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NOTES

Convenient Evaluation of Mental Stress With Pupil Diameter

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This study proposes a convenient method of evaluating mental stress. The potential of monitoring changes in pupil diameter as a measure of human reliability while operating human–machine systems was examined experimentally. An experiment was carried out to clarify the relation between changes in pupil diameter and autonomic nervous activity by measuring an electrocardiogram and pupil diameter when 10 subjects completed a time-sensitive task. The electrocardiogram was measured using a multitelemeter system and pupil diameter was measured using an eye-mark recorder. Several relationships between changes in pupil diameter and autonomic nervous activity were revealed and indicated that measurement of pupil diameter was an effective indicator of autonomic nervous activity. Therefore, it may be possible to develop a monitoring system that measures changes in pupil diameter as an indicator of the mental state of workers operating human–machine systems.

pupil diameter   heart rate variability   mental stress   human–machine system

1. INTRODUCTION

Human error is closely related to the safety and structural health of human–machine systems. While the reliability of a mechanical component can be improved by advancements in science and the technology, there remains the problem of human reliability. Human error is caused by an interaction between subjective uncertainties and various kinds of factors such as mechanical equipment and the work environment [1, 2, 3, 4]. Human performance is an important factor to consider in human–machine systems, and thus to prevent human error we must consider numerous factors including the worker's mental state, the design of the mechanical system and environment conditions [5].

In an automated system, the machine can work without an operator; however, error detection and system maintenance remain the operator's roles. Therefore, the operation of all mechanical equipment is considered to be a human–machine system. Recently, because human–machine systems have become not only large scale but also complex, the reliability of the systems has become dependent on the operator, thus making it important to deal with human error. However, since human error depends on events composed of various factors, little research has been conducted on the mechanism of human error [6, 7, 8, 9].

That is why the present study attempts to use an ergonomic approach to measure workers' mental stress, where mental stress is a cause of human error. The study aims to do so by clarifying the relation between change of pupil diameter and autonomic nervous activity.

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2. INVESTIGATION

A schematic of the experimental setup is shown in Figure 1. The electrocardiogram was recorded using a multitelemeter system (Nihon Kohden, Japan, Web-5500) at a sampling frequency of 100 Hz. The analogue output of the multitelemeter system was transferred to an A/D converter recorder (TEAC, Japan, DR-m50). Pupil diameter was measured with an eye-mark recorder (NAC Image Technology, Japan, EMR-8B) at a sampling frequency of 60 Hz. Output data were recorded with a personal computer. A 19" liquid crystal display (LCD) (Dell, USA, E197FP) was situated 600 mm from the subjects' eyes. The average of brightness and the luminance were, respectively, 135.2 cd/m^2 and 613.0 lx at 600 mm from the LCD. A numerical keypad was placed in front of the subject as shown in Figure 1.

The subjects were instructed to perform a time pressure task. A one-digit number from 0 to 9 with a size of 1.0º was displayed on the LCD at regular intervals with Hot Soup Processor version 2.61 (Onion Software, Japan) in line with an experimental paradigm. They were required to register on the numerical keypad the one-digit number displayed on the LCD within a specific time limit. As shown in Figure 2, the three levels of the time pressure task were 1.5, 1.0, and 0.5 s.

Ten healthy university students (mean age: 22.4 years; range: 21–24) were enrolled as subjects to examine the relation between changes in pupil diameter and autonomic nervous activity.

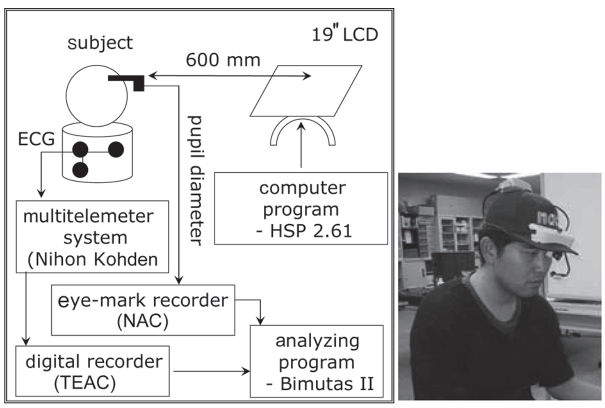

Figure 1. Experiment setup. *Notes.* LCD—liquid crystal display; ECG—electrocardiogram; HSP 2.61—Hot Soup Processor version 2.61 (Onion Software, Japan); Nihon Kohden—Nihon Kohden, Japan, Web-5500; NAC—NAC Image Technology, Japan, EMR-8B; TEAC—TEAC, Japan, DR-m50; Bimutas II—Bimutas RII-A, Kissei Comtec, Japan.

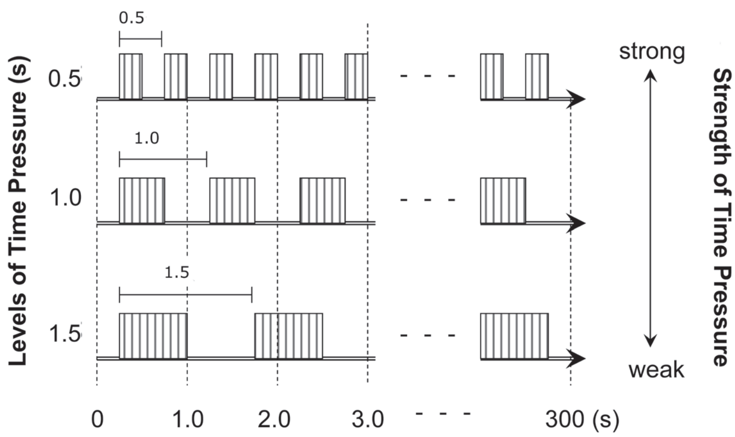

Figure 2. Time chart of experimental task.

3. RESULTS AND DISCUSSION

Figures 3–4 show the results of the experiment. Figure 3 illustrates the relation between time pressure and heart rate variability as indicated by LF/HF (low frequency component/high frequency component). Heart rate variability is indicated by LF, MF (mid-frequency component), and HF, where the LF frequency band ranging from 0.04 to 0.15 Hz reflects both sympathetic and parasympathetic nerve activity and the HF frequency band ranging from 0.15 to 0.4 Hz reflects parasympathetic nerve activity. For that reason, sympathetic nerve activity can be represented by the value of LF/HF [10, 11, 12, 13]. For comparison, the value of LF/HF at rest is 2.44. Two kinds of tendencies were shown for LF/HF. First, the value under a time pressure of 0.5 s was more than double that under the other time pressures. Second, a typical tendency was that increases in time pressure were accompanied by increases in the value of LF/HF. These results indicate that the activity of the sympathetic nervous system dominates under time pressure.

Figure 4 shows the relation between time pressure and pupil diameter. For comparison, pupil diameter at rest is 3.71 mm. Pupil diameter under a time pressure of 0.5 s was larger than that under the other time pressures. Also, increases in time pressure tended to be accompanied by increases in pupil diameter. These results indicate a common tendency between change in pupil diameter and change in LF/HF value.

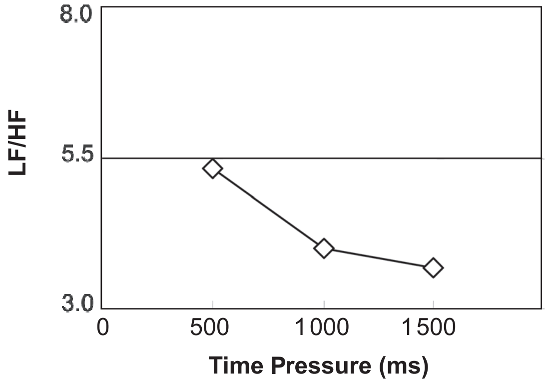

Figure 3. Relation between the time pressure and the low frequency component/high frequency component (LF/HF).

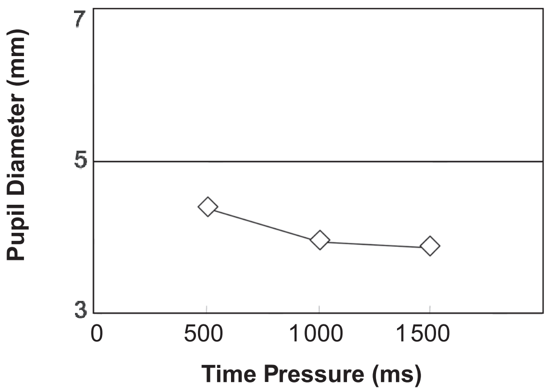

Figure 4. Relation between the time pressure and the pupil diameter.

Figure 5 shows a strong correlation between the value of LF/HF and pupil diameter, with a correlation coefficient of .896 ($p < .01$). Thus, change in pupil diameter is an effective indicator of autonomic nervous activity.

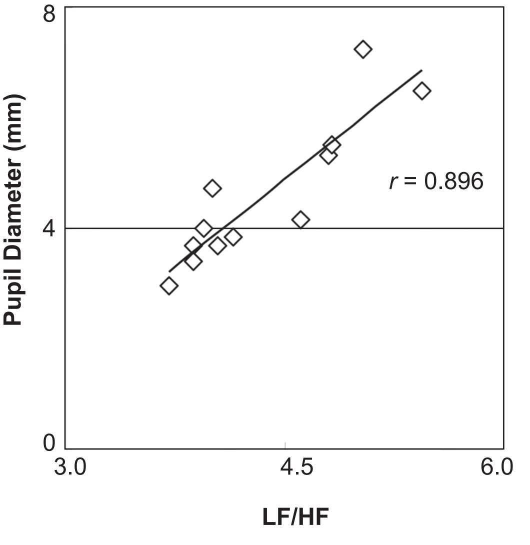

Figure 5. Correlation between the low frequency component/high frequency component (LF/HF) and the pupil diameter

4. CONCLUSION

This study proposes a convenient method of evaluating mental stress by measuring pupil diameter. Experimental results identified relationships between changes in pupil diameter and autonomic nervous activity. It was found that pupil diameter reflected changes in mental state caused by increasing time pressure during a time-sensitive task. It was also shown that the diameter of pupils was an effective indicator of autonomic nervous activity. The potential for monitoring changes in pupil diameter as a measure of monitoring human reliability while operating human–machine systems was thus experimentally verified. It may be possible to develop a monitoring system that measures changes in pupil diameter as an indicator of the mental state of workers operating human–machine systems.

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