Proposal of Intellectual Productivity Model Based on Work State Transition

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Abstract. Aiming to reveal the mechanism of intellectual productivity variation of office workers, the authors analyzed the behavior of subjective experiment assuming office work, and proposed an intellectual productivity model. The model is a three state transit model assuming "working state", "short-term rest state" and "long-term rest state". A subject experiment was conducted where illuminance on the desk and work motivation were controlled to vary their productivity. The result was analyzed with this model and it is confirmed that the model can explain the productivity variation.

Keywords: intellectual productivity, human modeling, working state, illuminance.

1 Introduction

In office buildings, the energy consumption of lighting and air-conditioning systems account for big percentage of total energy consumption [1]. Therefore many office building have been trying turning down air-conditioning and dimming a light off for saving energy. After East Japan earthquake and the following Fukushima nuclear disaster, the lack of electricity has promoted energy saving policies such activity. On the other hand, many studies have revealed that indoor environment condition affects intellectual productivity and health of office worker [2]. For example, a circadian rhythm lighting which adjusts human circadian rhythm by high illumination light, promotes intellectual productivity [3]. However, it is reported that the effectiveness of indoor environment is also dependent on other factors such as work motivation. In addition, the mechanism of intellectual productivity variation has not been revealed.

In this study, therefore, the authors analyzed the behavior of subjective experiment assuming office work, and proposed an intellectual productivity model. In addition, a subjective experiment was conducted, in which the intellectual performance was controlled by lighting environment and work motivation. With the experiment result, authors discussed the details of the model by comparing the results of the computer simulation based on the model with the experimental results. If this model is completed by the result of experiment, which the authors are planning to conduct for revealing the

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effect of indoor environment, we can predict productivity without experiment, and optimize the balance between productivity and energy use by the model.

2 Intellectual Productivity Model

2.1 Intellectual Productivity

There are various kinds of office works, and the human abilities for office work also various. But, works which occupy a considerable amount of working time are mental tasks which have standard routine. Therefore, in this model, an intellectual productivity means the performance of less-creative cognitive task such as deskwork or information management tasks.

The working style in real office is seem that office workers devote a given time period for their work. The period would be more than 30 minute or several hours. And workers address their works at their own pace in this period. Therefore, in this study, working style is assumed as above one.

2.2 Time-Series Analysis of Solving Tasks

Aiming to guess the mechanism of work productivity variance, the feature of an experimental result was extracted with time series charts like Figure 1. Its ordinate axis shows the times of answering each problem, when checking receipt task was given. Abscissa axis shows the lapsed time. A receipt checking task is simple and the answering time should be almost same in every receipt. But, the distribution is wide. And there is a tendency that the frequency of problems which need long time is high. For this analysis, the authors assumed that the main process of productivity variance is these short rests to relieve fatigue. In addition, the histograms sometimes have long tail. It suggests that there are two type of rest.

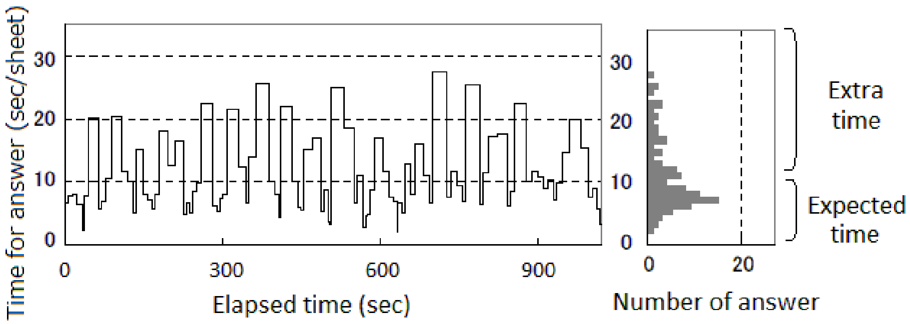


Fig. 1. Time series analysis of answering speed

2.3 Intellectual Productivity Model

Based on above analysis results, the authors had proposed an intellectual productivity model, which is assuming three state transition. Fig.2 shows the concept of this model. The features are as follows;

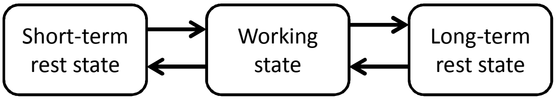


Fig. 2. Work state model

- There are 3 states, which are "Working state", "Long-term rest state" and "Short-term rest state".
- "Working state" is a state assumed working on a task without trouble. Under this state, the task progresses and MF (mental fatigue) increases.
- "Long-term rest state" is a state assumed conscious rest from several seconds to dozens of seconds. Under the long pause, the task does not progress and MF decreases.
- "Short-term rest state" is a state assumed working on a task with trouble. Under the short pause, the task does not progress and MF increases. This state might be a phenomenon of "Blocking" named by Bills [4].
- State transition probability between the work state and the long pause state is affected by MF.
- State transition probability between the work state and the short pause state is a fixed value.

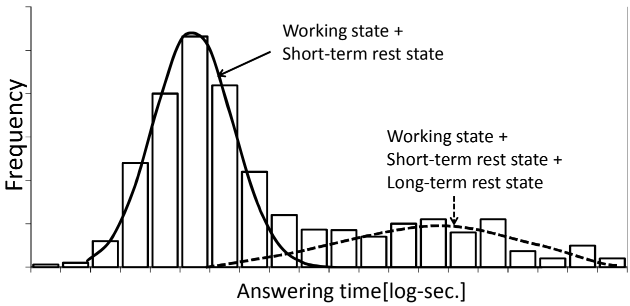


Fig. 3. Histogram of answering time and lognormal distributions

The transition probability is assumed that it is affected with mental fatigue, but it can be treated fixed value in long time scale. It means, these 3 state model could be considered as the superposition of two state Markov Model. It is known that a lognormal distribution is shown when two state Markov model (S1 to S2: p; S2 to S1: q) is assumed. Because of these reason, it is considered that the histogram of the answering time of each problem can be approximated as the sum of two lognormal distributions as shown in Figure 3. The parameters of two lognormal distributions can be calculated by the approximation as shown in Figure 4. At that time, the histogram can be expressed as formula (1) using the parameters.

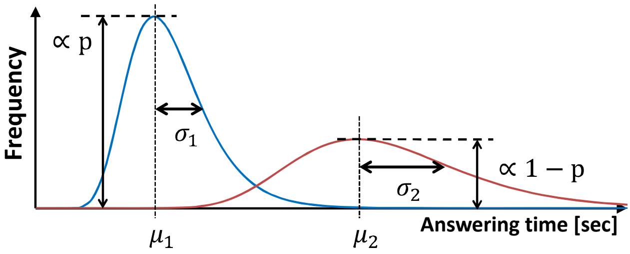


Fig. 4. Lognormal distributions and their parameters

$$f_1(t) = \frac{1}{\sqrt{2\pi}\sigma_1 t}\exp\left[-\frac{(\ln(t)-\mu_1)}{2\sigma_1^{\ 2}}\right]\cdot pt$$
$$f_2(t) = \frac{1}{\sqrt{2\pi}\sigma_2 t}\exp\left[-\frac{(\ln(t)-\mu_2)}{2\sigma_2^{\ 2}}\right]\cdot(1-p)t \quad (1)$$
$$f(t) = f_1(t) + f_2(t)$$

Here, μ_1, μ_2 expresses the averages of lognormal distributions, σ_1, σ_2 expresses their standard deviations, and $p, (1-p)$ express their height ratios.

3 Experiment Focused on Illuminance and Work Motivation

In order to confirm that the model can explain actual productivity variance, the authors conducted a subjective experiment, in which the intellectual performance was controlled by lighting environment and work motivation

3.1 Objective

The first purpose of this experiment was to collect the sample of intellectual productivity variation for simulating with the productivity variation models. The second purpose was to discuss the detail of intellectual productivity variation caused by illumination or work motivation with the model.

3.2 Experimental Method

In this experiment, 24 subjects (male: 22, female: 2, mean age: 26.4) participated. They were given two cognitive tasks and the performance was measured under two illuminance conditions and two work motivation conditions. Two illuminance conditions were prepared which are “Normal illuminance” and “High illuminance” conditions. Under the normal illuminance condition, the illuminance on the desk was fixed to 750 lux, which value is usually used in office. Under the high illuminance condition, the illuminance was fixed to 2,500 lux which is effective to improve arousal level and is expected to improve intellectual productivity [3]. As shown in Figure 5, the illuminance was controlled by task lighting.

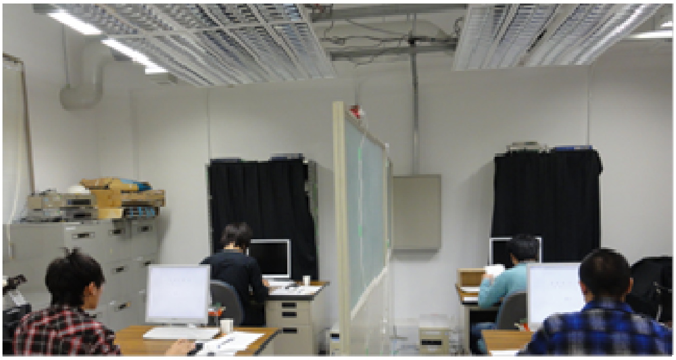


Fig. 5. Experimental environment

Two work motivation conditions were also prepared which were “High motivated” and “Low motivated” conditions. Under high motivated condition, the subjects were instructed that extra reward would be paid according to their task performances. Under low motivated condition, they were instructed that this task was not so important and they don’t need to conduct it hard.

The prepared cognitive tasks were a receipt classification and one-digit addition. The receipt classification was a cognitive task simulated office work. As shown in the right of Figure 6, twenty seven table cells categorized according to amount of money, date and type of shops was shown on the display of iPad. In this task, one of the cells should be chosen according to the fictitious receipts as shown in the left of Figure.XX. One receipt is usually processed in five to ten seconds. One-digit addition is a task to input the sum of two one-digit numbers on the computer. One addition task is usually solved about one second.

Figure 7 shows the flow of the experiment. The first day was the day for practice. After informed consent to the subject, the procedures of tasks were explained and they made a practice. The 2nd and 3rd day were the days for measuring intellectual productivity variation. On each day, a fatigue questionnaire and a CFF (Critical Flicker Frequency) measurement were conducted, and then four task sets were given to them. Each task sets consists of the receipt classification and the one-digit addition task for 30 minutes and the fatigue questionnaire and the CFF measurement. After the 2nd task set, there was a lunch break and the illuminance condition was changed from that in the morning. In the morning of the 2nd day, the normal illuminance condition was settled while the high illuminance condition was settled in the morning of the 3rd day for the half of the subjects. For the remaining half, the illuminance condition pattern was reversed. In the 1st and 3rd task set, high motivated condition was settled. In other task set, low motivated condition was settled. On the last day, a dummy task set was given to avoid a terminal effect.

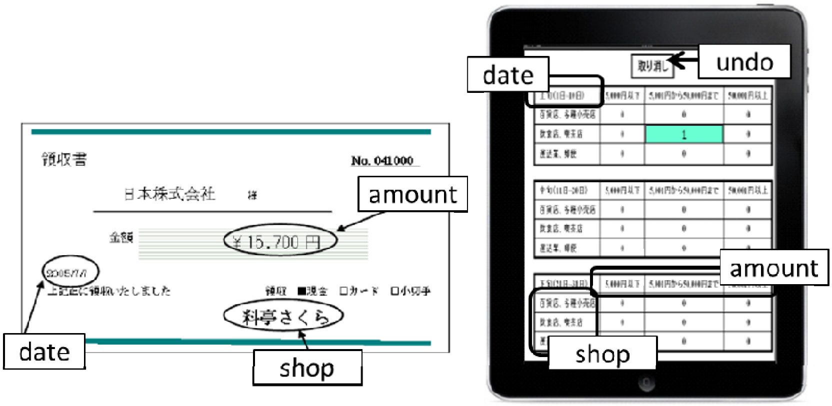


Fig. 6. Image of receipt classification task

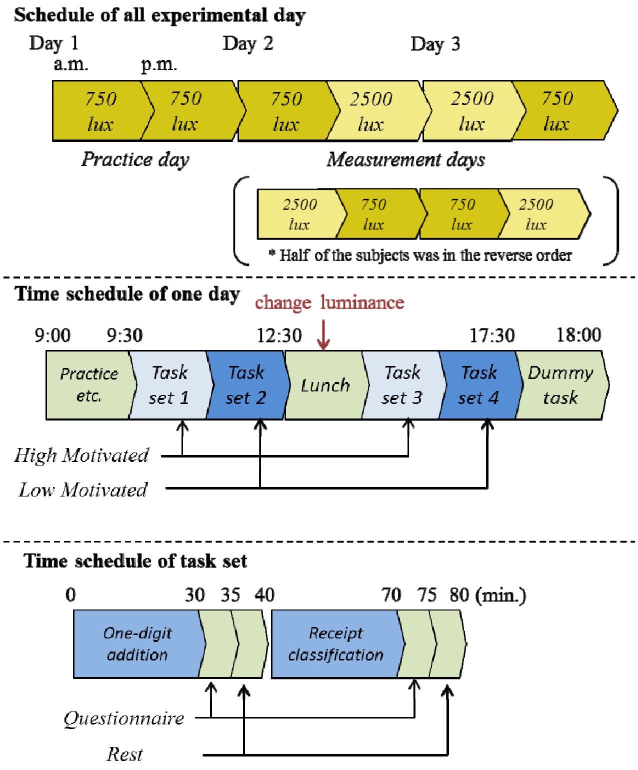


Fig. 7. Experimental procedure

3.3 Results

Experimental Results. Figure 8 shows the results of the task performances. The averages were compared with paired sample t-test. The performance of the receipt classification and the one-digit addition under the high motivated condition was higher than that under the low motivated condition ($p<0.01$). The illuminance conditions made no difference.

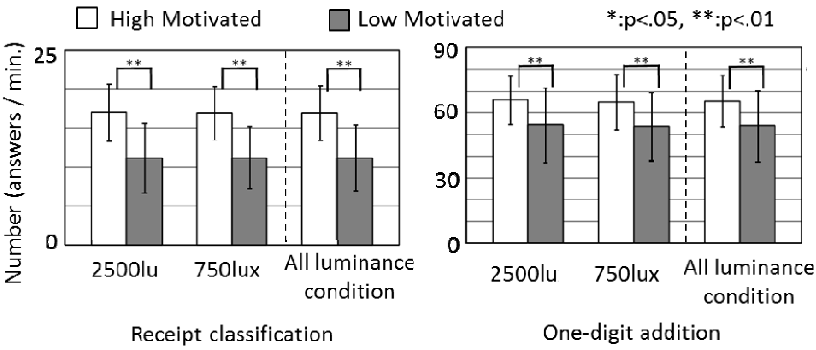


Fig. 8. Task performance of cognitive tasks

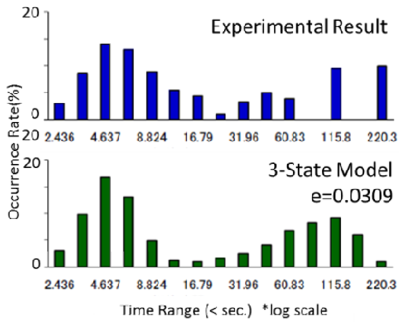


Fig. 9. Comparison of the model simulation and subjective experimental result

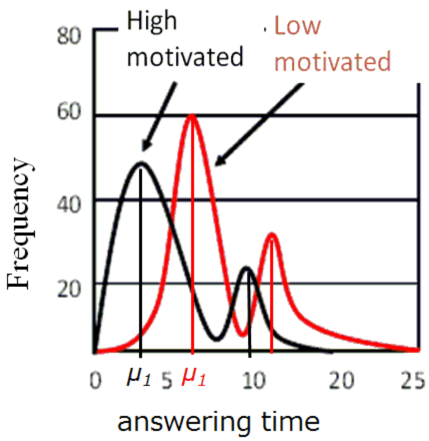
Analyzed Results with the Model. Using the concept of intellectual productivity mode, the answering time histogram of experimental data was approximated as sum of two lognormal distributions. five parameters (μ_1, μ_2, σ_1, σ_2, p) in formula (1) was optimized to minimize the error E, which is a quantitative index of reproduction accuracy and it is defined as formula (2).

$$Error\ E = \frac{1}{n}\sqrt{\sum_{1}^{n}(Y_{sim\_k} - Y_{\exp\_k})^2} \tag{2}$$

For each experimental data, model parameters which made the least Error E were derived with a genetic algorithm method. As a result, it is revealed that most of experimental result is well approximated as shown in figure 9.

3.4 Discussion

Derived model parameters were compared with work motivation condition. As shown in Figure 10, μ_1 and μ_2 in high motivated condition is shorter than them in low motivated condition (p<0.001). It means the time range of short-term rest and long-term rest become shorter in HM condition. This difference is the reason why the productivity was changed with work motivation condition.



Condition	HM	LM	Significant difference
μ_1	3.24	5.74	P < 0.001
σ_1	5.82	16.69	
μ_2	1.46	1.84	P < 0.001
σ_2	1.42	1.52	

Fig. 10. Comparison of model parameters with motivation condition

4 Conclusion

In this study, the authors have proposed an intellectual productivity model. In this model, there are three state, working state", "short-term rest state" and "long-term rest state" and they transit with probability. Considering with this model suggest that the answering time of cognitive tasks, in which the difficulty of each problem is almost same, approximated a sum of two lognormal distributions.

In addition, a subjective experiment was conducted, in which illuminance on the desk and work motivation were controlled to vary their productivity. As a result, the task performance was improved by high work motivated condition. And this histogram was well fitted with approximated equation. It means the intellectual productivity model can explain productivity variance well. The parameters, which was used for fitting the experiment results, was significantly changed by motivation condition. In the future, it is expected that the mechanism of productivity variance is revealed more detail with this model. And the authors planning a development of evaluating productivity method based on this model.

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