Form of anticipated information that supports resilient operations in Safety II systems

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We investigate whether safety II systems can be enhanced by focusing on system side interface design requirements, i.e., the form of offered anticipated information. We focus on “anticipating” as a factor that can increase resilience when workers are faced with varying circumstances. We conducted experiments and performed evaluations using task performance and physiological measurement. Our experimental results indicate that a safety II system can be enhanced by offering forms of anticipated information that enhance resilience.

Keywords: safety I, safety II, resilience, interface design

1. Background & Objectives

Conventionally, “safety” is simply defined as “conditions under which problems do not happen.” Therefore, operating procedures are established to ensure that problems are avoided as much as possible (safety I) (Hollnagel, 2011). It is appropriate to apply this concept when conditions are stable and management ensures that acceptable levels of risk are maintained and standard operating procedures are followed, e.g., producing parts on an assembly line. However, in some situations such conditions cannot be assumed. Therefore, a new concept of safety (safety II) that targets large-scale and complex systems, such as air traffic control and medical environments, has been proposed. Safety II is defined as a system’s ability “to succeed under varying conditions. (EUROCONTROL, 2013)” In safety II systems, flexible (resilient) human (or organizational) responses to varying situations are key. Hollnagel et al (2011) proposed a resilience analyses grid (RAG) to evaluate attributes that characterize circumstances in which workers (team) can respond flexibly. In the RAG, responding, monitoring, anticipating, and learning are resilience characteristics. We considered that the effectiveness of safety II systems can be enhanced by educating workers and fostering a supportive organizational culture.

In this study, we focused on whether safety II system design can improve human (or organizational) responses. It is suggested that appropriate anticipation can help workers prepare for changing circumstances. (Hollnagel, 2011) The purpose of this study is to clarify safety II system requirements, particularly the design requirements of the interface for the form of offered anticipated information. In this study, we verified experimentally that the resilience of human and safety II of human–system can be enhanced depending on how a system provides anticipated information.

2. Method

2.1 Experimental Task

The experimental task assumed that conditions are unstable, i.e., disturbances can occur and situations change constantly. In this experiment, subjects performed specified operations (click operations) on blocks dropped from the top of a PC screen. Figure 1 shows an example of the experimental display. The appearance frequency of the blocks varied and the required number of operations displayed in each block differed. In addition, the required number of operations increased, i.e., conditions deteriorated. Therefore, subjects were required to change operational strategies relative to the number of blocks and the urgency of the conditions. Blocks on which the required number of operations had been performed were removed from the screen. Here, the first objective was to ensure that no block reached the bottom of the screen before the number of operations displayed in the block was completed. Note that blocks that reached the bottom of the
screen represented accidents. If this occurred, the task terminated immediately. The second objective was to perform the required operations as quickly as possible, i.e., avoid near misses. The third objective was to perform extra operations to improve the condition of each block (i.e., improve quality) if there was sufficient capacity. The time allotted for one task was 5 minutes.

Figure 1. Experimental display.

2.2 Experimental Conditions

Considering a basic tradeoff, such as Efficiency–Integrity and Short-term–Medium or Long-term, is fundamental to analyzing the form of anticipated information effectively. In addition, the importance of the method by which the information is obtained has also been discussed. (Csete & Doyle, 2002; Woods, 2006) Based on these previous findings, the form of the anticipated information (the number and status of the next blocks) was varied in our experiment.

1) [Acquiring the information]: Should operators receive anticipated information passively or actively? (Fig. 2)
2) [Short-term–Medium or Long-term tradeoff]: How long after information should operators receive the anticipated information? (After One, or After Two, or After Three) (Fig. 3)
3) [Efficiency–Integrity tradeoff]: How much information regarding probability should operators receive? Should operators receive only information about the highest probable possibility or all possibilities (Fig. 4)?

In addition, an experimental condition by which no anticipated information was provided was set. The experimental conditions are shown in Table 1. Prior to the experimental run, subjects practiced the task repeatedly, and we confirmed that increasing proficiency did not alter performance accuracy.

Figure 2. Acquiring information.
2.3 Measurements

In this experiment, we used operational logs to evaluate task performance and physiological indexes (cerebral blood volume) to evaluate the psychological state of the subjects (OEG-16, Spectratech).

Table 1. Experimental conditions.

<table>
<thead>
<tr>
<th>Experimental Condition</th>
<th>Passively or Actively</th>
<th>After one or two or three</th>
<th>Probability</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1</td>
<td>Passively</td>
<td>1</td>
<td>Highest</td>
<td>(P·1·H)</td>
</tr>
<tr>
<td>Condition 2</td>
<td>Passively</td>
<td>1</td>
<td>All</td>
<td>(P·1·A)</td>
</tr>
<tr>
<td>Condition 3</td>
<td>Passively</td>
<td>2</td>
<td>Highest</td>
<td>(P·2·H)</td>
</tr>
<tr>
<td>Condition 4</td>
<td>Passively</td>
<td>2</td>
<td>All</td>
<td>(P·2·A)</td>
</tr>
<tr>
<td>Condition 5</td>
<td>Passively</td>
<td>3</td>
<td>Highest</td>
<td>(P·3·H)</td>
</tr>
<tr>
<td>Condition 6</td>
<td>Passively</td>
<td>3</td>
<td>All</td>
<td>(P·3·A)</td>
</tr>
<tr>
<td>Condition 7</td>
<td>Actively</td>
<td>1</td>
<td>Highest</td>
<td>(A·1·H)</td>
</tr>
<tr>
<td>Condition 8</td>
<td>Actively</td>
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<td>All</td>
<td>(A·1·A)</td>
</tr>
<tr>
<td>Condition 9</td>
<td>Actively</td>
<td>2</td>
<td>Highest</td>
<td>(A·2·H)</td>
</tr>
<tr>
<td>Condition 10</td>
<td>Actively</td>
<td>2</td>
<td>All</td>
<td>(A·2·A)</td>
</tr>
<tr>
<td>Condition 11</td>
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<td>3</td>
<td>Highest</td>
<td>(A·3·H)</td>
</tr>
<tr>
<td>Condition 12</td>
<td>Actively</td>
<td>3</td>
<td>All</td>
<td>(A·3·A)</td>
</tr>
<tr>
<td>Condition 13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(N·0·N)</td>
</tr>
</tbody>
</table>
2.4 Subjects and Ethics

Our subjects were 20 students (20–25 years old). Note that all participants provided informed consent. The obtained data were encrypted to protect participant identity.

3. Results and Discussion

3.1 Resilience characteristics diagram

To discuss the experimental results, factors needed to exert or enhance resilience characteristics were extracted from the literature and organized. From this, a resilience characteristics diagram (Fig. 5) was created to evaluate resilience characteristics. Using this figure, we considered the following.

![Resilience characteristics diagram](image)

3.2 Task Performance

3.2.1 Comparison of coordinates that subjects started processing to each block for each condition

We compared the coordinates that subjects started processing each block for each condition. Smaller coordinates reflect earlier initiation of the process. The results are shown in Fig. 6. In Fig. 6, the experimental conditions are on the horizontal axis, and the averages of the coordinates that started the processing for each block are on the vertical axis. Generally, the coordinates of Conditions 7(A•1•H) to 12(A•1•H) were significantly smaller than those of Conditions 1(P•1•H) to 6(P•3•A). This indicates that subjects with Conditions 7(A•1•H) to 12(A•1•H) initiated processing comparatively earlier than those with Conditions 1(P•1•H) to 6(P•3•A). From Table 1, Conditions 1(P•1•H) to 6(P•3•A) contain “passive” in the experimental conditions, and Conditions 7(A•1•H) to 12(A•1•H) contain “active.” We then compared the average of the coordinates of Conditions 1(P•1•H) to 6(P•3•A) and Conditions 7(A•1•H) to 12(A•1•H). Here, we compared the “passive” and “active” conditions. Figure 7 shows the results. As can be seen, the average of the “active” conditions was significantly smaller than that of the “passive” conditions. This indicates that processing is initiated earlier by obtaining information actively rather than passively. In other words, subjects can more quickly determine which block should be processed preferentially for each block. From the resilience characteristics diagram, “determination” (Waguild et al., 1993) is considered a factor that can enhance resilience. If the offered anticipated information is designed such that workers are required to obtain information actively, the determination of workers can be enhanced, which leads to resilience.
3.2.2 Comparison of coordinates that subjects completed processing each block for each condition

We also compared the coordinates that subjects completed processing each block for each condition. Smaller coordinates indicate earlier completion of the process. The results are shown in Fig. 8. In Fig. 8, the experimental conditions are on the horizontal axis, and the averages of the coordinates that finished the processing for each block are on the vertical axis. Generally, the coordinates of Conditions 7(A•1•H) to 12(A•1•H) were significantly smaller than those of Conditions 1(P•1•H) to 6(P•3•A). This indicates that subjects with Conditions 7(A•1•H) to 12(A•1•H) finished processing comparatively earlier than those with Conditions 1(P•1•H) to 6(P•3•A). We then compared the “passive” and “active” conditions. Figure 9 shows the results. These results show that the average of the “active” conditions was significantly smaller than that of the “passive” conditions. This indicates that process completion time is reduced by obtaining information actively. From the resilience characteristics diagram, “swiftness” (Norris, 2008) is considered a factor that can enhance resilience. If the offered anticipated information is designed such that workers are required to obtain information actively, worker swiftness can be enhanced, which leads to resilience.
3.2.3 Comparison of the maximum state value of each block for each condition

We also compared the maximum state value of each block for each condition. Figure 10 shows the results. In Fig. 10, the experimental conditions are on the horizontal axis, and the averages of the maximum state values for each block are on the vertical axis. Generally, the maximum state values of Conditions 7(A•1•H) to 12(A•1•H) were significantly smaller than those of Conditions 1(P•1•H) to 6(P•3•A). This indicates that the process was performed before the states of each block were too worse for Conditions 7(A•1•H) to 12(A•1•H) compared to Conditions 1(P•1•H) to 6(P•3•A). We then compared the “passive” and “active” conditions. The results are shown in Fig. 11. As can be seen, the average of the “active” conditions was significantly smaller than that of the “passive” conditions. This indicates that the process was performed before the states of each block were too worse when obtaining information actively rather than passively. In other words, subjects generally determined the states of each block that should be processed and that allocation of processing time was sufficient. Consequently, work efficiency increased. From the resilience characteristics diagram, “diversity of interest” (Oshio et al., 2002) is considered a factor that can enhance resilience. If the offered anticipated information is designed such that workers are required to obtain information actively, this prompts subjects to generally determine the states of each block that should be processed, which leads to resilience.

3.3 Physiological Indexes

The prefrontal cortex plays a role in cognition and executive functions, such as working memory, reaction inhibition, switching behavior, planning, and reasoning. In addition, it plays a role in decision-making processes based on higher emotion and motivation. Thus, we measured the cerebral blood volume in order to examine the psychological states of the subjects during the task. We then compared the average values for each experimental condition.

3.3.1 Medial Prefrontal Cortex

Here, we summarize the “how long after should operators receive anticipated information?” items for each condition. Figure 12 shows the results of comparing the activation amounts in the medial prefrontal cortex (MPFC). It has been stated that activation of the MPFC is primarily involved in “forming action plans” (Osaka et al., 2007) and “cognitive judgement” (Toshima, 2013). As can be seen in Fig. 12, the cerebral blood
volume of the MPFC with the “After One” conditions was activated significantly compared to the “After Three” conditions. These results indicate that, although it is preferable to provide “next” information, better results are not obtained by providing “after next” information. From the resilience characteristics diagram, “planning” (Mori et al., 2002) is considered a factor that can enhance resilience. In addition, the “After Three” conditions provided more information than the “After One” condition. This would likely confuse workers. If the offered anticipated information is designed such that it provides only “next” information, then this can enhance resilience.

Figure 12. Comparison of cerebral blood volume changes in the MPFC.

3.3.2 Orbitofrontal cortex

Here, we summarize the “how long after information should operators receive the anticipated information?” items for each condition. Figure 13 shows the results of comparing the activation amounts in the orbitofrontal cortex (OFC). Activation of the OFC is primarily involved in “re-orientation of attention” (Osaka, et al., 2007) and “leading appropriate action with inferring and judging current or future situations based on experience” (Ono et al., 2005). As seen in Fig. 13, the cerebral blood volume of the OFC with the “After One” conditions was activated significantly compared to the “After Three” conditions. This indicates that providing only “next” information directed more attention to important information than providing “After next” information, thereby making it easier to prioritize thinking. Thus, it can be said that understanding the current situation would prompt appropriate action. From the resilience characteristics diagram, “acceptance of change” (Mori et al., 2012) is considered a factor that can enhance resilience. With the “After One” conditions, workers would have sufficient time to grasp the current situation; therefore, it becomes easier to organize their thinking and take action than with the “After Three” conditions. In other words, it can prompt an “acceptance of change” in the workers, which enhances resilience.

Figure 13. Comparison of cerebral blood volume changes in the OFC.
4. Conclusions

In this study, we have attempted to clarify system side requirements needed to achieve safety II. We focused on the design requirements for the form of offered anticipated information and performed evaluations using task performance and physiological measurement. The results obtained in the experiment about the form of the offered anticipated information are shown in Table 2. These results indicate that a form that requires workers to obtain information actively can enhance resilience. We consider that obtaining information actively leads to “determination (Wagnild et al., 1993)” “swiftness (Norris, 2008)” and “diversity of interest (Oshio et al., 2002)” which have been considered in previous studies as factors that enhance resilience. In addition, we clarified experimentally that providing information for “next” has an effective effect; however, the physiological indices indicate that providing information for “After next” does not yield better results. This suggests that only providing information for “next” rather than both “next” and “After next” prevents the worker from becoming confused leads to “planning (Mori et al., 2002)” and “acceptance of change (Mori et al., 2012)” which have also been considered in a previous study as factors that enhance resilience. Collectively our results indicate that a safety II system can be enhanced by offering forms of anticipated information that enhance resilience. In future, we intend to clarify system side design requirements for factors other than “anticipating.”

Table 2. Summary of results for each form

<table>
<thead>
<tr>
<th>Offered Form</th>
<th>Passively</th>
<th>Actively</th>
</tr>
</thead>
<tbody>
<tr>
<td>How to acquire the information</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>Offered Form</td>
<td>After One</td>
<td>After Two</td>
</tr>
<tr>
<td>Tradeoff of Short-term – Medium or Long-term</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Offered Form</td>
<td>Only Highest</td>
<td>All</td>
</tr>
<tr>
<td>Tradeoff of Efficiency – Integrity</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

References

EUROCONTROL, 2013. “FROM SAFETY-I TO SAFETY-II: A WHITE PAPER.”

H.Miyake, 2010. “Comprehension of university student's personality that focused on Resilience: Research by SCT and semi-structured interview” Soka University Repository, 32, 355-384


