The influence of information presented on digital escape route signage on decision-making under mentally and emotionally strenuous conditions

Sonja Th. Meier, Jennifer Bützler, Christopher M. Schlick

Chair and Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, GERMANY

While passenger numbers on cruises are rising continuously, it is still impossible to fully rule out technical failures and events of disasters. Innovations from the digital age enable fast adaptation to complex situations in emergencies, for instance by networked, digital emergency signage for adjustments of escape routes according to the specific emergency conditions. Trust in the displayed, possibly changed escape routes despite potential social and familiarity influences is crucial to prevent crossing passenger streams and clogging of escape routes. An experimental study was conducted to identify the key information to be presented on digital emergency signage in order to inspire trust. Participants processed decision-making tasks for directions under three conditions with different stress levels. Results provide statistical evidence that temporal update information on emergency signage is most trust inspiring and significantly influences decisions for directions also in conditions with high stress levels. Decisions and reaction times highly depend on the timeliness of update information while total fixation times mostly depend on the complexity of the presented information. In conclusion, digital escape route signage with evidence for a recent update can prevent merging and crossing passenger streams and thereby enhance safety.

Practitioner summary: An evacuation on a cruise with thousands of passengers is a frightening situation. People tend to follow familiar routes and people. In cases of disaster, such as fire conditions, this behaviour might be fatal. Our study revealed that digital emergency signage is most trusted when it has recently been updated. These findings need to be considered in the design and implementation of escape route signage systems for passenger ships and other highly crowded domains to prevent wrong direction choices and clogging of escape routes.

Keywords: escape route signs, trust, decision-making, evacuation, safety

1 Introduction

Modern cruises cover up to 6,000 passengers and 1,000 crew members. Therefore, new concepts and technological solutions for evacuations are needed to ensure safety because technical failures and events of disasters can never be completely excluded. Adequate emergency signage is a key factor to aid passengers to orientate and to decrease evacuation time (Tang et al. 2009, Bode et al. 2014). Digital, networked emergency signage offers the advantage of easy and centralised updates to adapt escape routes to guide passenger flows to muster stations under all emergency conditions. However, decision-making is influenced by various aspects such as social influences (Kinateder et al. 2014), familiarity with places (Affiliation Theory, Mawson 2005, Mawson 2012) and, in specific, the familiarity with emergency exits (Sime 1983, Johnson 2005). The tendency to follow these cues is likely to interfere with emergency signage in cases, in which others than the standard escape routes known from evacuation exercises, are needed. Consequently, trust in digital emergency signage is crucial.

Moreover, time is a limiting factor in emergency situations and stress enforces automated behavioural patterns (Porcellini and Delgado 2009) and evokes rash decisions (Keinan et al. 1987, Stankovic et al. 2014). In contrast, human information processing efficiency decreases under anxiety according to the Attentional Control Theory (ACT, Eysenck et al. 2007) based on the Processing Efficiency Theory (PET, Eysenck and Calvo 1992) suggesting a conflict in time spent on decisions in safety-critical situations. Furthermore, attention is biased due to anxiety induced selective information processing (Mathews 1990, Mathews and MacLeod 1985, Mogg et al. 1997).

Thus, on the one hand, information on digital escape route signage needs to be short and easy to process considering human decision-making under stress. On the other hand, emergency signage needs to
inspire trust in order to influence the decision in the correct direction against potential social and affiliative influences. Otherwise, merging and crossing passenger streams might occur causing clogging of escape routes intensified by highly non-cooperative behaviours in high stress conditions (Dias et al. 2013).

This paper presents the findings of a study, in which the influence of additional information presented on escape route signage on decision-making under emotionally and mentally strenuous conditions was investigated. Three levels of induced stress were realised by variations in time limit, visual and acoustic stressors. Differences in the perceived stress levels were evaluated by psycho-physiological and subjective measures for mental effort and state anxiety. The dependent variables were the decisions for directions, reaction times and total fixation times.

2 Method

2.1 Design

The experimental design was based on a full factorial design. In three permuted stress conditions, every participant processed the same decision-making tasks for directions as the same ten specifications of escape route signs were tested against each other in form of randomized pairs with opposite directions (see Figure 1). Hence, the ten specifications resulted in a total of 90 pairs and, correspondingly, 90 decisions per condition including the laterally traversed equivalents.

Each sign showed the standardised escape route sign according to DIN EN ISO 7010:2011. Nine of the ten sign specifications included additional information of one information type: a degree of timeliness, the responsibility for the last update, with or without a photograph, the banned opposite escape route, with or without a danger sign for fire, or the reason for the evacuation, with or without a warning sign (see Table 1). These visual stimuli were shown on a 22’’ TFT monitor. A white dot, presented in the centre of the monitor for 500 ms, ensured a neutral eye scan starting point between the stimuli. Eye movement data was recorded with SMI RED 250 Hz.

Table 1. Additional information on the escape route signs, translated from German.

<table>
<thead>
<tr>
<th>Information type</th>
<th>Additional information expressions of the type used in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timeliness</td>
<td>“Last updated: 10 seconds ago” “10 minutes ago” “10 hours ago”</td>
</tr>
<tr>
<td>Responsibility for the last update</td>
<td>“Last updated: by captain Martin Wegner” (typical German name) with photograph</td>
</tr>
<tr>
<td>Banned opposite escape route</td>
<td>Prohibition sign on greyed-out standardised escape route sign with danger sign for fire</td>
</tr>
<tr>
<td>Reason for the evacuation</td>
<td>“Reason for the evacuation: Technical problems in the engine rooms” with warning sign from traffic</td>
</tr>
</tbody>
</table>
The three stress conditions varied in applied visual and acoustic stressors and time limit (see Table 2). Visual stressors for conditions B and C were seven horizontally balanced photographs of indoor evacuation situations, presented between the escape route pairs for 500 ms in randomised order. The acoustic stressor was an audio file with one minute of incomprehensible mumbling, arranged in a loop and played during conditions B and C. For this purpose, two external loudspeakers were placed at either side of the monitor.

Table 2. Applied stressors in the permuted stress conditions A, B and C.

<table>
<thead>
<tr>
<th>Stressors</th>
<th>Condition A</th>
<th>Condition B</th>
<th>Condition C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time limit</td>
<td>none</td>
<td>none</td>
<td>2000 ms</td>
</tr>
<tr>
<td>Visual and acoustic stressors</td>
<td>none</td>
<td>photographs of evacuations within ships and mumbling (60-70 dB(A))</td>
<td></td>
</tr>
</tbody>
</table>

Levels of induced mental and emotional stress were evaluated by objective data, i.e. saccade numbers and lengths, as well as by subjective data, i.e. mental effort and state anxiety. Decisions for directions, i.e. left or right escape route, reaction times and total fixation times were considered as dependent variables of the three stress conditions and the presented additional information.

2.2 Participants

A total of 24 participants (12m, 12f) with an average age of 26.88 years ($SD = 4.37$) volunteered for the study without payment. No participant violated the minimum boundary for visual acuity of $\geq .8$ or suffered from a red-green color-deficiency. The results from the Edinburgh Handedness Inventory from Oldfield (1971) showed that 50% of the participants were clearly right-handed (score above 80). The questionnaire results of the other participants were ambiguous.

2.3 Procedure

At the beginning of each trial participants confirmed informed consent and fulfilled a short questionnaire about demographic data. A standardised instruction was read to the participants in which they were asked to place their index fingers on marked keys on a keyboard with arrows to the left and to the right in the shape of the arrow according to DIN EN ISO 7010:2011 and to keep their fingers in that position during each condition in the experiment to receive precise reaction times without influences of finger or hand movements. They were instructed to decide spontaneously via keystroke for a direction at each displayed sign pair according to their trust in the presented escape route signs. Each condition started with calibration of the eye tracking software and two examples of escape route pairs that were not part of the experiment. After each condition the participants rated mental effort (RSME, Zijlstra 1993) and state anxiety (MRF, Krane 1994, Murphy et al. 1989) and reported their subjective impressions in a short interview.

2.4 Data analysis

IBM SPSS Statistics Version 21 was used for statistical analyses and visualisations. Data for mental effort, state anxiety, decision numbers, reaction and total fixation times were not normally distributed. Hence, non-parametric tests such as the Wilcoxon signed-rank test and the Friedman test were applied. Reaction and total fixation times were considered as dependent variables of the three stress conditions and the presented additional information. Time was not limited in stress condition A and B. As a consequence, especially in these stress conditions, means for reaction and total fixation times were likely to be overly influenced by times that were caused by participant distraction or by eye tracking problems, e.g. because of contact lenses. Therefore, extreme values more than three standard deviations above the mean reaction or total fixation times, calculated separately for each escape route sign in each stress condition, were removed.
3 Results

3.1 Mental effort and state anxiety

Conditions B and C with visual and acoustic stressors (and time limit) were perceived more emotionally and mentally strenuous. The Wilcoxon signed-rank test indicated significant increases in state anxiety ($Z_{AB} = -3.07, p_{AB} < .01, \phi_{AB} = .63, Z_{AC} = -3.23, p_{AC} < .01, \phi_{AC} = .66$) and mental effort ($Z_{AB} = -2.44, p_{AB} < .05, \phi_{AB} = .50, Z_{AC} = -3.71, p_{AC} < .01, \phi_{AC} = .76$) resulting also in psycho-physiological effects such as significantly increasing saccade numbers from condition A to C ($t(22) = -2.27, p < .05, r = .44$) and significantly decreasing saccade lengths ($t(22) = 4.16, p < .01, r = .66$).

3.2 Decisions

The decision numbers as indicators for trust in an escape route sign are shown in Figure 2, differentiated according to the ten escape route sign specifications and the three stress conditions.

Information on timeliness had the strongest effect on decisions. The decision numbers in favour of signs with the last update 10 seconds or 10 minutes ago were significantly higher than for standard signs without additional information over all stress conditions. Moreover, the decisions highly depended on the timeliness level, indicated by large effect sizes (see Figure 2 and Table 3).

![Figure 2](image)

**Figure 2.** Means of decision numbers for directions according to an escape route sign with 95%-CI. Marked decision numbers are significantly different from the standard escape route sign, round brackets mark significant differences between levels within an information type, indicated by the Wilcoxon signed-rank test, *$p < .05$, **$p < .01$, ***$p < .001$.

**Table 3.** Comparisons of the decision numbers for the standard sign and signs with timeliness information and of decision numbers between timeliness levels, by the Z-score of the Wilcoxon signed-rank test and its effect size $\phi$.

<table>
<thead>
<tr>
<th>Condition</th>
<th>&quot;10 seconds ago&quot;</th>
<th>&quot;10 minutes ago&quot;</th>
<th>10s against 10min</th>
<th>10min against 10h</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard sign</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>without</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stressors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Condition A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without stressors</td>
<td>-3.674***</td>
<td>-2.889**</td>
<td>-2.819**</td>
<td>-3.860***</td>
</tr>
<tr>
<td><strong>Condition B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>with vis./ac. stressors</td>
<td>-3.167**</td>
<td>2.005*</td>
<td>-2.014**</td>
<td>-3.532***</td>
</tr>
<tr>
<td><strong>Condition C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>with vis./a. s. + time limit</td>
<td>-3.627***</td>
<td>-2.407*</td>
<td>-3.690</td>
<td>-2.910***</td>
</tr>
<tr>
<td><strong>Comparisons between levels of timeliness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*$p &lt; .05$, **$p &lt; .01$, ***$p &lt; .001$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.3 Reaction times

The reaction times of decisions are shown in Figure 3. The applied time limit of two seconds in condition C led to significant decreases from the reaction times in conditions A and B for all escape route signs. The lowest reaction times were found for the standard escape route sign without additional information with an average mean over the three stress conditions of $M = 1.109$ seconds ($SD = 0.532$), followed by the escape route sign with the timeliness information "Last updated: 10 seconds ago" ($M = 1.139 , SD = 0.570$).

While there were no significant differences in the reaction times between a standard sign and a sign with the additional information "Last update: 10 seconds ago", the reaction times for signs that were last updated 10 minutes or 10 hours ago were significantly higher than the reaction times for the standard sign with rising effect sizes $\phi$ from condition A to condition B and C. These results suggest that the time since the last update is positively associated with the reaction time (see Figure 3, Table 4).

Table 4. Comparisons of the reaction times for displays including the standard escape route sign and for displays including signs with information about timeliness of the last update, by the reaction times (RT), the $Z$-scores of the Wilcoxon signed-rank test (comparison to standard sign) and its effect size $\varphi$.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Standard sign</th>
<th>Standard sign against “Last updated:”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>without add. inf.</td>
<td>“10 seconds ago”</td>
</tr>
<tr>
<td>Condition A</td>
<td>RT (SD) [s]</td>
<td>1.253 (0.612)</td>
</tr>
<tr>
<td>without stressors</td>
<td>Z</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$\varphi$</td>
<td>-</td>
</tr>
<tr>
<td>Condition B</td>
<td>RT [s] (SD)</td>
<td>1.196 (0.577)</td>
</tr>
<tr>
<td>with vis./ac. stressors</td>
<td>Z</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$\varphi$</td>
<td>-</td>
</tr>
<tr>
<td>Condition C</td>
<td>RT [s] (SD)</td>
<td>0.885 (0.265)</td>
</tr>
<tr>
<td>with v./a. s. + time limit</td>
<td>Z</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$\varphi$</td>
<td>-</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001

Reaction times for escape route signs with additional information about the responsibility for the last update and about the reason for the evacuation were significantly higher than the reaction times for standard escape route signs without additional information over all stress conditions and independent from additional
photographic or symbolic elements on the display (see Figure 3). In contrast, the reaction times for signs showing a banned opposite escape route were not significantly different from the reaction times for standard signs.

3.4 Total fixation times

The total fixation times in areas with additional information are shown in Figure 4, differentiated according to the escape route sign specifications and the three stress conditions.

Figure 4. Means of total fixation times in areas with add. information, in seconds with 95%-CI. Marked total fixation times are significantly different from total fixation times for timeliness information, round brackets mark significant differences between levels within an information type, indicated by the Wilcoxon signed-rank test, *p < .05, **p < .01, ***p < .001.

In line with the unaffected complexity of temporal update information by changing the degree of timeliness, no significant differences in the total fixation times in areas with timeliness information were found depending on the three levels of timeliness differentiated by the stress conditions A, B and C, indicated by the Friedman test, \( \chi^2(2) = 0.078 \) to 1.493, \( p \geq .474 \). Taken together with the higher reaction times for less recent updates, participants spent a lower proportion of their reaction time fixating timeliness information, the longer the last update had been ago (see also Figure 3).

The total fixation times in areas with information about the responsibility for the last update were significantly higher than the total fixation times for timeliness information in every stress condition and independent from inclusion of a photographic element (see Figure 4). However, there is still a significant reduction in the total fixation times when the responsibility for the last update is supplemented by a photo of the responsible person in stress conditions A \( (Z = -2.405, p < .05, \varphi = .116) \) and C \( (Z = -2.816, p < .01, \varphi = .135) \).

The total fixation times for banned opposite escape routes did neither significantly differ from the total fixation times for information about timeliness nor depended on the inclusion of a fire symbol.

The total fixation times for information about the reason for the evacuation were significantly lower than for information on timeliness, except in stress condition A without a warning sign in the reason area. A highly significant reduction in total fixation time was found in stress condition A when a warning sign was included, with a moderate effect size \( (Z = -5.580, p < .001, \varphi = .271) \).
4 Discussion

An experimental study was conducted in order to systematically investigate the influence of information presented on digital escape route signage on decisions for directions, reaction and total fixation times under different stress levels.

Psycho-physiological reactions, i.e. changes in saccade numbers and lengths, as well as ratings on mental effort and state anxiety provided statistical evidence that higher levels of stress were experienced in conditions B and C with visual and acoustic stressors (and time limit) than in condition A without stressors and without time limit. Furthermore, the reaction times in condition C were significantly lower than the applied time limit. This behaviour suggests that a high level of stress was experienced resulting in rash decisions in accordance with the findings of Keinan et al. (1987), Porcellini and Delgado (2009) and Stankovic et al. (2014) superimposing potential effects of decreasing information processing efficiency in anxiety states according to the Attentional Control Theory (ACT, Eysenck et al. 2007) based on the Processing Efficiency Theory (PET, Eysenck and Calvo 1992).

The largest effect on decision-making was found for temporal update information on emergency signage over all stress conditions. However, it should be noted that the influence of update information strongly depends on its timeliness. In line with the dependence of decisions on the level of timeliness, significant increases in reaction times were found for signage that stated to be last updated 10 minutes or hours ago contrary to the short reaction times for signage that had been updated 10 seconds ago. However, the total fixation times did not significantly change in dependence on the level of timeliness, suggesting the dependence on the information complexity.

The investigation of the reaction and total fixation time results for signage with additional information regarding the responsibility for the last update revealed the interesting effect of shorter reaction and total fixation times, i.e. shorter perception and processing times, when the textual information is accompanied by a photograph.

The results for signs with additional information about the evacuation reason suggest that visual attention was influenced by the relation between evacuation stimuli in the stress conditions B and C and the threat related warning sign. The total fixation times were found to decrease in condition A when a warning symbol was included, whereas the total fixation times were stable in conditions B and C, meaning that participants were prevented from rash decisions by the inclusion of a warning symbol. These findings are in accordance with previous work on attention biased by threat cues (Mathews 1990, Mathews and MacLeod 1985, Mogg et al. 1997).

Similar results were expected for signage with banned opposite escape routes and an additional danger sign for fire but not found, which might refer to the perceived high complexity of this information, which was reported in the short interviews after each condition. As a consequence information about banned opposite escape routes might not have been considered for the decisions, which is supported by the similarity of decision numbers and reaction times with standard signage without additional information.

Validation of the results by a realistic field study is desirable though unethical as also stated in other related scientific work, such as in Bode et al. (2014). However, the realisation of three different conditions varying in emotional and mental effort, which was confirmed by psycho-physiological and subjective data, allowed deducing important recommendations also for situations of high perceived stress levels.

5 Conclusion

Update information on escape route signage was revealed to be a key factor for inspiring trust and thereby influencing decision-making for directions. Escape route signs presenting their timeliness have a higher influence on decision-making over standardised signage without additional information and other potential information such as the reason for the evacuation. These effects were stable over the different stress conditions, i.e. update information still determines decisions under conditions with high stress levels. These findings need to be considered for future designs of digital escape route signs not only on cruises but also in other domains such as airports and large buildings as the choice for a direction is critical in emergencies to prevent clogging of escape routes and to save lives.
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References


