Process in Evaluation Index of Intellectual Productivity Based on Work Concentration

K. Uchiyama, K. Oishi, K. Miyagi, H. Ishii, and H. Shimoda

Abstract—The authors have proposed a concentration time ratio (CTR) as a new evaluation index of intellectual productivity, which had been difficult to be quantitatively evaluated, with a concept of concentration on intellectual work. When quantitatively evaluating intellectual productivity with simple cognitive task method, the result is often affected by learning effect. In order to evaluate how office environment affects the CTR when an office environment is changed, a subject experiment was conducted in which the illumination condition of the room was changed. As the result, the performances of cognitive tasks were affected by the learning effect, however it was found that the index was affected not by the learning effect but by changing the illumination conditions.

Index Terms—Intellectual productivity, EM algorithm, cognitive performance, task and ambient light, work concentration.

I. INTRODUCTION

After the accident of Fukushima Daiichi NPP in Japan, we are suffering from lack of electricity and various energy saving activities have been carried out not only in industrial sector but also office buildings. There are many intellectual works, such as information management and document creation conducted in offices, and the drop of their productivity caused by the energy saving may extend their labor time and this may consume more energy. However, it is difficult to evaluate the difference of intellectual productivity caused by the work environmental changes. Intellectual productivity is defined by Woods [1], and is the efficiency to do intellectual works when people invest the cognitive resources. There are some methods to measure it, for example, subjective evaluation [2], use of physiological indicators [3] and use of cognitive tasks [4], [5]. However, the method which evaluates office productivity objectively has not been established. A learning effect causes a difficulty to measure intellectual productivity when cognitive tasks are used. In order to cancel the learning effect, a long term experiment as 2-3 weeks is needed in many cases to deduce the learning curve and compensate the effect by the curve [6].

In this study, therefore, a new evaluation index and its measurement tool has been proposed based on a concept of

work concentration and a subject experiment was conducted with the index to confirm its effectiveness. Original cognitive tasks, a word classification task and a mental addition task, had been used in the experiment.

II. COGNITIVE MODEL OF WORK CONCENTRATION

The authors have already proposed the three-state work model [7], and it assumes that the cognitive process of office workers can be classified into "working state", "short-term rest state" and "long-term rest state". In the working state, they conduct the task and work process is proceeding. In the short-term rest state, they unconsciously stop the task for a short time. In the long-term rest state, they consciously stop working to take a break or think other things for a long time. Fig. 1 shows a work state model which is used in this study. In this model, the cognitive state of office workers can be expressed the transition of these three states while conducting an intellectual work. When they concentrate on their work, they are considered in the working state or short-term rest state. On the other hand, in the long-term rest state, they don't concentrate on them. Along with this idea, the intellectual productivity can be expressed as a time ratio of concentration state among total labor time.

When they perform cognitive tasks which have a uniform difficulty, the answering time must be the same. However, according to the model, the answering time will be distributed as how the short-term rest and the long-term rest are inserted in the work time. When the probabilities of the state transitions are assumed to be fixed values, the distribution of the answering time can be expressed by superposition of two log-normal distributions as shown in (1), (2) and (3). A lower distribution is decided by μ_l and σ_l , while a higher distribution is decided by μ_h and σ_h . In addition, parameter p is the ratio of mixture distributions as shown in Fig. 2.

In this study, the answering time of cognitive tasks is measured and the two log-normal distribution functions are estimated by the distribution of the answering time.

$$f_l(t) = \frac{1}{\sqrt{2\pi}\sigma_l t} \exp\left(-\frac{(\ln(t)-\mu_l)^2}{2\sigma_l^2}\right) \cdot pt \quad (1)$$

$$f_h(t) = \frac{1}{\sqrt{2\pi}\sigma_h t} \exp\left(-\frac{(\ln(t)-\mu_h)^2}{2\sigma_h^2}\right) \cdot (1-p)t \quad (2)$$

$$f(t) = f_l(t) + f_h(t) \quad (3)$$

The left log-normal distribution expresses the state transition between the working state and the short-term rest

Manuscript received May 15, 2013; revised August 20, 2013.

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state, while the right one expresses among the working state, the short-term rest state and the long-term rest state. The parameters of the distributions are estimated from the measured answering time by maximum likelihood using EM(Expectation Maximization) algorithm [8], [9]. When concentration time(CT) is defined as the total amount of time in the concentration state, it can be calculated by multiplying expected answering time of the left distribution by the total number of answers(N) as shown in (4). Using this CT, concentration time ratio(CTR) can be calculated as an index of intellectual productivity as shown in (5). In this study, the authors have proposed the CTR as a new index of intellectual productivity.

$$CT = \exp\left(\mu_l + \frac{\sigma_l^2}{2}\right) \cdot N \quad (4)$$

$$CTR = \frac{CT}{T_{total}} \quad (5)$$

where T_{total} means total working time.

Fig. 1. Work state model.

Fig. 2. Histogram of answering time as lognormal distributions.

III. EVALUATION EXPERIMENT

A. Design

An experiment was conducted to confirm that the proposed concentration time ratio can evaluate the influence of intellectual productivity by change of illumination environment. 19 male subjects in their age of 20-55 participated in the experiment. The illumination conditions are “Ambient” condition and “Task&Ambient” condition as shown in Table I. An example of the experimental environment is shown in Fig. 3. There were a desk, a chair

and posters that simulate the bookshelf in front of the subjects in order to realize similar situation to actual office environment. In Task&Ambient condition, spot light irradiation was expected to make the subjects easy to concentrate on tasks. The room temperature was set to 25 ± 1 degrees Celsius, humidity was set to 20-40 %, CO2 concentration was kept under 800 ppm and noise level was kept under 55 dBA. By introducing the task light, the energy consumption of Task&Ambient condition is only 46 % of that of Ambient condition.

The experiment time schedule is shown in Fig. 4. The subjects have been participated the experiment in three consecutive days, and they were instructed to perform both a mental 2-digit addition task and a word classification task in 30 minutes respectively in one task set. They practiced both tasks in the morning on the first day, after lunch they performed three sets of two tasks including the training set, and they also performed the extra set in 15 minutes in order to prevent from the terminal effect. The illumination condition on the first day and the third day was different from that on the second day. In order to take the counter-balance, the subjects were divided into two groups. In addition they also responded to the questionnaires.

TABLE I: ILLUMINATION CONDITIONS

Illumination Conditions	Ambient Light	Task Light
Ambient	750 lux(5,000K)	0 lux
Task&Ambient	100 lux(3,000K)	650 lux(6,000 K)

Fig. 3. An example of experimental environment (“Task&Ambient” condition).

Fig. 4. Experimental procedure.

The cognitive tasks are required some conditions in an evaluation experiment. One of them is that they can continuously answer problems with their own paces. As the second, they should have the unified difficulty of each problem. Lastly, they should not change their solving strategy.

Although it is necessary to create new ideas and something complete by dialogue in offices, most of office works are typical and regular works. Therefore, a word classification task and a mental addition task were introduced.

A word classification task is shown in Fig. 5. It is the task where a given word on a sheet of paper is required to be classified into one of 27 categories. Sorts of the first character, hiragana, katakana and kanji. The first vowels, “i”, “u” and “o”. The meaning categories of the word, creature, proper noun and artificiality. The subjects are required to answer the proper category by pressing one of 27 buttons on the display of iPad. The answering time of each problem is measured by iPad and recorded into a server computer connected by a network.

A mental addition task is shown in Fig. 6. It is the task answering added 2-digit number. At first, 2-digit number is shown on a display of PC and they are required to memorize it, then another 2-digit number is shown after pressing enter key. They do a sum of two numbers in their heads and input the answer with a numeric keypad. Pressing enter key moves to the next problem after inputting the answer. The answering time of each problem is measured by PC and recorded into a server computer.

Fig. 5. Word classification task.

Fig. 6. Mental addition task.

B. Result

Fig. 7 and Fig. 8 show the performance of word classification task which is expressed as the number of answers a minute while Fig. 9 and Fig. 10 show the performance of mental addition task. Here the performance is defined as the number of answering problems per minute. They were compared in corresponding tasks in corresponding days. As the result of t-test, it was found that their performances of both tasks were improved day by day. Even on the first day and the third day in which the illumination conditions were the same, the performances were obviously

improved. This can be explained by a learning effect. In order to compensate it, they must performed at least several tens sets to deduce the learning curve and the performances would be modified by the curve. Therefore, the difference of the intellectual productivity cannot be measured correctly by the task performance in a short term.

Fig. 7. Comparison of task performance (classification task).

Fig. 8. Comparison of task performance (classification task).

Fig. 9. Comparison of task performance (addition task).

On other hand, the concentration time ratios were calculated by dividing the total labor time by the total answering time of each condition, however, a few of them could not be calculated because the parameters could not be found by EM algorithm as shown in Fig. 11. It indicates that they were continuing to focus on the task closer to 100 % in the set of tasks. Fig. 12 and Fig. 13 show the comparison of the concentration time ratios in each day for each task. It was

not found that the both tasks were significantly varied in the same illumination conditions. In other words, the concentration time ratios are not affected by the learning effect. Fig. 14 shows the comparison of the concentration time ratios for difference illumination condition for each task. In a word classification task, the concentration time ratio under Task&Ambient condition was 2.7 % point higher than that under Ambient condition ($p<0.05$). In a mental 2-digit addition task, the concentration time ratio under Task&Ambient condition was also higher however there was no significant difference. As the result of the above, it was found that the concentration time ratios proposed in this study has a possibility to evaluate the change of intellectual productivity quantitatively by the change of work environment with cancelling the learning effect. And also Task&Ambient condition is better than Ambient condition for keeping concentration.

Fig. 10. Comparison of task performance (addition task).

Fig. 11. An example image of Analyzed data.

Fig. 12. Concentration time ratio each day (classification).

Fig. 13. Concentration time ratio each day (classification).

Fig. 14. Comparison of concentration time ratio.

IV. SUMMARY AND FUTURE WORK

In this study, the authors have proposed the concentration time ratio (CTR) as a new index of intellectual productivity. To evaluate how the proposed index is affected by changing office environment, a subject experiment was conducted in which the illumination condition of the room was changed. As a result of evaluation experiment in this study, it was found that evaluating the change of office illumination environment by task performance is difficult in short term experiment procedure. However, it was also found that the CTR has a possibility to evaluate it objectively and quantitatively. There are some problems remaining to evaluate the change of intellectual productivity more accurately. One of them is that there were a few experimental data which distribution parameters could not be estimated because their long-term rest occurred irregularly. To solve this problem, the authors will try to fit a log-normal distribution with a focus on only “working state” and “short-term rest state”.

In the future, the estimation method should be improved in order to deal with such irregular work state behaviors. Furthermore, the authors will measure the changes of CTR in various office environment factors by the developed tool and will pursuit an ideal office environment.

ACKNOWLEDGMENT

A part of this work was supported by JSPS KAKENHI Grant Numbers 23360257.

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