Study on dangerous and safe errors of human towards realizing collaborative safety - Examine of workability using safety/danger signals on tablet

Shimizu S[1,2]., Omata K[3]., Nobuhiro M[4]., Araya S[4]., Koremura Y[1,5]., Hojo R[6].

1 Safety and ANSHIN Technical Research Center (SATEC), GOP corporation
2 National Institute of Occupational Safety and Health, Japan (JNIOSH)
3 Nihon University
4 TOYOTA MOTOR CORPRARION
5 Ballast Dept., KOREMURA-GIKEN
6 Nagaoka University of Technology

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1. INTRODUCTION

In conventional machinery safety, workers are assumed to make mistakes, and safety is guaranteed by isolation, guards, and protective devices. However, in recent years, the number of production sites where the working areas and/or working times of workers and machines overlap has increased, and the principle of machinery safety of "isolation and stopping" is not always valid. In this type of machine-human collaborative work, the intrusion of the worker into the machine's working area is permitted, but contact between the worker and the machine is not permitted. Under such circumstances, conventional protective devices are capable of detecting the approach of the worker and stopping it. However, because the worker's behavior is treated as an unpredictable black box, it is not assumed that the worker's attention will be utilized to make collaborative work safer. In the current situation, it has not been fully confirmed how to present information from the machine side to the worker so that the intended behavior, such as avoidance, can be obtained for efficient collaborative work.

It is assumed that in actual accidents involving machinery, guards and protective devices are removed or disabled. One of the reasons for this is that workers may feel that protective devices reduce work efficiency. In other words, to maintain the risk reduction effect of using visual stimuli, it is necessary to develop guards and protective devices that workers are likely to continue using. As a clue to this, in this study, an experimental model was constructed that can verify how worker behavior changes depending on the difference in the presentation of danger and safety information by visual stimuli from the machine side using a tablet. In doing so, the aim was to differentiate human erroneous behavior into "dangerous" and "safe" and to clarify the relationship with visual stimuli.

2. MATERIALS and METHODS

2.1 Model leading up to the occurrence of harm

In order to create an experimental tool using a tablet, the process leading up to a hazard side error and a safe error was modeled as state transition as shown in Fig. 1. The work starts in a safe state, and when some failure occurs in the machine during the work, it enters a hazardous state where the risk is increased. If the worker does not notice the malfunction and continues the work, it is a harm occurrence (a hazard error). If the worker notices the malfunction and presses the emergency stop button, it is avoided. Also, if the emergency stop button is pressed even though no malfunction has occurred, it is a safe error. A safe error is an error that impedes work efficiency, but does not mean that the worker is in danger.

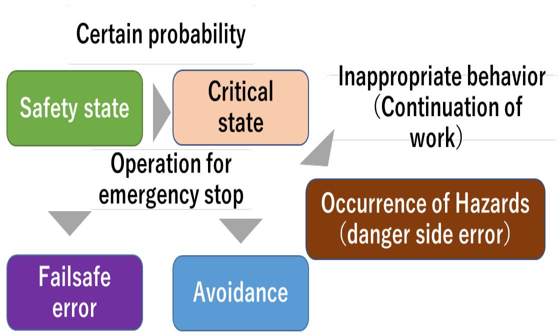

Fig. 1 Processes leading to hazard side errors and safety side errors

2.2. Creation of an experimental application

We created a tablet application that can be used for experiments based on the above model (Fig. 2). The tasks are as follows: 1) Pressing the work button earns 5 points. 2) Even if the work button is pressed, there is a certain probability that the score will not increase. 3) In such a case, the emergency stop button must be pressed. 4) Pressing the emergency stop button when it should not be pressed is a safety error, and pressing the work button when the emergency stop button should be pressed is a dangerous error. In other words, if the emergency stop button is not pressed correctly and the button is pressed, a dangerous-side error occurs, a certain "waiting time" is generated, and the point-earning scene is delayed (the previous points are maintained). 5) If the emergency stop button is pressed when it should not be pressed, a "safety-side error" occurs and a 5-second "waiting time" is generated, as in the case of a danger-side error. The application layout is shown in Figure 2. The message box ① is used to provide the operator with work instructions, errors, and other work status information. The message has the following display items.

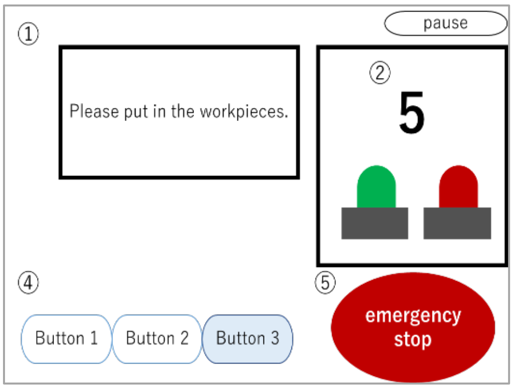

Fig. 2 Layout of the experimental application

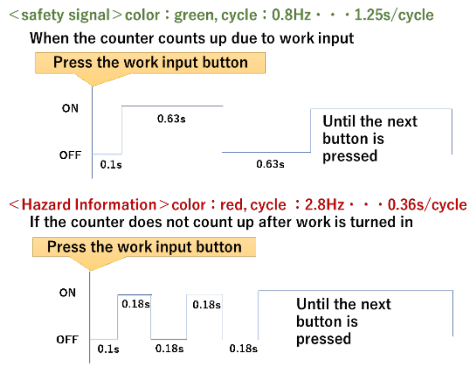

Fig. 3 Discriminative stimulus specifications

- Please put in your work...Displayed when workpiece is safe and ready to be loaded.
- Loading workpiece...Displayed until the next workpiece is ready to be loaded after the workpiece is loaded.
- Emergency stop Checking...Displayed during "waiting time" for error on the safe side
- Error occurred Restarting Displayed during "waiting time" for hazardous error
- Emergency stop In repair...Displayed during transition from avoidance to safe state

Five points are added to the counter (② in Fig. 2) each time the work button is pressed at the appropriate timing according to the instructions in the message box. There are two types of visual stimuli ③: safety signals and danger signals (Fig. 3). The safety signal blinks once at 0.8 [Hz] when the counter counts up. The danger signal blinks twice with a period of 2.8[Hz] when the workpiece is turned on but does not count up. ④ in Fig. 2 are the work button, which appears randomly in one of the three positions. When a work button is fixed, a finger is placed on the button to suppress the loss of eye movement. ⑤ is the emergency stop button.

The internal state of an application begins with the safety state. If the emergency stop button is pressed during the safe state, a safe-side error occurs. When the work button is pressed, the machine enters a count stop mode in which the count does not increase with a certain probability (30%), and pressing the work button at this time places the machine in a dangerous state. If the user presses the work button again without noticing that the count does not rise, a hazard (error on the hazard side) occurs. If an abnormality is noticed and the emergency stop button is pressed, avoidance occurs. When a safe or dangerous error occurs, a 5-second wait time occurs.

2.3 Experiment Schedule and Implementation

An experiment was conducted with eight university students and 36 manufacturing employees under four conditions: (1) no information was presented, (2) only safety information was presented, (3) only hazardous information was presented, and (4) both safety and hazardous information were presented. The experimental conditions and number of tasks were 300 times and four conditions for the university students and 200 times and two conditions for the manufacturing employees, respectively.

2.4 statistical analysis

A one-factor analysis of variance was conducted on the following indicators using the HAD software for analysis. If there was a significant difference ($p<0.05$), sub effect tests were performed using the Holm method.

Hazardous error rate: the value obtained by dividing the number of hazardous errors by the number of hazardous conditions
Safe side error count: Total number of safe side errors
Work reaction latency: Elapsed time from when the work button is pressed to when the button is pressed to increase points.
Emergency stop reaction latency: The time elapsed from the time when the work button is pressed in the appropriate scene but the point does not increase, i.e., a dangerous state, to the time when the emergency stop button is pressed.
***Treatment of outliers*:** Five cases (three without visual stimuli, one with safety stimuli only, and one with hazardous stimuli only; four manufacturing employees and one university student) were excluded from the trials in which the subjects did not seem to understand the content of the experiment, such as the 100% error rate on the hazardous side.

3. RESULTS AND DISCUSSION

3.1 Dangerous error rate

A comparison of the means of the risk-side error rates for each experimental condition for both college students and manufacturing employees combined showed a significant main effect of visual stimuli ($F(3, 97) = 3.482$, $p=.019$, Fig. 4). The results of the subtest showed that the condition in which both the safety and danger signals were presented had a significantly lower error rate on the danger side ($t(97)=2.996$, $p=.003$) than the condition in which only the safety signal was presented. No significant differences were observed among the other conditions. In particular, there is no significant difference between the no visual stimulus condition and the condition in which both are presented, suggesting that the safety signal has the effect of inducing a hazard side error.
Next, to see the relationship between familiarity with the task and the error rate on the hazardous side, Figure 5 shows the correspondence between the time elapsed for each visual signal and the error rate on the hazardous side. The error rate of the danger side was low immediately after the start when both safety and hazardous signals were presented, and it dropped with a similar inversely proportional curve when both signals were presented without visual stimuli (no information) and only hazardous signal was presented. On the other hand, when only the

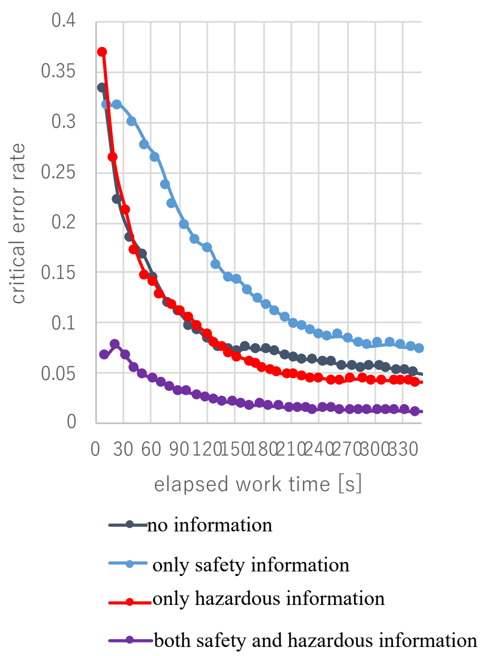

Fig. 4 Time variation of dangerous side error rate

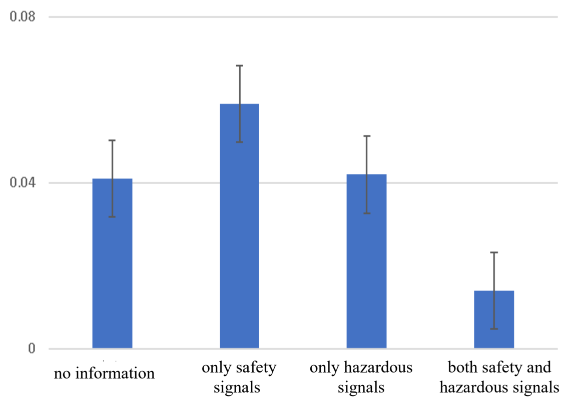

Fig. 5 Hazard side error rate (overall)

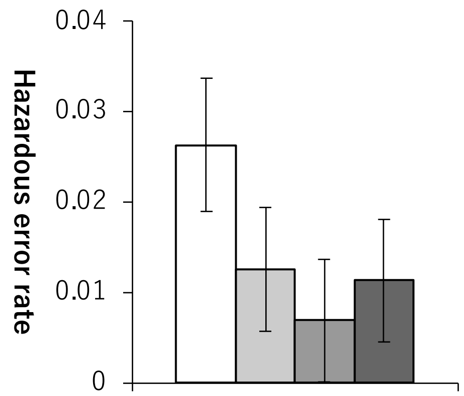

Fig. 6 College Students' Hazard Side Error

safety signal is presented, the error rate on the hazardous side decreases linearly, indicating that it takes more time for the user to become aware of the error.

The average number of safe side errors per visual stimulus for college students only is shown in Figure 6. As with the safety stimuli, no differences in visual stimuli were found. The hazardous side error rate for manufacturing employees was significantly increased in the safety signal only condition compared to the safety signal plus hazardous signal condition.

3.2 Safe error counts

Safe error count is shown in Fig. 7. A one-factor analysis of variance revealed a significant main effect of visual stimuli ($F(3, 97) = 4.627$, $p=.005$). The results of the Holm test showed that the mean difference was significantly higher for the safety signal alone than for the safety signal and the hazard signal ($t(97)=2.765$ $p=.007$). This indicates that the safety and hazard signals are more effective in preventing safe errors than the safety signal alone. The safety and hazardous signal was also found to be significant without visual stimuli ($t \simeq -2.936$ ($p=.004$)), indicating that there were fewer safe-side errors when the two stimuli were presented. No significant differences were observed in the other conditions. Although the safety signal showed the possibility of inducing hazardous errors, it is inferred that it has no such effect in safe errors and simply has no effect on safe errors.

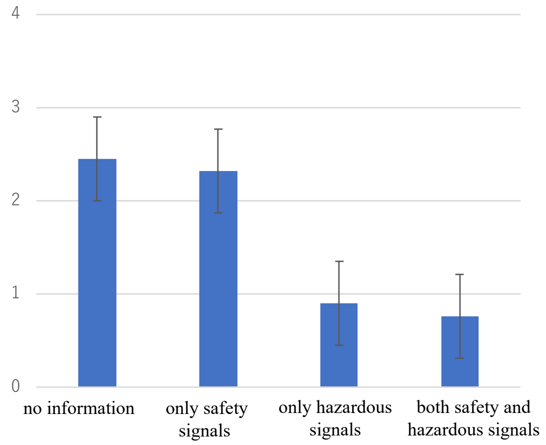

Fig. 7 Safe error counts

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