A Detection Method of Temporary Rest State while Performing Mental Works by Measuring Physiological Indices

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Abstract. In order to evaluate intellectual productivity such as the efficiency of performing mental works, several studies were conducted where specially designed tasks were given. However, the result may not be reflected the actual intellectual productivity because the designed tasks are different from office works. Meanwhile, there are two mental states (work and temporary rest state) in office workers which are changing alternatively during mental work and the ratio of the two states reflects the productivity. If the mental states of the workers can be detected, the productivity can be measured more accurately. In this study, a detection method of temporary rest state while performing mental works by measuring physiological indices has been developed. As the result of the subject experiment, it was found that the detection accuracy was 80.2%. This result shows the possibility to use the physiological indices as one of the mental state detection methods.

Keywords: intellectual productivity, physiological psychology, cognitive psychology, office work, mental work

1 Introduction

Recently, mental works such as intellectual works have occupied most of office works in companies and have become more and more valuable in our society. Therefore economic and social benefits can be bigger by improving intellectual productivity such as the efficiency and accuracy of performing mental works. In order to achieve this, the evaluation of intellectual productivity is required, and several studies have been conducted. Obayashi et al. have developed specially designed tasks for quantitative evaluation of intellectual productivity [1]. However, a number of tasks used in experiments for the evaluation are different from actual office works, because the tasks have been designed in order for experimenters to collect operation logs easily and accurately. In order to evaluate intellectual productivity in actual office, it is desired to use actual office works. It is, however, difficult to collect and evaluate most of their logs.

On the other hand, Miyagi et al. [2] have revealed that there are two mental states (work and non-work state) in the office workers which change alternatively during mental work. And, intellectual productivity can be evaluated quantitatively by using the ratio of these two states. In particular, the non-work state has a negative influence on the intellectual productivity.

Meanwhile, physiological indices are supposed to reflect various mental states such as arousal, concentration, anxiousness, stress, relaxation. Thus, there have been several studies as to the detection of mental states by using physiological indices: Miyagi et al. measured brain activity during mental works with Near-Infrared Spectroscopy [3]. Hosseini, S.A. et al. proposed a new system recognizing emotional stress using electroencephalogram (EEG) [4].

In this study, therefore, the authors have aimed at developing a detection method of the non-work state (it is called " temporary rest state " here and after) by measuring physiological indices such as electrocardiogram (ECG), electromyogram (EMG), around left eye and EEG. If this detection method can be developed, intellectual productivity in office works can be evaluated quantitatively because this method requires only measuring physiological indices of office workers, not specially designed tasks.

2 Method

2.1 Participants and Measurement

26 healthy volunteers participated in this experiment who are the ages of 19 to 25 and could operate PC without difficulty and their native language was Japanese. The experimental period was approximately 2 hours. The subjects were instructed to conduct mental tasks and their physiological indices were measured. And based on these indices, their two mental states (work state and temporary rest state) have been detected. The temperature, illuminance, and ambient noise of the experimental room were controlled to $25 \pm 1°$C, 680lx, and 50 ± 3db respectively.

In this experiment, the subjects equipped the instruments, and their ECG, EMG around left eye, EEG have been measured. The position of these electrodes is shown in Fig. 1.

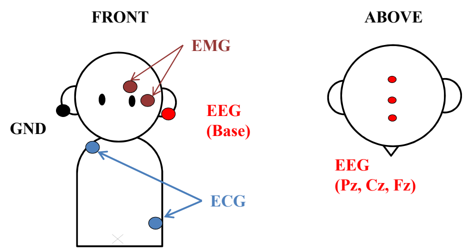

Fig. 1. The position of these electrodes.

EEG electrodes were placed on Pz, Cz and Fz according to the international 10-20 system and their midline electrode was placed on left earlobe. ECG electrodes were placed on the left side of the body and the right side of the neck. EMG electrodes were placed on the left temple and upper part of the left eye blow.

2.2 Experimental Design

The experiment consisted of 2 measurements ,where the subjects performed tasks in 3 conditions which were defined as follows:

Task Condtion
: In this condition, the subjects were instructed to perform mental tasks, which require intellectual ability. Therefore, the physiological indices measured in this condition were regarded as that in the work state.

Control Condition
: The subjects were instructed to move their arms and fingers as the same way as the task condition without thinking. In other words, they performed non-mental tasks demanding little intellectual ability. Hence, the physiological data in this condition were regarded as that in the temporary rest state.

Rest Condtion
: In this condition, the subjects were instructed to stop moving, relax, and gaze a black fixation cross without thinking. The physiological data in this condition were also regarded as that in the temporary rest state.

In one of these 2 measurements, the subjects were required to change these 3 conditions in turn as a presented display was switched automatically every 30 seconds as shown in Fig. 2, and these procedures were repeated 5 times. Tasks, figures (squares, triangles, and circles), and a black fixed cross were presented respectively in the task condition, the control condition, and the rest condition. This measurement is called “Automatic Switching Measurement (ASM)”. It was conducted in order to collect the same amount of the data in these 3 conditions.

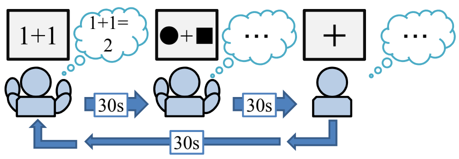

Fig. 2. The sequence of task in automatic switching measurement.

In the other measurement, a presented display was not switched, and the subjects were instructed to perform tasks for 7.5 minutes by switching these

3 conditions freely. This measurement is called “Free Switching Measurement (FSM)”. It was expected that the subjects changed the work state and temporary rest state spontaneously in this measurement.

5 types of tasks such as 1-digit addition, classification, and text typing were employed in order to confirm the independence of the detection performance on tasks.

2.3 Tasks

5 types of tasks were used which were 1-digit addition, 3-digit addition, classification, block assembling, text typing in the experiment. These tasks are supposed to be relatively similar to office works [1].

1-Digit Addition
The subjects were instructed to do the sum of two 1-digit integers presented on a PC display in their heads, and type the answer by using a numeric keypad of the PC.

3-Digit Addition
They were instructed to remember one 3-digit integer and press the enter key. Then another 3-digit integer was presented and they were instructed to do the sum of these two 3-digit integers in their heads and type the answer by using a numeric keypad of the PC.

Block Assembling
In the case of this task, they were instructed to freely assemble blocks presented on a PC display and name a assembled figure as shown in Fig. 3.

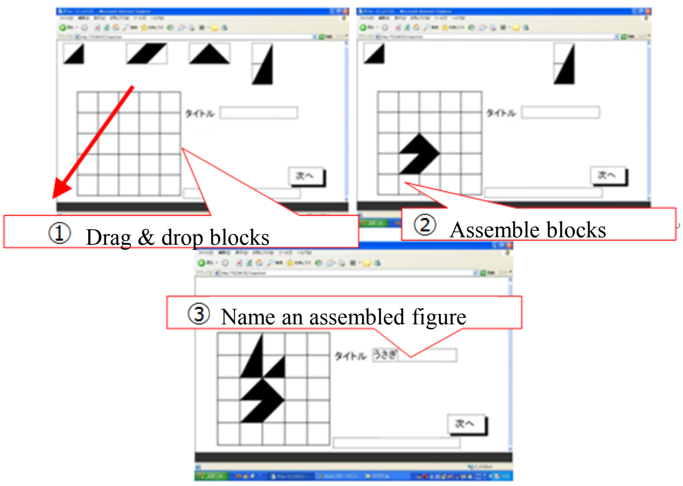

Fig. 3. Block assembling task.

Text Typing

They were instructed to type sentences presented on a PC display with a keyboard. The presented sentences were the Japanese proverbs which are well-known in Japan. Owing to this, the subjects whose native languages are Japanese were employed in this experiment.

Classification

They were instructed to look at the amount, date, name of a company in a receipt as shown in Fig.4 and classify it by tapping one of 27 buttons in the classification table on iPad display as shown in Fig.5.

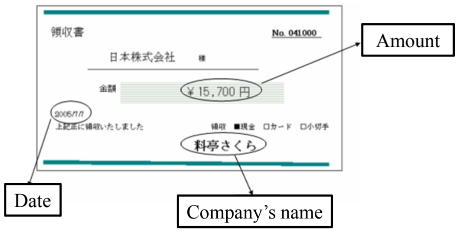

Fig. 4. An example of receipts in classification task.

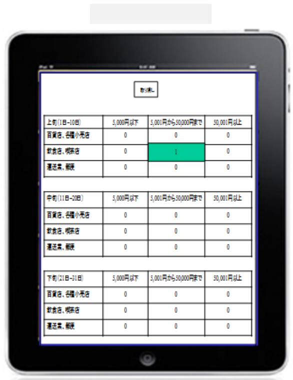

Fig. 5. The classification table on iPad display.

2.4 Data Analysis

After each measurement, 6 feature values were extracted every 2 seconds from the measured physiological indices, and these values were divided into the work state group or temporary rest state group by using the operation log of the presented tasks. Finally, Mahalanobis distance between these 2 groups was calculated so that the correct discrimination probability (theoretical value) was calculated. In this study, Mahalanobis distance, D^2, is a generalized measure of the distance between the work or temporary rest state groups. The distance is defined as

$$D_{12}^2 = (n + h - 2) \sum_{i=1}^{p} \sum_{j=1}^{p} w_{ij}^{-1} (\overline{X_{i1}} - \overline{X_{i2}})(\overline{X_{j1}} - \overline{X_{j2}}) \quad (1)$$

where n is the number of samples in work state, h is the number of samples in temporary rest state, p is the number of variables ($p = 6$ in this study.), $\overline{X_{i1}}$ is the mean for the i^{th} variables in work state, $\overline{X_{i2}}$ is the mean for the the i^{th} variables in temporary rest state, w_{ij}^{-1} is an element from the inverse of the within-groups covariance matrix. If the distribution of samples is assumed to be a multivariate normal distribution, the error rate (e) in Mahalanobis discriminant analysis is defined as

$$e = \frac{1}{\sqrt{2\pi}} \int_{D/2}^{\infty} exp(-\frac{u^2}{2}) du \tag{2}$$

Then, the correct discrimination probabilities is $1 - e$. Note that the minimum of the probabilities is 50 % .

The method of extracting feature values from physiological indices is described below.

ECG

In this analysis, the high (0.20 to 0.35 Hz) and low (0.05 to 0.20 Hz) frequency wave of heart rate were calculated. In order to calculate these feature values, the Gabor Wavelet transform [5, 6] have been applied among various types of frequency analysis methods because 2 second time window was too short to apply other frequency analysis method. The concrete transform equation is described below;

$$WT(b, a) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(t) \overline{\psi(\frac{t-b}{a})} dt \tag{3}$$

$$\psi(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{t^2}{2\sigma^2} - i2\pi t} \tag{4}$$

where $1/a$ and b correspond to frequency and time respectively. And $\psi(t)$ is Gabor's function.

EMG around left eye

From EMG around left eye, the intervals of eye blink and saccade eye movement were extracted. Several studies have reported that eye blink and saccade eye movement reflect human higher cognitive process and psychological state [7–9].

EEG

In the analysis of EEG, brain waves of EEG at Fz and Cz were excluded from this analysis because EMG caused by eye blinking affected the brain waves as artifact. And alpha (8 to 13 Hz) and beta (13 to 30Hz) wave at Pz were calculated by the Fourier transform.

3 Result

R waves of ECG of 5 subjects could not be detected properly or the amplitude of these waves have been found too small, so that the measured data of these subjects were excluded from the analysis. And there were 2 cases where a task could not be performed for a fault of experimental PC, so that the measured data when the fault occurred were also excluded.

Table 1 shows the correct discrimination probabilities in ASM and FSM. The average of the detecting performance as to all the presented tasks in these 2 measurements was 80.2% .

Table 1. Correct discrimination probabilities in ASM and FSM

Task	n	Correct discrimination probability			
		ASM		FSM	
		Mean(%)	SD	Mean(%)	SD
1-digit addition	21	85.4	10.7	83.4	10.1
3-digit addition	21	83.4	9.0	82.6	9.5
Block assembling	20	75.5	5.4	78.3	10.3
Text typing	20	71.0	6.1	81.1	8.0
Classification	21	78.5	7.6	79.3	7.7

As shown in Table 1, the accuracy of the proposed method in ASM is significantly lower than in FSM in only the case of text tying task ($p < 0.01$).

4 Discussion

As noted above, the detecting performance as to only text typing in ASM was significantly lower than in FSM. Likely explanations are hinted at by the low mental workload of text typing and the difference between the time length of task condition in the case of ASM and FSM: while subjects were performing text typing, it required them only to look at the presented sentence and type it, not to perform higher cognitive activities (e.g. assembling a sentence, correction in some words, and so on). In addition, they had no trouble in typing words with keyboard because they could operate PC without difficulty. Thus, text typing required lower mental workload than the other tasks, which probably caused the physiological data to change a little and slowly under task condition. Owing to this, the authors consider that in comparison with the other tasks, text typing required longer time length of task condition in order to measure the significant differences between the physiological data under task condition (the work state) and control/rest conditions (the temporary rest state). In the case of ASM, each condition was changed automatically every 30 seconds. The time length of task condition were probably too short for the data under this condition to change significantly. On the contrary, as for FSM, the subjects could change each condition at their own paces. According to the operation logs of this task, most of the subjects remained under task condition for more than 30 seconds (the mean time length of task condition was 59.0 seconds.). The time length was probably long enough for the physiological data under this condition to change significantly. Besides, if the significant differences between the data under task condition and control/rest conditions cannot be measured, the detecting performance becomes low. For these reasons, the accuracy of the proposed method as to text typing in ASM was significantly lower than in FSM.

Based on analysis of variance, no significant differences were found in the results between these 5 tasks in FSM ($F(4, 98) = 2.47, p = 0.435$), while as for ASM, significant differences were found ($F(4, 98) = 2.47, p < 0.01$). Hence, it can be argued that as for FSM there is no dependence of the detection performance on tasks. This suggests that the experimenter should let subjects perform mental works at their own paces in order to detect their mental states accurately.

As mentioned above, the mean accuracy of the proposed method was 80.2 %. The value is not close to 100%, which is the maximum of the discrimination probability, but 30.2% higher than the minimum of the probability (50%). This suggests that there is still room remaining to improve this method, but there is also the possibility that the work state and the temporary rest state in mental workers can be detected based on physiological indices by using this method.

In this study, the presented tasks were designed in order to collect their operational logs and to evaluate the discrimination probability of the proposed method. However, it is necessary to use actual office works so as to evaluate intellectual productivity in office. In the future, the authors will confirm whether the method can be applied to other tasks and actual office works.

Meanwhile, this study have employed the physiological indices such as EEG, ECG and EMG around left eye, but others such as electrodermogram (EDG) [10,11], cerebral blood flow (CBF) [12] have a possibility to reflect mental states. Therefore other physiological indices should be considered in order to establish more accurate detection method.

5 Conclusion

There are two mental states (work and temporary rest state) in office workers which are changing alternatively during mental works [2]. In this study, the authors have aimed at developing the detection method of these states by measuring physiological indices and conducted a subject experiment.

As the result, the average of the discrimination probability is 80.2 %. This result suggested the possibility that physiological indices could be used to evaluate intellectual productivity such as the efficiency and accuracy of performing mental works. However, the proposed method still cannot be applied to the evaluation of intellectual productivity in actual office works, because the employed tasks were specially designed in order to collect the operation logs in this study. Therefore, it is necessary to consider the detection method available to office works.

Finally, the authors are aiming at developing the more accurate detection method applied to the evaluation of the intellectual productivity in office.

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