposal is intended to become and additional tool for ergonomists to simplify recovery time calculations from physical variables such as moment and maximum voluntary contractions to personal and operational variables with an easy procedure to get recovery time referred to a 60 seconds cycle time.

Additionally, the local muscular fatigue concept is considered, introduced by Chaffin et al (1999), the recovery time is a factor to minimize muscular fatigue and consequently reduce the risk of an WRMSD without the need to supply additional recovery time, converting recovery time on a double added value, to reduce the risk in the first place and by allocating recovery within the cycle time.

The delimitation of the variables is for occupational variables, the times correspond to a static posture duration worth at least three seconds to a maximum of eleven seconds. For effort, the model was tested with a minimum of four pounds and a maximum of thirteen pounds. Working posture was considered as worker standing.
The characterized repetitive work model does not consider job rotation and assumes permanence of worker in the tested workstation. It is relevant to note that several types of working postures were considered. The model was tested for shoulder bending angles in a minimum of 50° to a maximum of 113°. These values are consistent with those seen in the literature for blood flow restriction.

A statistical model has been obtained to estimate shoulder recovery time without the need to use difficult to determine complex variables such as maximum voluntary or maximum force of contraction resistance.

Visiting companies to obtain basic data analysis attached to real working conditions has been paramount for model development. Observation of the amount of activities involved to get results has been a pleasant activity, enabling involvement in the context of the production lines and workstations, people relying on academic work with the expectation of encouraging results, in the hope that someday the job can be more bearable, fatigue free, less routine based, more human.

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