Development of "Comparison Task" to Measure Intellectual Concentration Affected by Room Environment

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ABSTRACT
The authors have been developing CTR (Concentration Time Ratio) index, a quantitative measurement index analyzing the answering time distribution of receipt classification task as a cognitive task with uniform difficulty. However, the receipt classification task has some issues. In this paper, a new cognitive task, "comparison task" has been proposed. It has been developed based on the aspect of cognitive psychology and human information processing. Two experiments were conducted to assess the comparison task. One experiment was conducted by using NIRS (Near-infrared spectroscopy) to investigate cerebral blood flow of prefrontal area and Broca's area while conducting the task to confirm that it employs linguistic ability and numerical ability. The other experiment was an environmental evaluation experiment to confirm that the answering time distribution of the task was properly affected by the room environment. As the result, the calculated CTRs showed the difference of environmental conditions.

Keywords
Intellectual productivity, Environmental evaluation experiment, NIRS, Work environment, Cognitive task

1. INTRODUCTION
As intellectual activity has been getting important in not only education but also our daily works, research studies on intellectual productivity have become popular these days. Recent studies show improvement of intellectual productivity brings great benefits [1], and many developers have been working on to promote the intelligent productivity by using various ways. On the other hand, there is no established quantitative measurement method of intellectual productivity, so it is difficult to compare many researches comprehensively and the research results have no universality. Therefore, the authors have been developing CTR, a quantitative measurement index of intellectual productivity based on the time ratio of intellectual concentration [2].

A receipt classification task has been conventionally employed as the cognitive task for CTR, which is a question set of unified difficulties. However, the cognitive task has some issues, such as the difficulty of conducting experiments and the less appropriateness of the measurement method for concentration in office environment or learning environment. Thus, in this research, a new cognitive task has been developed to overcome the issues of CTR.

1.1 Related Studies
Recent studies have revealed that improvement of office environment may improve the intellectual productivity of office workers. In these studies, mainly four methods have been applied to evaluate the improvement of intellectual productivity caused by the improvement of office environment. They are (1)subjective evaluation [3], (2)estimation by physiological indices [4], (3) direct performance measurement of office work and (4)measurement of cognitive task performance [5][6]. As a versatile and quantitative measurement method of intellectual productivity, (4) measurement of cognitive task performance has been often utilized because the results given by (4) are quantitative. Also, experiments using (4) can be conducted in various environments, such as an actual office environment and educational environment. From these aspect, (4) measurement of cognitive task performance is moderate to obtain quantitative and versatile evaluation of intellectual productivity. It is however difficult to accurately evaluate the change of intellectual productivity by the change of work environment because the performance is greatly influenced by learning effect. In order to solve this issue, the authors have been developing a quantitative measurement of intellectual productivity, CTR.

1.2 Receipt Classification Task
A receipt classification task has been employed as the cognitive task for CTR. The questions of a receipt classification task have unified difficulty. The questions require abilities used in office work, because the answering time data has to be affected by exerted condition of cognitive activities used in office work. In order to show the answering rule clearly, the questions are designed in a style resembling a receipt.

Though a receipt classification task satisfies basic conditions of calculating CTR, some issues have been found through conducting many experiment experiences. It has a physical limitation that thousands of paper receipts should be prepared in advance for the measurement. Moreover, it also has other issues such that the measured answering time includes not only the cognitive activity but also a motion of turning over the paper receipts, that it is difficult to measure the error rate, that it may cause boredom because of low abstraction as a cognitive task or because of low difficulty after learning, and that the motivation for the task may change because they can see the progress of the task as remaining bunch of the paper receipts.

In order to solve these issues, digitization of the task has been proposed, however, it could not duplicate the task because it often caused strong sleepiness so that the cognitive task using the paper receipts has kept to be employed until now.

1.3 Purpose

Therefore, the purpose of this study is to develop a new cognitive task to measure intellectual productivity, in order to conduct experiment more easily and appropriately in various environments, and to solve issues mentioned above.

The cognitive task to be developed has to satisfy conditions for calculating CTR, which will be described in the section 3. In addition, because the results of environmental evaluation experiment has high demand for office environment which can bring benefits by improving work place productivity, it has to abstract office work, different from the conventional cognitive tasks such as Stroop test [7] and GO/NO-GO test [8], which focus on the basic brain activities and the concentration on to the task.

2. CTR

CTR is an evaluation index of intellectual productivity by calculating concentration time ratio during working time based on the hypothesis that their works progress while they are concentrating on them. A state when occupying cognitive resources in the ongoing work is defined as concentration state. The advantage of the CTR is that it can cancel learning effect which often appears when repeating cognitive task again and again, by not using the task performance directly as an index.

Figure 1 shows the basic idea of CTR. Its idea originated from cognitive model by Cards [9]. In the concentration model, one of three cognitive states is assumed to appear alternatively while they are being employed intellectual work [10]. The states are (1) working state, (2)short-term pause state and (3)long-term rest state. In (1)working state and (2)short-term pause state, their cognitive resources seem to be occupied in the target work, while they seem to be taking rest in (3)long-term rest state. In the concentration model, therefore, the states (1) and (2) are considered as concentration state while (3) is non-concentration state. When assuming the transition probabilities between (1)working state and (2)short-term pause state are constant and the primitive cycle time of the brain activity is also constant, the answering time distribution of the questions shapes a log-normal distribution as shown in Figure 2 [11]. And the answering time at the right side of the graph which is not included in the log-normal distribution can be considered as the non-concentration state. By calculating the ratio of log-normal distribution among total working time, CTR index can be deduced.

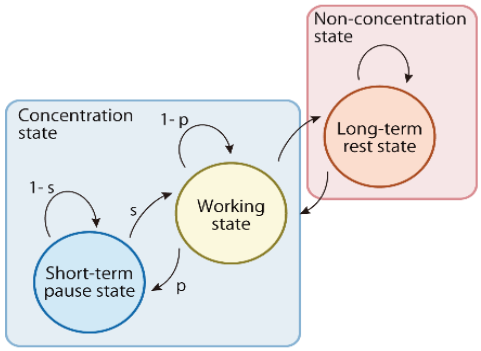

Figure 1. Concentration model of three states.

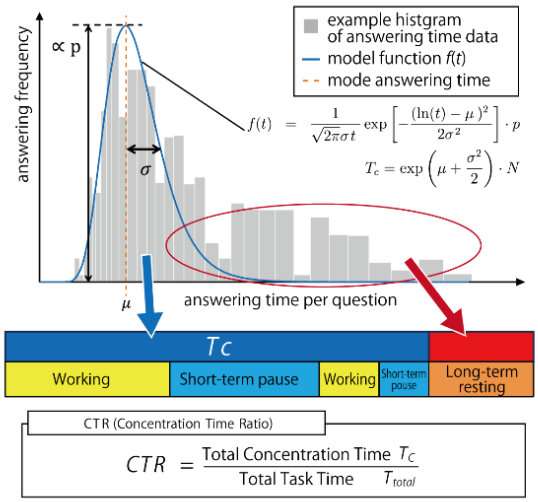

Figure 2. Calculation model of the CTR index.

3. DEVELOPMENT OF COMPARISON TASK

3.1 Requirements for a New Cognitive Task

In order to collect answering time data suitable for calculating the CTR index, a developed cognitive task has to satisfy the following three requirements.

First, all the questions should have unified and proper difficulties. If the difficulties are changed, answering time histogram would be superimpose histograms which have different frequency value as shown in Figure 3, and CTR can't be calculated correctly.

Second, solving strategy has not change while conducting the task. Changing strategy means different actual difficulty even if the task was designed with unified difficulty, which causes the same issues as shown in Figure 3. Thus it is required that the question has a unique solving strategy.

Third, the difficulty of each question has to be appropriate, not too hard nor too easy. Too low degree of difficulty causes sleepiness and daydreaming because participants get bored with answering the tasks. On the other hand, too high degree of difficulty causes longer answering time for each question, which results in reducing motivation in the measurement and extending measurement time. Appropriate difficulty is also important for getting enough number of answering time data in a moderate measurement time.

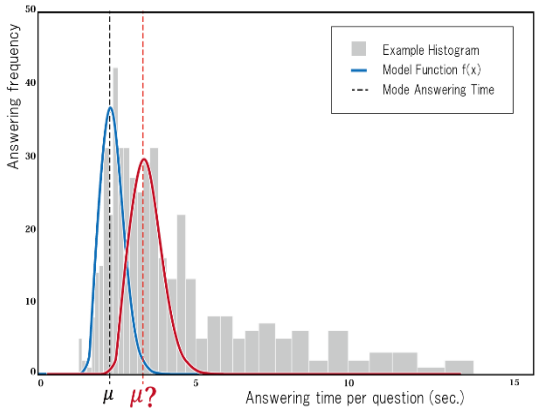

Figure 3. Example of answering time histogram with different difficulties.

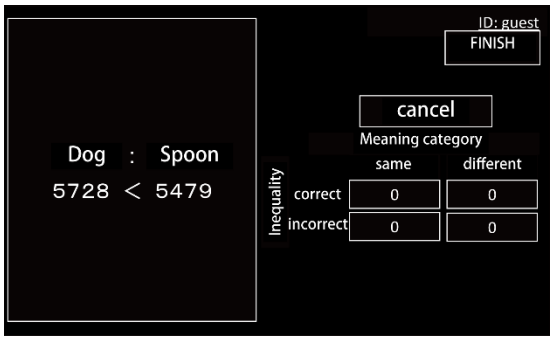

Figure 4. Example of comparison task.

In addition of these three requirements, the task has to employ the cognitive abilities to be used in office work, because CTR has been developed mainly to evaluate office environment. Thus, the new cognitive task should be designed to employ both linguistic and numerical abilities, judging skill and to allocate some cognitive resources to answer.

3.2 Comparison Task

The task developed in this study is called "comparison task" and it has been realized as an iPad application. Figure 4 shows an example snapshot. The task has two factors for one question, which are word comparison and number comparison. Word comparison corresponds to the requirement of linguistic abilities and number comparison corresponds to the requirement of numerical abilities. When solving the questions, they first look at the left half area of the screen as shown in Figure 4, and compare words and numbers, then touch one of the four buttons in the right half area to answer the question.

The simplified questions achieve short learning time and less possibility of changing answering strategy.

3.2.1 Word Comparison Task

In the word comparison task, two words will be presented, and they are selected from four meaning categories, animals, plants, man-made objects and place name. Testers have to recall their meaning categories and judge whether the meaning categories of both words are the same or not.

In order to unify the difficulty of the questions of word comparison task, three meaning subcategories are provided to every meaning category, so that cognitive distance between two presented words can be adjusted not to cause difference of judging difficulty, such that two words has too similar meaning to be easy to judge the answer. In addition, the words to be presented are limited to some range by the meaning subcategories, which results in shorter learning time. In actual condition of the measurement, word lists including the information of four meaning categories are distributed to testers, without the information of meaning subcategories.

All words given in word comparison task have less than five characters in order to be recognized at a time. Words were selected from general everyday words to avoid too high difficulties, and not to make any concurrence relation between words which belong to different categories, based on several preliminary experiments and on interview surveys.

Priming effects are also avoided to unify the difficulties, by setting questions where words of the same meaning category are not given less than 3 times in succession.

3.2.2 Number Comparison Task

In number comparison task, a simple inequality is presented and testers are required to judge whether the inequality is correct or not. This is not a task that asks them to calculate, but a task that asks them to focus on necessary information and compare the numbers. The questions are simplified to unify their difficulties. The most left figure, the Thousand digits of the two four-digit numbers are the same, while the Hundreds digits are different in every question, so that they have to focus on the Hundreds digits to answer the questions.

3.2.3 Acquired Data and CTR Analysis

In order to implement the comparison task, the software was developed using html and JavaScript and it works on Web

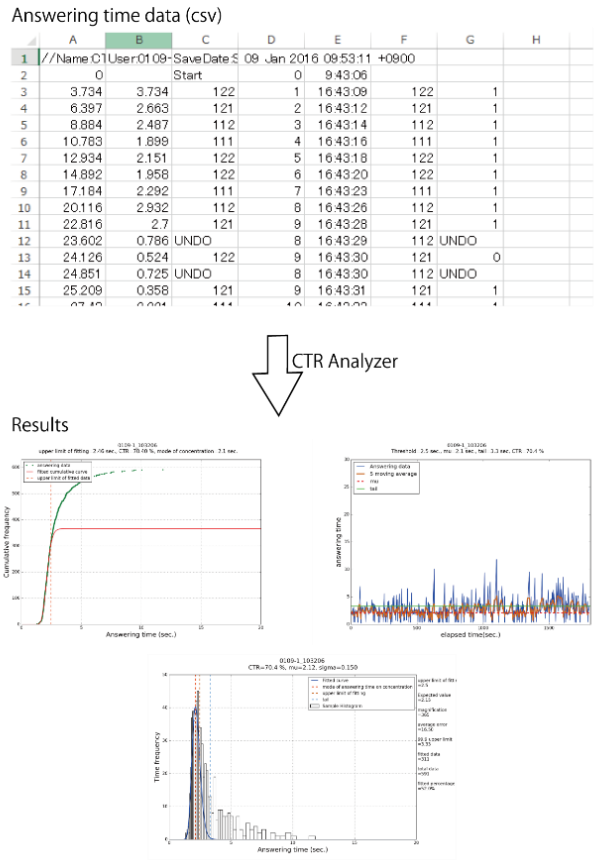

Figure 5. Example of answering time data and CTR calculation results by using comparison task.

browsers. The example of the collected answering time data and their analysis result are shown in Figure 5.

4. EXPERIMENT 1

A measurement experiment of cerebral blood flow was conducted by using NIRS to confirm that the task employs high level of cognitive activities as linguistic ability and numerical ability.

4.1 Experimental Methods

The experiment was conducted on December 10th, 17th and 18th in 2015 at an experimental room. Totally 5 master course students participated and the details of participants are shown in Table 1. NIRS, FOIRE-3000 made by SHIMADZU were used.

Figure 6 shows the experimental procedure. The experiment time was designed to be less than 1 hour to reduce the equipping load for the participants. The equipment of experimental room was arranged as shown in Figure 7. Experimenters were located in a position which was out of the participants' sights, so that they could easily concentrate just on their experimental tasks.

As shown in Figure 6, in addition to the original comparison task, a task including only word comparison and a task including only number comparison were prepared in order to observe the differences of cerebral blood flow condition between two different kinds of task requirement. A control task was also prepared as a task including only the activity of pushing answering buttons without any comparison. After finishing the measurement, the results when conducting the tasks were averaged and that of the control task was subtracted from results, in order to remove the effect of brain activities related to physical activities.

NIRS probes were set on prefrontal cortex and temporal lobe regions, such as Broca's area as shown in Figure 8 to observe expected activation of these areas when conducting the proposed task which was designed to employ linguistic, numerical and judging abilities.

4.2 Result and Discussion

Figure 9 explains the meaning of the following graph of NIRS measurement results and typical example results are shown in Figure 10 to 12, which were averaged in each channel and data of control task was subtracted from each result. In the graphs of Figure 10 to 12, the correspondence between measured position and brain activities is shown as colored circles. In general, Broca's area is activated when recognizing meanings and doing dynamic linguistic activities such as utterance, and Wernicke area is activated when recognizing meanings and doing static linguistic activities such as context formation. Auditory area is activated by listening something, and is also known to be activated when read something silently or imagine phoneme of one's head [12].

When conducting a word comparison task, prefrontal cortex and Broca's area were activated at the start of answering time as shown in Figure 10. Although same areas were activated when conducting a number comparison task as shown in Figure 11, the activation was higher in prefrontal cortex and was lower in Broca's area compared with a word comparison task. There were individual differences of the area which were the most strongly activated. It was possible that the auditory area was activated occur when reading words or numbers silently in the tasks.

Table 1. Participant list of NIRS experiment

Experiment	ID	F/M	age
2015/12/10	1	M	24
2015/12/17	2	M	25
2015/12/17	3	M	23
2015/12/18	4	M	23
2015/12/18	5	M	23

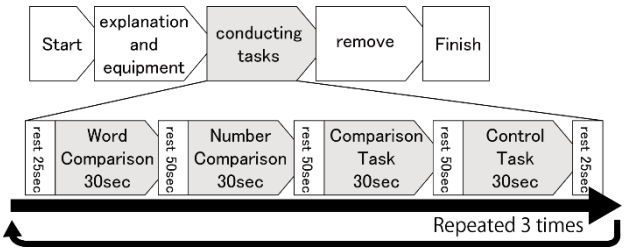

Figure 6. Protocol of NIRS experiment.

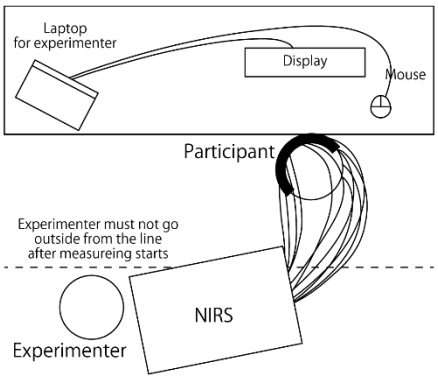

Figure 7. Room setting of NIRS experiment (top view).

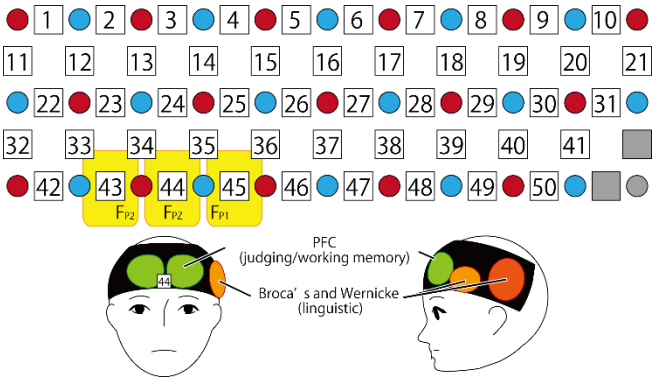

Figure 8. Probe position of NIRS measurement

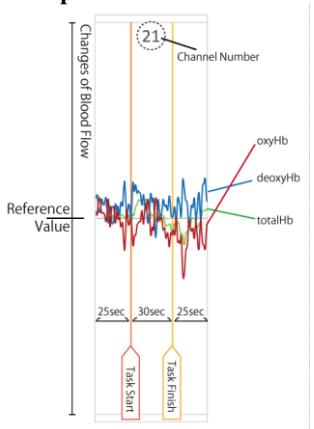

Figure 9. Meanings of NIRS result graph.

As shown in Figure 12, brain activation caused by the original comparison task was lower than that of the word comparison and the number comparison, though the activation was certainly obtained in the same areas, Broca's area and Wernicke area. When performing word cognition and numerical cognition in parallel, brain blood flow is thought to be dispersed, so that the observed brain activation when conducting the original comparison tasks were lower than that of the word comparison and the number comparison.

As the results above, it was confirmed that the proposed comparison task could employ high level of cognitive activity such as linguistic and numerical activities by measuring brain activation as cerebral blood flow mainly in prefrontal cortex and Broca's area.

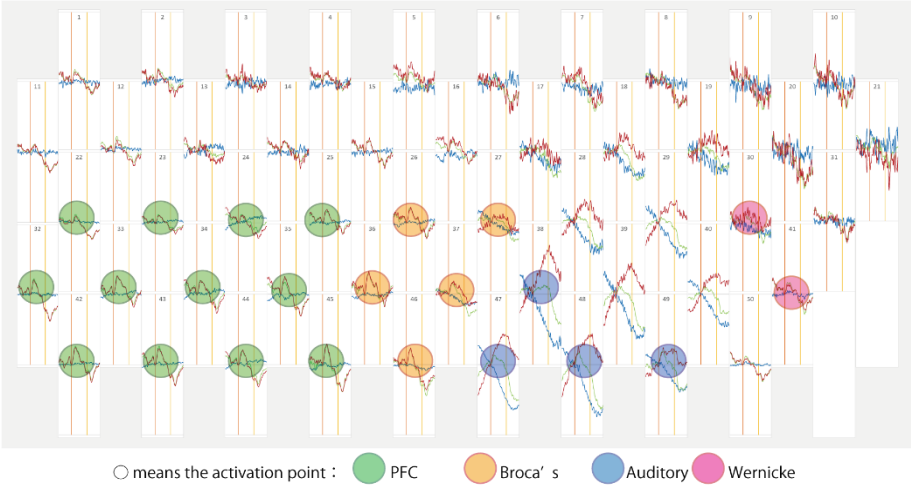

Figure 10. Results of Word Comparison Task.

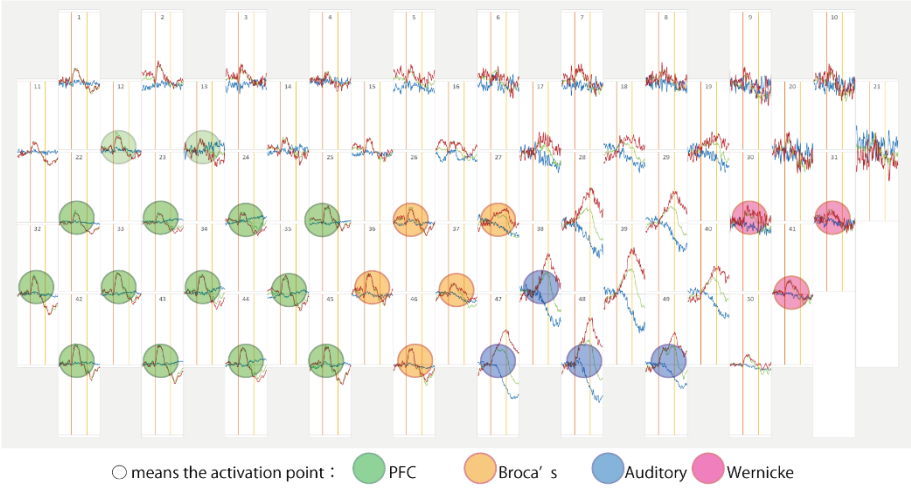

Figure 11. Results of Number Comparison Task.

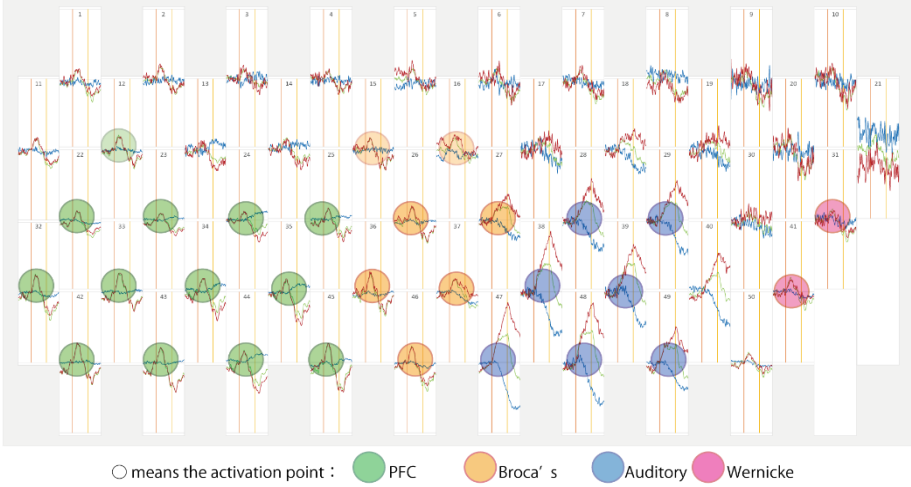

Figure 12. Results of Comparison Task.

5. EXPERIMENT 2

A subject experiment was conducted to confirm that the comparison task is feasible to deduce CTR index and can be utilized to evaluate intellectual concentration affected by room environment.

5.1 Experimental Methods

The experiment was conducted for 5 days from January 9th to 13th in 2016 at an experiment room on the basement of a research building in Kyoto University. Totally 37 high school students and university students participated in the experiment. The prepared room conditions are two for thermal environment (Cool, Hot) and two for illumination environment (Task and Ambient light; TA, Ambient light; A) so that totally four combinations were prepared as shown in Table 2.

Figure 13 shows the experimental procedure. Besides the comparison task, SUDOKU puzzle task was given as a dummy task in order to avoid causing their boredom and to secure enough time to adapt the room environmental conditions. The concentration under TA illuminating condition was expected to be higher than that under A illuminating condition [13]. Because of this expectation and experimental time limitation, the order of the illumination condition was fixed from A to TA, because of the difference of adopting time, while that of the thermal condition was counterbalanced by participant groups.

In order to examine their impressions of the room conditions as designed, several questionnaire surveys about the environment were conducted just after the tasks. In addition, another questionnaire survey about their fatigue [14] was also conducted at the same time to check unexpected sudden change of their physical status.

5.2 Result and Discussion

The results of all the participants could be acquired without deficit. The participant data when their physical status or motivations were obviously changed during the tasks were omitted for the later analysis. The participant data which don't have enough number of answering time data for the approximation to the log-normal distribution when calculating CTR index were also omitted based on the standard of CTR analysis software. As the result of above omission, 26 participant data out of 37 remained as valid data.

The answering time data which were not feasible for the approximation to calculate CTR were only 3% of total acquired so that it was found that the comparison task could provide enough number of answering time data even in 30 minute task. In addition, it was also found that the difficulty of each question is unified, that they had got learned to solve the questions quickly, and that their answering strategies had not changed while conducting the tasks.

Figure 14 shows the average and the standard deviation of CTRs.

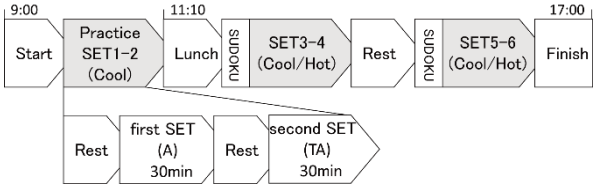

Figure 13. A protocol of Experiment 2.

Table 2. Detail of the experimental room environment.

Environment (thermal/illumination)	Room Temperature	Illuminate Condition
Hot / A	25-26℃	300-350lux
Hot / TA	25-26℃	about 1800lux
Cool / A	21-22℃	300-350lux
Cool / TA	21-22℃	about 1800lux

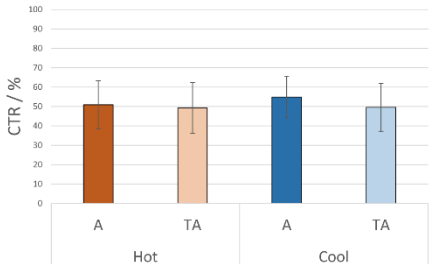

Figure 14. Results of CTR index.

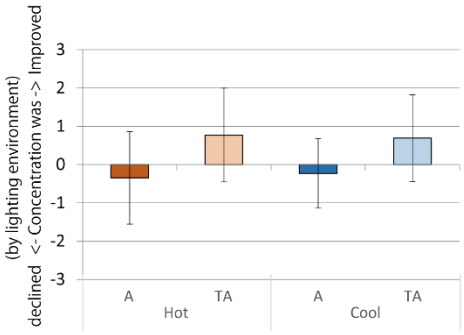

Figure 15. Subjective illumination effect on concentration.

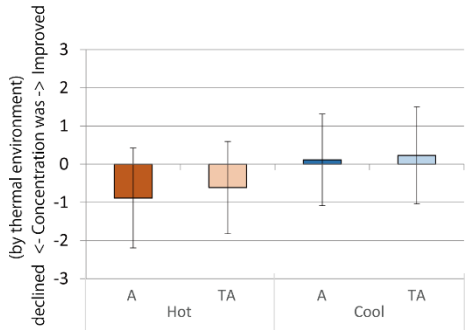

Figure 16. Subjective thermal effect on concentration.

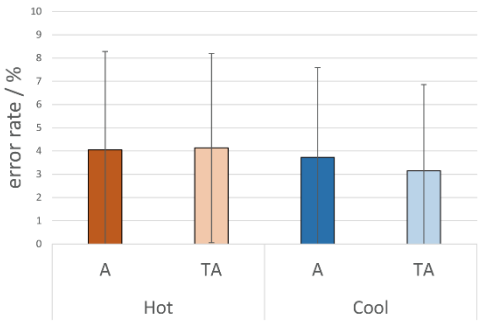

Figure 17. Results of error rate.

Although there was no significant differences found between four environments by ANOVA, average CTRs under A condition in illumination environment, and Cool condition in thermal environment seemed to be higher. However, in the questionnaire results of subjective concentration evaluation for the illuminating conditions, TA condition was evaluated significantly higher as shown in Figure 15. Therefore, because of no counterbalance in illuminating environment, the fatigue accumulated by short resting time affected and made CTR lower in the latter TA condition. On the contrary, the results of subjective concentration evaluation for thermal conditions, Cool condition was evaluated higher than HOT condition, which seemed to have some relationship with CTR results.

As the results of this experiment, the possibility has been suggested that the CTR index calculated by using answering time data of comparison task has sensitivity for concentration change caused by room environment even in the thermal condition which has been considered to give less influence on work concentration. For the further study, the experimental design has to be modified to control accumulation of fatigue.

In addition, it could provide error rate of the questions as shown in Figure 17, which is also valuable for further study such as combined use with the CTRs.

6. CONCLUDION

As the results of two experiments in this study, the developed comparison task was feasible for the CTR analysis to evaluate the concentration during intellectual work. The result of environmental evaluation experiment shows the shorter learning time needed when using comparison task than conventional receipt classification task, which can realize the whole experiment time shorter. In addition, it could provide error rate of the questions and overcome the physical limitation of the conventional task because it can be conducted only by using Web browser, without any paper instrument.

In the future, it is necessary to conduct more experiments using the comparison task and shows its usefulness for conducting experiment in real environment such as real office room or educational environment.

7. REFERENCES

[1] Ministry of Land, Infrastructure, Transport and Tourism. 2009. Research Report by Study Group of Intellectual Productivity. (In Japanese)

[2] H. Shimoda, K. Ooishi, K. Miyagi, K. Uchiyama, H. Ishii, F. Obayashi, M. Iwakawa. 2013. An Intellectual Productivity Evaluation Tool Based on Work Concentration. 15th International Conference on Human-Computer Interaction, 16, pp.364-372.

[3] T. Sugiura, T. Hashimoto, M. Terano, M. Nakamura, T. Kawase, Y.Kondo. 2007. Evaluation method of work place productivity, the first report – Organizing productivity evaluation methods and suggestion of the standard methods. Academic lecture papers of The Society of Heating. Air-Conditioning and Sanitary Engineers of Japan, 123, pp.11-22. (In Japanese)

[4] N. Nishihara, S. Tanabe. 2007. Monitoring Cerebral Blood Flow for Objective Evaluating of Relationship Productivity and Thermal Environment. Proceedings of IAQVEC 2007, 655/662.

[5] P. Wargocki, D. P. Wyon, J. Sundell, G. Clausen, P. O. Fanger. 2000. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. Indoor Air, 10, pp.222-236.

[6] D. R. Throne, S. G. Genser, H. C. Sing, F. W. Hegge. 1985. The Walter Reed Performance Assessment Battery. Neurobehavioral Toxicology and Teratology. 7, pp.415-418.

[7] C. M. MacLeod. 1991. Half a Century of Research on the Stroop Effect: An Integrative Review. Psychological Bulletin, 109, No.2, pp.163-203.

[8] B. Dubois, A. Slachevsky, I. Litvan, B. Pillon. 2000. The Fab: a frontal assessment battery at bedside. Neurology 2000, 55, pp.1621-1626.

[9] S. K. Card, T. P. Moran, A. Newell. 1983. The Psychology of Human-Computer Interaction. Erlbaum Associates.

[10] K. Miyagi, S. Kawano, H. Ishii, H. Shimoda. 2012. Improvement and Evaluation of Intellectual Productivity Model based on Work State Transition. The 2012 IEEE International Conference on Systems, Man, and Cybernetics, pp.1491-1496.

[11] K. Uchiyama, K. Miyagi, H. Ishii, H. Shimoda, F. Obayashi, M. Iwakawa. 2014. Development of calculation method of intellectual concentration for evaluate intellectual productivities. Journal of Human Interface Society, 16, No.1, pp.29-40. (In Japanese)

[12] K. Brodmann. Vergleichende Lokalizationlehre der Grosshirnrinde in ihren Prinzipien dargestellt auf Grund des Zellenbaues. 1909. J.A. Barth, Leipzig.

[13] Y. Shimamura, H. Shimoda, K. Miyagi, H. Kanagawa, H. Ishii, K. Uchiyama, F. Obayashi. 2014. Evaluation of Intellectual Productivity with High-Concentration Light Using the evaluation method of intellectual concentration: 4. Adaptation Evaluation of High-Concentration Light, Summaries of technical papers of annual meeting Architectural Institute of Japan Paper, No.40015, pp.29-30. (In Japanese)

[14] Japan Society for Occupational Health and Working Group for Occupational Fatigue.1988. Industry fatigue handbook. Labor Standards Committee. (In Japanese)