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The Psychomotor Cognition Test for Measurement of Sleepiness/Fatigue on a Touch Screen*

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***Abstract*— The Psychomotor Vigilance Test (PVT) is a simple and reliable performance test that measures sustained attention, alertness level, and fatigue level. The PVT is a convenient tool that can be used in real time in situ through a mobile device without the assistance of experts and therefore can be used to improve safety and prevent accidents. However, the original PVT is vulnerable to the subject's intentional concentration on the test, and the variance range among tests is narrow; these factors limit its usefulness in classifying the level of fatigue. This study overcome these limitations and develop the Psychomotor Cognition Test (PCT) by transforming the PVT into a tool that stably classifies fatigue levels, still requiring a short period of time. In the PCT, compared to the PVT, reaction time is significantly longer, and success rate is significantly lower (both $p<0.0001$). Whereas reaction time and success rate of the PVT do not show a significant correlation with fatigue level, those of the PCT show significant correlations with fatigue level, respectively ($p<0.001$). This study suggests that the PCT can be used in real time in situ as a risk management tool for workers performing dangerous tasks and can become an even more powerful tool when combined with other physiological indicators.**

I. INTRODUCTION

Decreased arousal caused by accumulated fatigue can be measured by questionnaires and behavioral tests. Alertness testing tools in the form of questionnaires include the Toronto Hospital Alertness Test (THAT) scale, mental alertness scale, and objective alertness scale [1][2][3]. The behavioral test is a performance test which eventually becomes a tool to evaluate an individual's level of alertness [4][5][6]. Among the performance tests, the Psychomotor Vigilance Test (PVT) has been verified for reliability and is a tool that can measure an individual's alertness level in real time in situ [7][8][9]. The simple PVT is a tool to measure the reaction time to a single visual stimulus repeated for 3-5 minutes at 2-5 seconds intervals. In addition to measuring sustained attention and alertness through reaction times, the test also measures sustained attention and hyperactivity through a success rate that is calculated from cases of missing a stimulus without a response or showing a response even though there is no stimulus present. Error responses are also measured quantitatively. Reaction time and success rate to visual stimulation quantitatively measured in the PVT correlated with delayed problem-solving speed, reduced psychomotor function, and false responses to stimuli resulting from reduced alertness. As the PVT is easy to quantify, has simple measurement standards, it has been used as a tool for diagnosing ADHD and safety management [10][11][12]. However, the PVT test, which is performed for a relatively short time, has a weak point that the individual's alertness level could be distorted through the subject's brief intentional concentration on the test. In addition, the deviation of reaction time in the simple PVT is small, so it is insufficient as a tool for classifying the level of fatigue. In order for the PVT to be more useful for repeated estimation of fatigue/sleepiness, the disadvantages of the simple PVT need to be overcome. The PVT repeatedly uses simple visual stimuli, but the modified PVT utilizes complex visual stimuli, and is designed so that working memory can be used to respond. The PVT, which measures the reaction time and error for single-colored visual stimuli, has been transformed into a response test that remembers irregularly-appearing visual stimuli of various colors and responds by comparing and judging color matching with the next stimulus. The modified PVT, which requires a response through working memory, is referred to as the Psychomotor Cognition Test (PCT) for explanation. Working memory was correlated with chronic fatigue syndrome, and chronic fatigue syndrome patients are known to have significantly longer response times to cognitive stimuli compared to the control group [13] [14]. This study was conducted to verify the effectiveness of the PCT compared to the original PVT.

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II. EXPERIMENTAL PROTOCOL

A. Limitation of Psychomotor Vigilance Test (PVT)

When the PVT starts, a small black dot appears on the screen, followed by large circular stimuli at irregular intervals (Fig. 1). The subject responds to the circular visual stimulus in the fastest time by clicking or touching, and the reaction time, non-response error to the visual stimulus, and response error when there is no stimulus are recorded. The PVT repeats these simple stimuli and response tests about 20 to 25 times, and calculates the mean reaction time and the

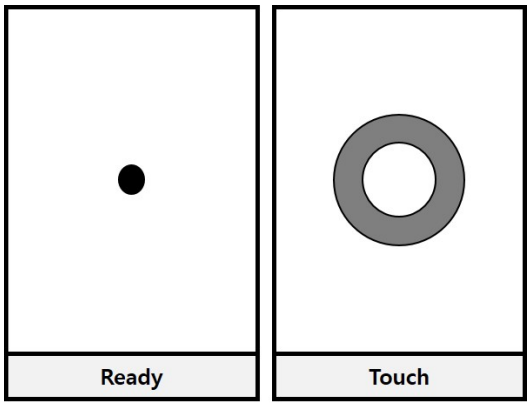

Fig. 1. Scheme of the PVT

success rate excluding errors in the subjects' reaction. Mean reaction time and success rate are known to be related to sustained-attention, sleepiness, alertness level, and fatigue level [11][15]. The PVT is a test that repeats simple stimulus and response, and can be used to diagnose ADHD patients or to evaluate arousal levels for a short period of time[16][17]. However, when used repeatedly for risk management in industrial fields, it has not been a suitable tool for several reasons. The subject's intentional short concentration on the test was able to overcome the accumulated fatigue [18], and there was ambiguity in determining the level of fatigue because the reaction time and success rate had narrow range of deviations after the test procedure became familiar.

B. Modification of PVT to Psychomotor Cognition Test (PCT)

In order that such a test can be used for repeated fatigue management, the disadvantages of the simple PVT should be reduced. In order to minimize the effect of intentional concentration, in which subjects try to hide their accumulated fatigue, the simple stimulus-response test was transformed into a stimulus-response test that requires working memory. A small dot used as a ready signal for a response appears transformed into a colored underlined circular stimulus, and the subject must remember the color. The circular color stimulus disappears from the screen, and the circular color stimulus reappears at irregular intervals without an underline (Fig. 2). The subject touches the lower left side of the screen as quickly as possible if the color stimulus without underlining appears and is the same color as the memorized

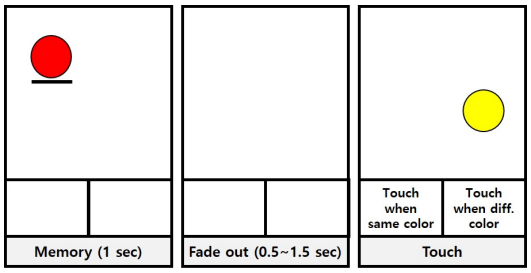

Fig. 2. Scheme of the PCT

TABLE I
CRITERIA FOR CLASSIFYING FATIGUE LEVELS

Levels	Description
Level 1	Fully alert, wide awake.
Level 2	Actively responsive, but not at peak.
Level 3	Okay, somewhat fresh.
Level 4	Moderately tired, but no effort to keep alert.
Level 5	Extremely tired, very difficult to concentrate.

color, and touches the lower right side of the screen if it is a different color. The response time will be longer than that of the simple stimulus-response test, and the deviation of the reaction time will increase due to the influence of the level of alertness or fatigue. In addition, the effect of intentional concentration can be minimized, and differences in fatigue levels can be found with a small number of stimulus-response tests.

C. Subjects

Forty-six volunteers, who are healthy men and women in the ages between 30 and 49, participated in this study. The subjects were office workers who had been educated for more than 16 years and worked at the workplace from 8:30 to 17:30 every day. All experimental procedures involving human subjects were approved by Research Ethical Review Board at Korean Air Force Academy. All volunteers agreed on their bio-signal collection. Collected data were coded and then analyzed for privacy protection.

D. Data Acquisition Flow

The 46 subjects were divided into two groups, one group of 23 subjects installed the PVT app on their smartphones, and the other group of 23 subjects installed the PCT app on their smartphones. Subjects participated after understanding the purpose of the experiment and learning how to conduct the experiment. Over a period of 10 weeks, at various times during ordinary working days, Subjects first reported their fatigue level according to the criteria described in Table 1, then performed either the PVT or the PCT, and transmitted the results [19]. 19 subjects in the PVT group and 20 subjects in the PCT group conducted more than 45 experiments. 1850 data from 39 subjects were analyzed.

III. STATISTICAL SIGNIFICANCE BETWEEN PVT AND PCT

Fig. 3 shows the change in reaction time in repeated tests. When both the PVT and the PCT were repeated 10 times, no further learning effect appeared, and a plateau was formed. Both tests stably indicated that it could be used repeatedly as a performance test tool. In addition, in both tests, more than 10 times of practice were required to obtain stable data without making errors due to learning effects. The mean reaction time of the PVT was 218.4 milliseconds, and the standard error (SEM) was 10.9. On the other hand, the mean reaction time of the PCT was 254.5 milliseconds and SEM was 13.2. The PCT had a statistically significant longer reaction time compared to the PVT, and the deviation

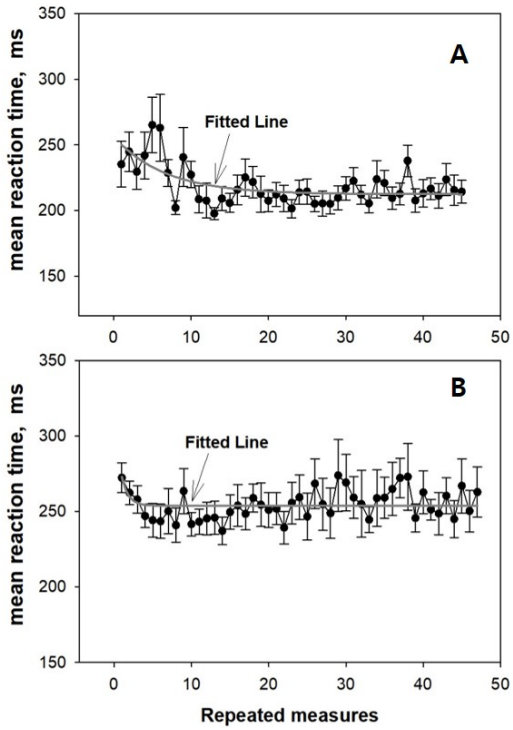

Fig. 3. Mean reaction time in repeated measurements. Panel A shows the reaction time of PVT, and panel B shows the reaction time of PCT.

also increased ($p<0.001$). Also, the success rate of the PCT was 92.3% significantly lowered ($p<0.001$) than that the success rate of the PVT was 94.3%. The PCT requires working memory to respond, so the reaction time of the PCT was longer and the deviation increased than those of the PVT. Since the PCT is more affected by alertness level than the PVT, it was expected that the effect of intentional concentration could be minimized and the resolution of alertness level classification could be improved.

IV. Application to Classification of Fatigue Levels

A. Differential Reaction time depending on Fatigue Levels

Fig. 4 represents the difference in reaction time according to the fatigue levels. Open circles represented the mean reaction times of the PVT and closed circles represented those of the PCT. In the PVT, the mean reaction time did not show a significant correlation with the levels of fatigue classified into 5 stages. However, the mean reaction times in the PCT showed a significantly positive correlation with fatigue levels ($p<0.0001$). The mean reaction time of fatigue level 1 in the PCT showed a significant difference from the mean reaction time of fatigue levels 2, 3, 4, and 5 ($p<0.001$), and the mean reaction time in fatigue level 2 was significantly shorter than it in fatigue level 5 ($p<0.05$). Although the PCT alone cannot be an absolute tool to classify fatigue level into 5 levels, it can be used as a tool to distinguish whether a worker is suitable for a specific task or not. The PCT can be installed on a mobile device and become a tool to ensure safety and prevent accidents in real time, in situ.

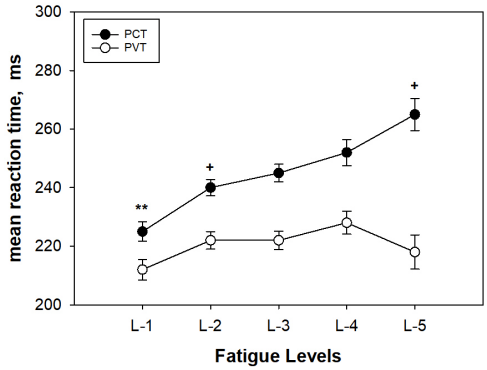

Fig. 4. Change in mean reaction time versus rising fatigue level

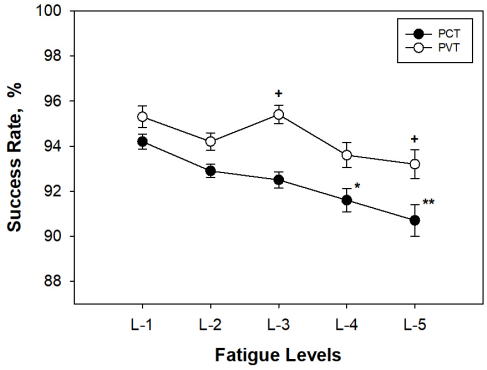

Fig. 5. Change in success rate versus rising fatigue level

B. Differential Success Rate in the PCT depending on Fatigue Levels

Fig. 5 shows the change in success rate according to the increase in fatigue level. Open circles indicate the change in success rate in the PVT, and closed circles indicate the change in success rate in the PCT. The success rates in the PVT did not show a significant correlation with the levels of fatigue classified into 5 levels. However, in the the PCT, the success rates showed a significant negative correlation with the levels of fatigue ($p<0.001$). In the PVT, the success rate of fatigue level 3 was significantly different from the success rate of fatigue level 5, but it did not have a meaning in the classification of the fatigue level. On the other hand, the success rate of fatigue level 1 in the PCT was significantly different ($p<0.05$) from the success rate of fatigue level 4 ($p<0.05$) and fatigue level 5 ($p<0.001$). Although the success rate of the PCT alone cannot be an absolute tool to classify fatigue level into 5 levels, it has shown the potential to be a sufficient fatigue level classification tool when combined with reaction time and other physiological indicators.

V. CONCLUSIONS

The PVT has long been used as a tool to measure the level of sustained attention and alertness, and is a performance test that is also used in diagnosing ADHD. In addition, the web version PVT is used as a remote performance test tool by experts, and the mobile version PVT is used as a simple inspection tool that can be used to prevent safety accidents in real time in situ [20][21][22]. Although the PVT is a reliable tool to test sustained attention, it has limitations in measuring and subdividing alertness levels. The limitations of the PVT in classifying alertness or fatigue levels could be overcome by adding cognitive interference, as known as Stroop effects, to the test. The PVT, which used to measure reaction time by repeating simple stimuli and behavioral responses, is transformed into a method that memorizes colored visual stimuli and responds by distinguishing whether newly created color stimuli are of the same color or different colors. The response time of the PCT, a modified PVT, increased, and the deviation increased. The PCT was a tool that is able to reduce the effects of intentional concentration on the test that distorts accumulated fatigue or low alertness. If the PVT is suitable as a tool for assessing sustained attention, the PCT may be a more suitable tool for classifying the level of alertness or fatigue. This study suggests that the PCT can be used in the field as a risk management tool for workers performing dangerous tasks in real time, and can become a more powerful risk management tool when combined with other physiological indicators.

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