Development of an Evaluation Method for Office Work Productivity

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Abstract. The authors have developed a performance test, CPTOP2 (Cognitive Performance Test of Productivity), which consists of four task tests to evaluate cognitive abilities of office workers in order to quantitatively and objectively evaluate their productivity by controlling office environment. In addition, the testing time of CPTOP2 becomes shorter than conventional CPTOP2 in order to introduce it in evaluation of actual office environment. In this study, two subject experiments were conducted to verify its function and accuracy. The function of CPTOP2 was verified by measuring brain activity by fNIRS when conducting CPTOP2 test. The accuracy of CPTOP2 was verified by comparing improvement of performance indexes of CPTOP2 with that of simulated office work.

Keywords: office environment, performance test, fNIRS, cognitive ability.

1 Introduction

Energy saving is one of the countermeasure of increasing green house gas emission caused by increasing recent worldwide energy consumption. In Japan, the government has promoted that the temperature of air-conditioning system in the summer should be 28 degree Celsius and office workers are recommended to wear casual style cloths. However, the drop in productivity of office workers caused by the energy saving may extend their labor time and this may consume more energy[1].

On the other hand, recent studies have revealed that improvement of office environment may improve the productivity of office workers[2]. However, the method which evaluates office productivity objectively and quantitatively has not been established yet, because office works include not only simple repetitive works but also creative and atypical work. If such method is developed, it is expected that it can be utilized for the design of office room and the evaluation of energy consumption based on office work productivity.

As mentioned above, it is difficult to directly measure the office work productivity because there are various kinds of office works. In this study, therefore, the followings are assumed.

1. Office work is a brain work so that it mainly employs human cognitive abilities.
2. The productivity of office work is decided how much the cognitive abilities can be utilized.
3. The utilization of each cognitive ability can be measured by the corresponding performance test.
4. Total office work productivity can be valuated as the utilization of each cognitive ability and its weight depending of the office worker's individual task.

The authors, therefore, had developed an office work performance test, CPTOP (Cognitive Performance Test for Office Productivity) based on the above assumptions, aiming at establishing an evaluation method of office work productivity[3]. CPTOP can evaluate how much cognitive abilities can be applied in an office environment by conducting performance tests.

In order to reveal the abilities necessary for the office work, the authors defined essential abilities based on "Handbook of Human Abilities" written by E.A.Fleishman[4]. Among the human abilities, 21 cognitive abilities such as "oral comprehension" and "memorization" were picked up as the elementary abilities for the office work. In addition, the interview and questionnaire were conducted to the workers who were general clearks, engineers, managers, researchers and so on. Based on the results of the interview and questionnaire, 11 essential abilities were picked up and CPTOP consists of 11 task tests corresponding to the 11 essential abilities.

In addition, the authors have conducted laboratory experiments where office work productivities were measured by using CPTOP under two lighting conditions which are normal lighting (fixed to 750 lux) and circadian rhythm lighting where illumination was controlled from hour to hour in order to adjust human circadian rhythm[5]. As the experimental result, it was found that the results of both CPTOP and simulated office work under the circadian rhythm lighting were improved approximately 4% comparing with the normal lighting.

The above experiments were conducted with employing subjects in laboratory experiment room. Environmental conditions such as temperature, humidity, noise, air circulation were strictly controlled in the experiments, however, it take 95 minutes to conduct 11 performance tests of CPTOP. When office work productivity in an actual office is measured by using CPTOP in the future, the testing time of 95 minutes is too long because it disturbs their office works for 95 minutes. It is, therefore, required to shorten the testing time in order to introduce it to the evaluation of office work productivity in actual office environment.

2   Development of CPTOP2

In this study, 11 task tests for 11 cognitive abilities were reconsidered to reduce the number of task tests and to shorten the whole testing time. As the result, the authors have developed a new performance test, CPTOP2, which is summarized the 11 task tests into only four. Table 1 shows the task tests and the corresponding abilities which each task test can evaluate.

In addition, CPTOP2 has been developed as a web-based software, so that the test can be conducted by using only a PC connecting with the Internet. The total time of CPTOP2 is 34 minutes approximately and is much shorter than that of the conventional CPTOP. Figure 1 shows the example screen shots of CPTOP2.

**Table 1.** Task test of CPTOP2 and cognitive abilities to be evaluated

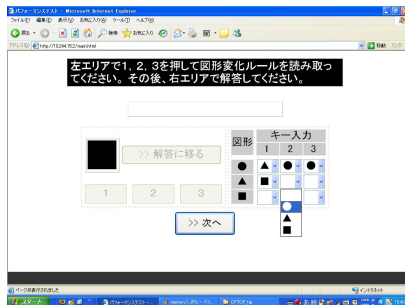| Task test of CPTOP2	Cognitive abilities to be evaluated
1.Word reordering	Oral Comprehension
	Written Comprehension
	Oral Expression
	Written Expression
2.Block assembling	Fluency of Ideas
	Originality
3.Filling a blank of number series	Mathematical Reasoning
	Number Facility
4.State transition memorization	Inductive Reasoning
	Memorization
Total performance of the above	Selective Attention
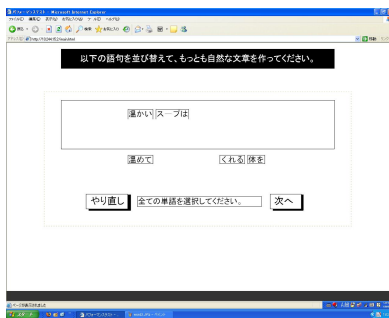
Word reordering
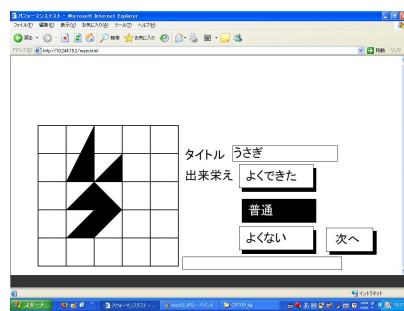
Block assembling
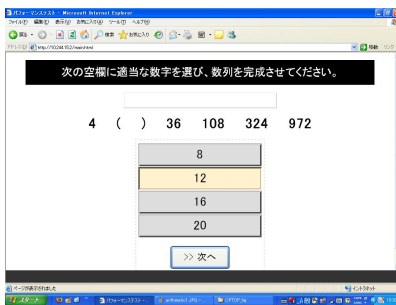
Filling a blank of number series

State transition memorization

Fig. 1. Screen shots of CPTOP2

The details of each task test will be explained in the following sections.

2.1   Word Reordering

As shown in top left of Figure 1, five words are randomly displayed in the window. In this task, these words should be reordered to make a grammatically and semantically correct sentence by clicking the words in correct order. The performance indicator of

this task test is number of correct sentences in a unit time. This task test evaluates linguistic abilities such as oral comprehension, written comprehension, oral expression and written expression.

2.2   Block Assembling

As shown in top right of Figure 1, four black blocks should be rearranged by dragging a mouse to create a meaning shape and entitle it. The example figure shows a shape of "rabbit". The performance indicator of this task test is number of assembled figures in a unit time. This task test evaluates the abilities related to ideas such as fluency of ideas and originality.

2.3   Filling a Blank of Number Series

As shown in bottom left of Figure 1, a number series with a blank is displayed in the window. In this task, a number which matches the blank should be chosen among four choices below. The number series is one of arithmetic progression, geometric progression and Fibonacci sequence. The performance indicator of this task test is number of correct answers in a unit time. This task test evaluates mathematical abilities such as mathematical reasoning and number facility.

2.4   State Transition Memorization

As shown in bottom right of Figure 1, one of the figure "circle", "triangle" and "square" and the buttons of "1", "2" and "3" are displayed in the window. The figure is changed by pressing one of the buttons and all of the change pattern should be memorized. After pressing "answer" button, "1", "2" and "3" buttons can not be pressed and memorized change pattern can be input in the right part. The performance indicator of this task test is number of correct memorized patterns in a unit time. This task test evaluates inductive reasoning and memorization.

3   Verification of Evaluation Function of CPTOP2

In order to verify the evaluation functions of CPTOP2, a subject experiment was conducted using fNIRS (functional Near-Infrared Spectroscopy). Concretely, based on the localization of brain functions, brain activity was measured with fNIRS while the subjects were conducting each test, in order to check whether corresponding brain anatomies are activated or not. In the verification experiment, the control tasks had been prepared in advance, which realized only mouse movements of each task test without the cognitive parts. And the brain activity during each task test was calculated by subtracting the activities while conducting the control task from that while conducting CPTOP2 task test. Six subjects (three males and three females) joined the experiment in total.

As the result of the measurement, it was confirmed that each CPTOP2 task test activated the corresponding brain anatomies, for example, the state transition memorization test activated both sides of frontal lobe which corresponds to short term memory of human cognitive function as shown in Figure 2.
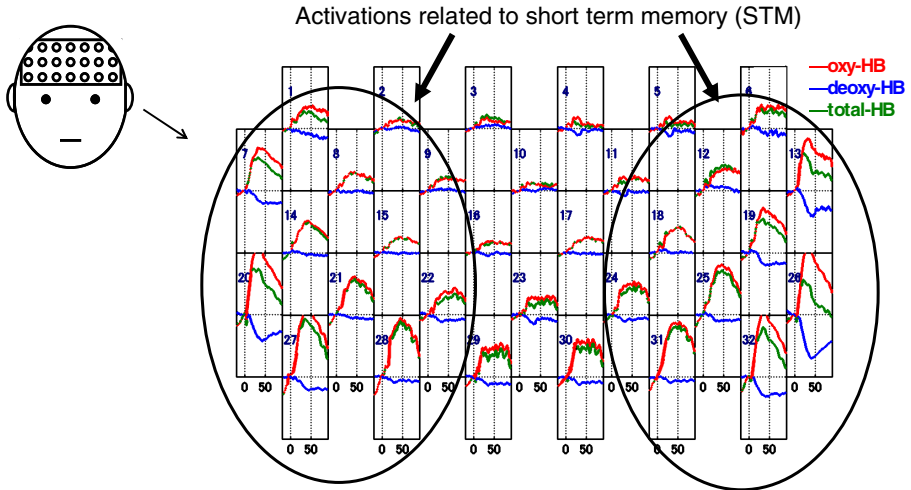
Fig. 2. An example result of measurement while conducting state transition memorization test

4 Verification of Evaluation Accuracy of CPTOP2

In order to verify the evaluation accuracy of CPTOP2, another subject experiment was conducted where illumination conditions were controlled. The details of the experiment will be described in this chapter.

4.1 Purpose

The purpose of this experiment was to verify the evaluation accuracy and sensitivity of CPTOP2 by comparing the results of CPTOP2 under normal lighting condition and circadian rhythm lighting condition by task light. Here, the task light means a luminaire which is set just above the desk in order to ensure enough illumination and save energy.

4.2 Experimental Method

Experimental environment. This experiment was conducted in an experimental room where environmental conditions can be controlled. Figure 3 shows the top view of the experimental room and a scene of experiment. There are four desks and four PCs in order that four subjects could join the experiment at the same time. An illumination controllable fluorescent light was installed above each desk as a task light, which color temperature was 5000K and Ra was 84.

In the experiment, two illumination conditions were applied which were "normal condition" and "circadian condition". Under the normal condition, the illumination on the desk was fixed to 750 lux by the task light and other fluorescent lights on the ceiling. Under the circadian condition, the illumination on the desk was controlled as Figure 4.
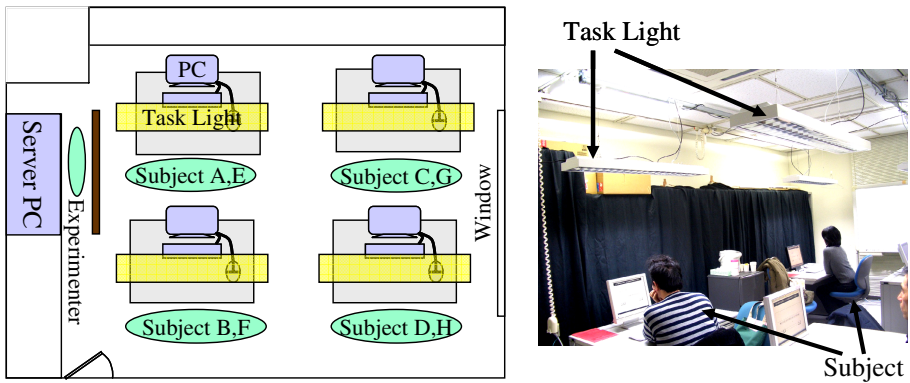
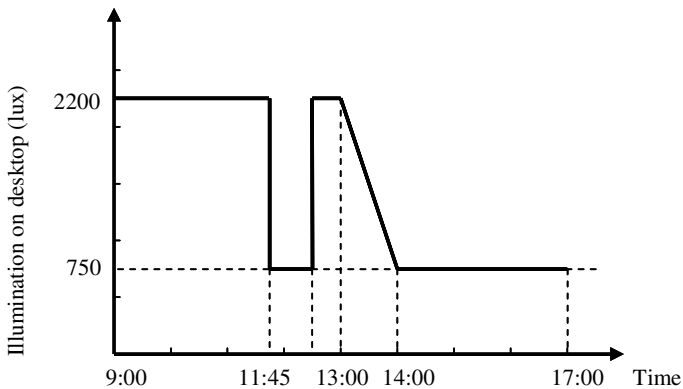**Fig. 3.** Top view of experimental room and a scene of experiment

Fig. 4. Illumination control sequence under circadian condition

Human circadian rhythm can be adjusted by being exposed high illumination in the morning and it leads deep sleep in the night and high arouse in the day time. By applying this illumination condition, human circadian rhythm is supposed to be adjusted properly. In the experiment, the performances of intellectual productivity under these two conditions were compared.

Subjects. Eight subjects joined this experiment, who are three males and five females. The range of their ages were from 27 to 54, and the average age was 40.9. All of them had experiences of office work.

Experimental procedure. The experiment was conducted for eleven days in total as shown in Figure 5. Figure 6 shows the experimental procedure in each day. The first day was a day for practice where task procedures of CPTOP2 and simulated office task were explained by the experimenter and the subjects made a practice for them. At "normal condition I" from 2nd day to 4th day in Figure 5, the lighting condition of the experimental room was set to "normal condition" mentioned in 4.2.1 and the procedure in Figure 6 was conducted. At "circadian condition" from 5th day to 7th day, the

lighting condition was set to "circadian condition" and the procedure in Figure 6 was conducted as well. At "normal condition II" from 8th day to 10th day, the lighting condition was set to "normal condition" again and the procedure was conducted as well. On the last day, the same procedure was conducted as a dummy experiment in order to cancel terminal effect.
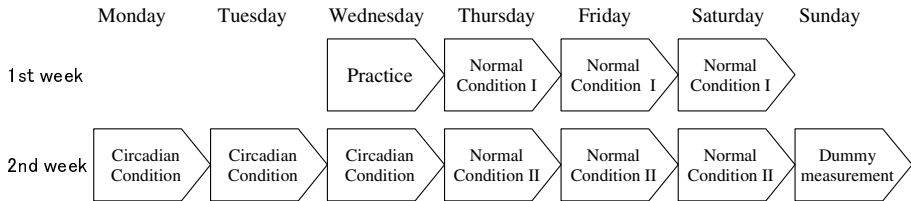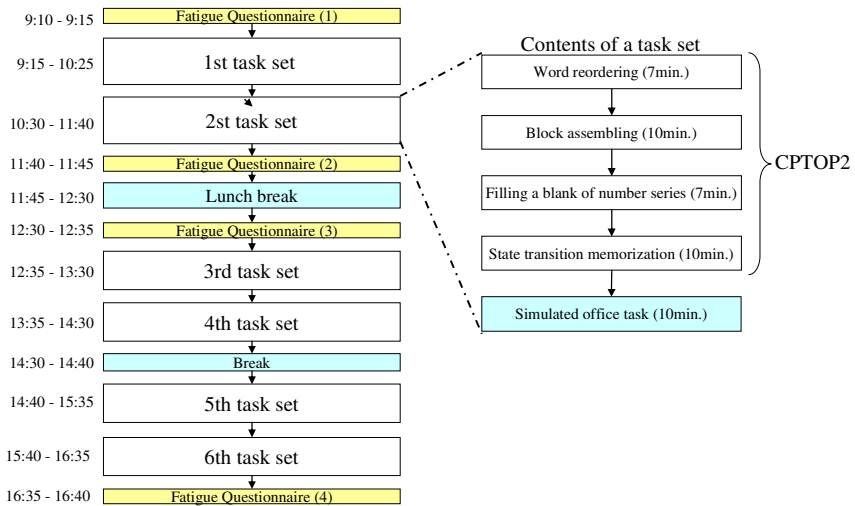
Fig. 5. Schedule of experiment

Fig. 6. Experimental procedure in a day

On each day, fatigue questionnaire was first conducted, then two task sets were given to the subjects. Each task set consists of four task tests of CPTOP2 and a receipt classification task as a simulated office task. After the two task sets, the fatigue questionnaire was conducted at the last of the morning. After lunch break, the fatigue questionnaire was conducted again and two task sets were given as well. After a short break, two task sets were given to the subjects again then the fatigue questionnaire was conducted at the last of the day. Namely six task sets and four fatigue questionnaire were given in a day.

Measured Indexes. The performance indicators of four task tests of CPTOP2 and the simulated office work were measured as performance indexes. The simulated office task was the receipt classification task as mentioned above, in which maximum 200

receipts should be classified into 27 categories according to their amount of money, payee, payment method and account of money spent. The performance indicator of this task is number of classified receipts in a unit time.

Fatigue questionnaire, on the other hand, examines the fatigue states of the subjects in five viewpoints which are sleepiness, discomfort, haze, instability and dullness. It consists of 25 questions and they are answered with five grades.

4.3   Experimental Results and Discussions

Figure 7 shows the average of the normalized performance indexes of each task set. When calculating the normalized performance indexes, it is assumed that the
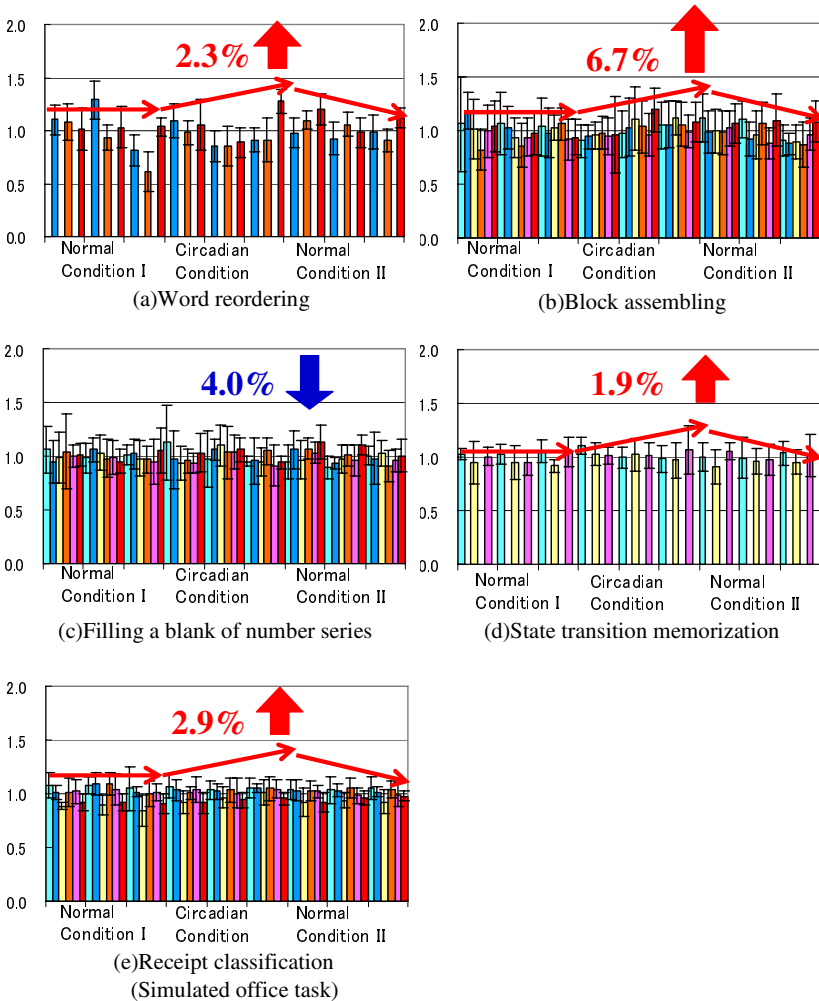

Fig. 7. Normalized performance indexes of CPTOP2 and simulated office task

performance indexes under both "normal condition I" and "normal condition II" are the same, then learning curve of each task test is deduced. The learning curve is assumed to be expressed as the following equation;

$$P_n = P_{\lim} - (P_{\lim} - P_1) \cdot (1 - r)^{n-1}$$

(1)

where

P_n : Performance index of nth test

$P_{\lim}$: Performance index when finishing learning

r : Improvement rate

The parameter $P_{\lim}$ and r can be determined with method of least squares by the performance index of each test under "normal condition I" and "normal condition II". The normalize performance indexes are calculated with the learning curve as the standard line. In this procedure, the normalized performance indexes in which the learning effect was compensated were deduced.

In each graph of Figure 7, the horizontal axis means experimental term and they express "normal condition I", "circadian condition" and "normal condition II" from left to right, while the vertical axis means the normalized performance indexes as bar graphs and their standard deviation as error bars.

As the results, the performance of (e) simulated office task improved 2.9% under "circadian condition" comparing with those under "normal condition". Because the circadian rhythm illumination could adjust the human biorhythm, the concentration of day time could be improved. This result matches well with the previous studies by the authors[6]. On the other hand, the result of CPTOP2 which were (a) word ordering test, (b) block assembling test and (d) state transition memorization test improved 2.3%, 6.7% and 1.9%, respectively. The average of these results matched well with that of (e) simulated office task. The result of (c) filling a blank of number series test, however, dropped down -4.0%. It was because the solution strategy of the filling a blank of number series test changed frequently so that the learning effect of the test could not be compensated properly. This test should be improved in the future, especially the answering method should be changed.

On the other hand, most of the results of fatigue questionnaire have no significant difference between normal condition and circadian condition. The only cases which have significant difference ($p<0.01$) are;

1. sleepiness under circadian condition was lower than that under normal condition and
2. discomfort under circadian condition was higher than that under normal condition.

The reason of (1) is supposed that biorhythm of the subjects were adjusted by the circadian rhythm lighting, while the reason of (2) is supposed that the circadian rhythm lighting kept subjects' arousal level for longer time.

5 Conclusion

In this study, an intellectual performance test, CPTOP2, has been developed from the viewpoint of human cognitive functions. The test time of CPTOP2 was shortened

comparing with conventional CPTOP in order to introduce it into actual offices. In addition, subject experiments were conducted in order to verify its evaluation function and accuracy. As the result of fNIRS measurement, it was found the each task test of CPTOP2 activated the corresponding brain anatomies. As the result of the illumination experiment, average improvement of each test except filling a blank of number series test under the condition of circadian rhythm illumination matched well with that of the simulated office task.

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