An Experimental Study on Improvement of Office Work Productivity by Circadian Rhythm Light

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ABSTRACT

Recently, companies have been promoting energy saving by controlling office environment such as temperature of air-conditioning system and lighting. However, the drop of productivity of office workers caused by the energy saving may become a big problem because it may extend labor time and increase energy consumption. In this study, the authors have proposed a new lighting control method which is expected to adjust circadian rhythm of office workers and improve their work productivity. Then, in order to evaluate the effectiveness of the proposed method, a subject experiment was conducted where 15 subjects joined for 18 days. In the experiments they were given three test sets of CPTOP (Cognitive Performance Test of Productivity) and their corresponding simulated tasks under two illumination conditions, high illumination condition as the proposed method and standard illumination condition as the control condition. The result shows that the improvement rate of the performance indexes under the high illumination condition against the standard illumination condition are 4.20% to 5.49%.

Keywords: Productivity, Circadian rhythm, Lighting control method, Performance test

1. INTRODUCTION

Global warming has been one of the most serious problems all over the world in these days. As a countermeasure of this problem, energy saving have been promoted not only in factories, industrial plants but also in office buildings.

In order to reduce the amount of green house gas emission from office buildings, office environment control such as temperature of air-conditioning system and lighting has been promoted. On the other hand, the drop of productivity of office workers caused by the office environment control may become a big problem because it may extend the labor time and increase energy consumption. Therefore, energy saving in office has to be considered not only the reduction of direct energy consumption but also the improvement of the productivity of office workers.

In this study, the authors have paid attention to lighting condition in office buildings, and have proposed a new lighting control method which is expected to adjust circadian rhythm of office workers and improve their work productivity. In addition, a subject experiment was conducted to evaluate the improvement of the productivity quantitatively by the proposed lighting control method.

2. LIGHTING CONTROL METHOD

Desk illumination of office is usually set to approximately 700 lux from the viewpoint of the sight. From the viewpoint of workers' circadian rhythm, however, it is not appropriate. In order to adjust human circadian rhythm, it is necessary to be exposed thousands lux illumination in the morning[1]. Therefore, a lighting control method has been proposed as shown in Fig 1. In the morning, the illumination of the light is controlled to thousands lux to adjust their circadian rhythm and to enhance their arousal level in short term, then reduce it to 500 lux to promote to take a nap in lunch time. In the early afternoon, the illumination is controlled to thousands lux again to prevent from sleepiness for an hour, then it is reduced to 700 lux to the end of the working time not to accumulate fatigue by keeping high arousal level to the next day.

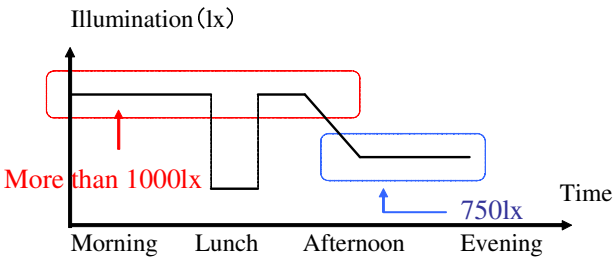

Fig.1: Proposed Lighting Control Method.

3. EVALUATION METHOD OF OFFICE PRODUCTIVITY

There are various studies and proposals for evaluation indexes of office productivity[2-5]. However, there is no objective and quantitative evaluation method which reflects actual office work and useful evaluation method has been required.

Since the office work has lots of atypical variations from simple repetitive work to creative work, the abilities which are necessary to execute the office work

are first revealed, then the office productivity is measured by evaluating the performance how much the abilities can be applied for the work. The authors, therefore, paid attention to 21 human cognitive abilities defined by Fleishman[6]. Among these abilities, 11 elementary cognitive abilities which are essential to office work were picked up by questionnaires and interviews for office workers as shown in Table 1[7]. As the evaluation method of these abilities, a performance test, CPTOP (Cognitive Performance Tests for Office Productivity) has been developed to evaluate a productivity of office workers objectively and quantitatively. It consists of 11 performance test sets which correspond to these abilities and it can be conducted using a personal computer connected to the Internet[8].

Table 1: 11 Elementary Abilities Necessary to Perform Office Work

Abilities		
Oral Comprehension	Written Comprehension	Oral expression
Written expression	Memorization	Mathematical Reasoning
Deductive Reasoning	Inductive Reasoning	Information Ordering Category
Perceptual Speed	Time Sharing	

In addition, although it was found in the past studies that the proposed lighting method has possibility to improve the office productivity by adjusting their circadian rhythm through field experiment[8], there was a still problem that the objectiveness of the result was not enough because of a little number of subjects, less exact control of experimental conditions and use of some less objective tasks among CPTOP.

4. DISCUSSION OF PRODUCTIVITY INDEX

4.1 Task Performance

In this study, three test sets of CPTOP which measures performance of “Perceptual speed”, “Time sharing” and “Information ordering category” are chosen among 11 performance test sets as shown in Table 2 because the task questions of these three test sets are generated by computer and the difficulty of each question can be assumed uniform.

In addition, three simulated tasks, “Receipt Check”, “Schedule Arrangement” and “Receipt Classification” are used in order to compensate the above three test sets of CPTOP. The simulated tasks are often done in an actual office and the abilities which mainly used in the simulated tasks are corresponding to the abilities measured by the three test sets of CPTOP.

The details of the three test sets of CPTOP and corresponding three simulated office tasks are described as follows;

Table 2: Three abilities chosen in this study

Ability	**Explanation**
Perceptual Speed	the ability of comparing objects precisely and quickly
Time Sharing	the ability of processing more than two information effectively
Information Ordering Category	the ability of dividing objects based on a given order

Perceptual Speed (CPTOP)

Fig. 2 shows an example screen shot of the perceptual speed test of CPTOP. A figure is displayed on the left of the screen and they choose the same figure among four figures on the right within 10 seconds. After they choose the same figure, the next question will be displayed. Each question is randomly generated so that the difficulty is uniform. The measured performance index is number of right answers in a unit time.

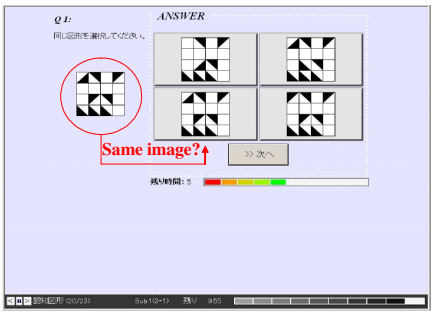

Fig. 2: An Example Screen Shot of Perceptual Speed Test (CPTOP).

Receipt Check (Simulated Task)

Fig. 3 shows an example of receipt check task. A set of receipts are given and they check 7 items on each receipt by comparing with 7 items displayed on PC screen. If all of the items match, they press “Accept” button on the screen. If not, they press “Deny” button. The tasks evaluate the ability of perceptual speed. Since the mismatch of each receipt is randomly generated by computer, the difficulty is uniform. The performance index of this task test is number of right answers in a unit time.

Fig. 3: An Example of Receipt Check (Simulated Task).

Time Sharing (CPTOP)

Fig. 4 shows an example screen shot of time sharing test of CPTOP. Bombs and bulbs are moving along with a route at a certain speed on the right of the screen. When they come to an intersection, they move to one of two causes which are to a bomb warehouse and to a bulb warehouse. The course can be selected by pressing TAB key of PC. They should lead the bombs and bulbs to the corresponding warehouse. At the same time, 10-digit number is displayed on the right of the screen and they should type in it by numeric keyboard. This task needs leading bombs and bulbs to the corresponding warehouse and typing in 10-digit number at the same time. The performance index of this test is the product of number of correct typing and the rate of correct leading to the corresponding warehouse.

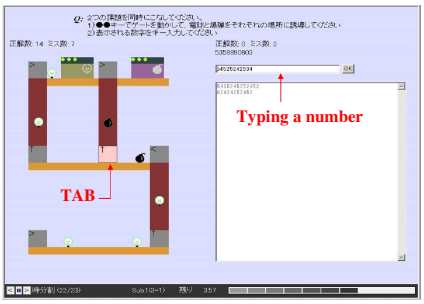

Fig. 4: An Example Screen Shot of Time Sharing (CPTOP).

Schedule Arrangement (Simulated Task)

The corresponding simulated task of time sharing is schedule arrangement test. Fig.5 shows an example screen shot of schedule arrangement task. In actual work, some office workers have to arrange a schedule such as meeting frequently. On occasion, they may have to arrange more than two schedules at the same time.

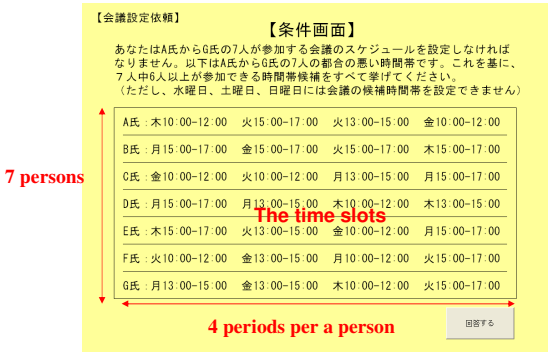

Fig.5: An Example Screen Shot of Schedule Arrangement (Simulated Task).

This task is to find time slots which satisfy the given conditions. The schedules of seven persons are displayed on the screen, which means they are occupied by other tasks and the time slots when more than six persons are free should be found. While finding the time slots, another schedule arrangement task may cut in as shown in Fig.6 and they should finish the cut-in schedule arrangement first, then return to the original one. This task requires switching over two sorts of information effectively and memorizing much more information than other tasks. The performance indexes of this test are both the number of the correct schedule arrangement and that of original schedule arrangement.

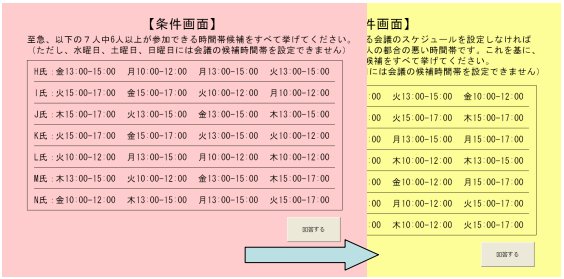

Fig. 6: Cutting in Another Schedule Arrangement.

Information Ordering Category (CPTOP)

Fig. 7 shows an example screen shot of information ordering category test. This test requires arranging eight books in a certain order. The book information such as title, author, publisher, publishing date and price is randomly listed on the left of the screen. According to the given order such as ascending order of the price and descending order of the author, they should arrange the book information to eight boxes on the right within 60 seconds. The performance index of this test is number of correct arrangement in a unit time.

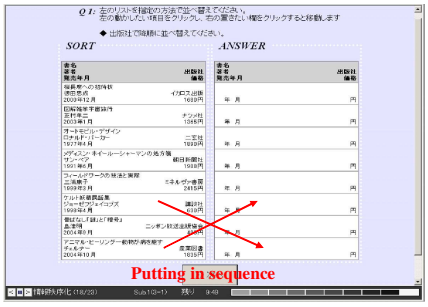

Fig. 7: An Example Screen Shot of Information Ordering Category (CPTOP).

Receipt Classification (Simulated Task)

This task is to classify a set of receipts according to the given conditions such as issued date, payee, amount of money and payment method. Fig. 8 shows an example of the receipts. The performance index of this task is number of classified receipts per a unit time.

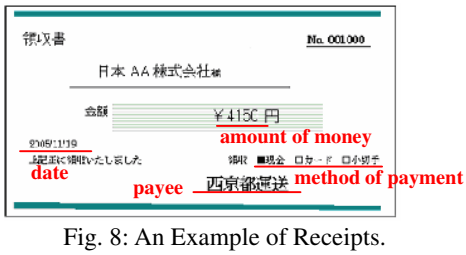

Fig. 8: An Example of Receipts.

4.2 Subjective Fatigue

The proposed lighting method is expected to enhance arousal level in the day time and to improve the quality of sleep by adjusting circadian rhythm. In this study, a subjective questionnaire is applied to evaluate this effect.

The questionnaire is widely used to evaluate subjective fatigue, such as sleepiness and visual fatigue, provided by Japan Society for Occupational Heath[9]. It asks 25 questions which are classified into five categories such as "Sleepiness", "Instability", "Uncomfortableness", "Dullness" and "Haze". Each question should be answered by one of 5 grades. The sums of the answers of each category express subjective fatigue.

4.3 CFF

CFF (Critical Flicker Frequency) is used to measure brain fatigue and arousal level as a physiological index. It can be measured in short time and gives less measuring load.

5. EVALUATION EXPERIMENT

5.1 Purpose

The purpose of this experiment is to evaluate the improvement of productivity quantitatively by the proposed lighting control method.

5.2 Experimental Method

The experiment was conducted in an experimental room as shown in Fig.9 where illumination can be controlled up to thousands lux. The color temperature of the light used in the experiment was 5500K and its Ra was 84. The air temperature of the room was controlled to approximately 25 degree Celsius and the humidity was also controlled to approximately 60% by air-conditioning system. The air ventilation system always exchanged the air in the room, and the density of O_2 and CO_2 were monitored to confirm no large variation. The sound noise of the room during the experiment was approximately 55dB.

In this experiment, two conditions were prepared in which the maximum illumination was 3500 lux based on the proposed method as shown in Fig.4 (high illumination condition) and the illumination was fixed to 750 lux all day(standard illumination condition).

Fig. 9: Experimental Room.

The subjects of the experiment were 15 persons who have experiences of office work. Their average age was 38.5 (28 to 55, 11 males and 4 females). During experimental period, they are told not to drink alcohol nor caffeine too much and to take enough sleep. Before the experiment, the informed consent was taken from all the subjects.

In order to evaluate of their productivity quantitatively under the given lighting conditions, three test sets of CPTOP and their corresponding simulated tasks as mentioned in 4.1 were given to the subjects. In addition, the questionnaire investigation to measure subjective fatigue and CFF measurement were conducted.

The experiment was conducted for 18 days from November to December in 2006 and the schedule is shown in Fig.10. In each day, three sets of tasks were given, once in the morning and twice in the afternoon. As shown in Fig.11, the questionnaire and CFF measurement were conducted four times in a day, before giving the task set in the morning and after finishing each task set. One task set consists of the proposed 6 tasks as shown in Fig.12.

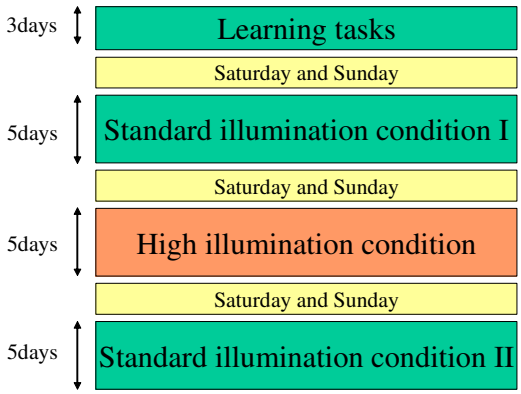

Fig.10: Schedule of Experiment.

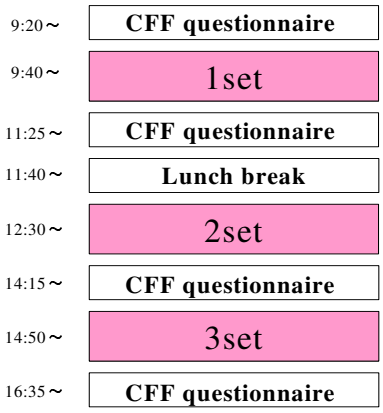

Fig.11: Schedule of Task in a Day.

5.2 Correction of Learning Effect

Since the purpose of CPTOP and simulated tasks is to evaluate office environment by testing how much cognitive abilities can be brought out in different office environments, the result of the same person in the same

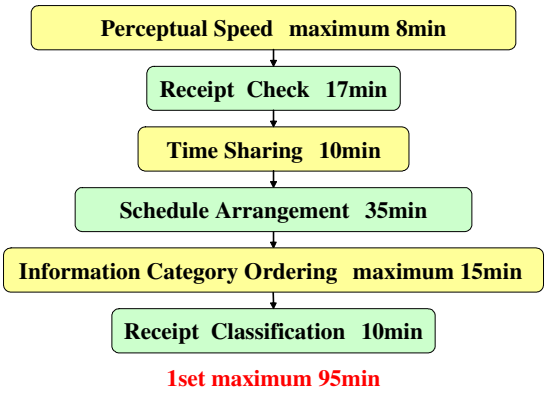

Fig.12: Tasks in a Task Set.

environment should be always the same. However, there might be learning effect when repeating the same tasks again and again. If there is such learning effect, it is difficult to evaluate the task performance accurately.

Since it can be assumed that the performance score is saturated to a certain score after infinite repetition, the learning effect of each task can be expressed the following learning curve.

$$P_n = P_{saturated} - (P_{saturated} - P_{initial}) \cdot (1-r)^{n-1} \quad \text{Eq.(1)}$$

This equation can be simplified as follows;

$$y = k - ab^x \quad \text{Eq.(2)}$$

An example of the learning curve is shown in Fig. 13.

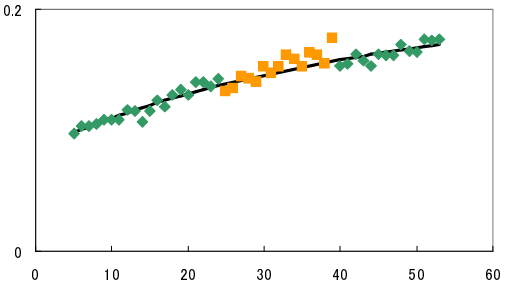

Fig.13: An Example of Learning Curve.

In the equation Eq.(2), the saturated score k by learning is assumed to be the standard point and the test result can be compensated by the correction rate which is the saturated score divided by the score in x times. In other words, the correction rate is;

$$C_x = \frac{k}{k - ab^x} \quad \text{Eq.(3)}$$

And the compensated score T_x is;

$$T_x = C_x \cdot S_x \quad \text{Eq.(4)}$$

where S_x is the test score of x's set. The results of the performance test described in the following section would be corrected by this method.

5.3 Experimental Result

Table 3 shows the average performance indexes of CPTOP and simulated tasks of all subjects under the standard illumination condition and the high illumination condition. The values shown in Table 3 are corrected by the method mentioned in 5.2 in order to remove learning effect. The right row shows the improvement rate under the high illumination condition. Considering the adjustment of subjects' circadian rhythm, the performance indexes of the standard illumination in this table are the averages of the fourth and fifth day under the standard illumination condition I and II, while that of high illumination is the average of the fourth and fifth day under the high illumination condition. In addition, the performance index of the last set of the fifth day was excluded from the average calculation in order to remove a terminal effect. The result shows that the performance indexes under the high illumination condition are higher than those under the standard illumination condition (except "Perceptual Speed"). The result also shows that the improvements rate of three test sets of CPTOP are lower than those of the simulated tasks.

Table 3: Performance of each illumination condition and rate of improvement

Test	Standard illumination	High illumination	Rate of improvement
Perceptual Speed	0.171	0.171	-0.32%
Time Sharing	99.7	100.6	0.98%
Information Ordering Category	0.245	0.247	0.82%
Receipt Check	0.204	0.214	4.50%
Schedule Arrangement	0.0103	0.0107	4.20%
Receipt Classification	0.293	0.310	5.49%

As the results of the questionnaire and CFF, the averages of fourth and fifth day under each illumination condition were also calculated. From the viewpoint of circadian rhythm and the illumination conditions, The result of questionnaire, "Sleepiness" and "Haze" among five categories were picked up as shown in Fig.14 and Fig.15, respectively. Fig.16 shows the result of CFF. The result of the questionnaire and CFF, however, could not prove adjustment of circadian rhythm.

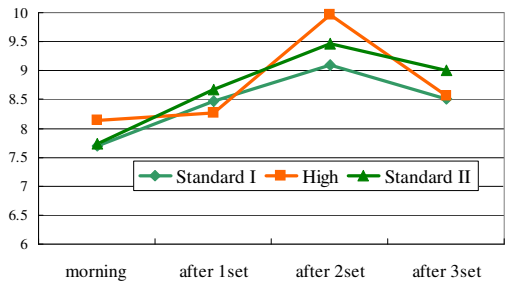

Fig.14: Result of Questionnaire "Sleepiness".

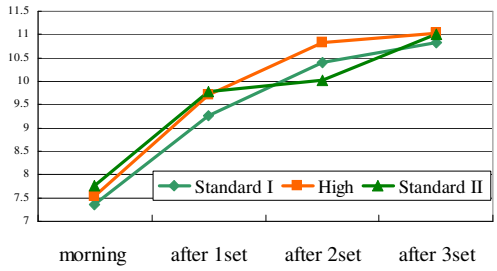

Fig.15: Result of Questionnaire “Haze”.

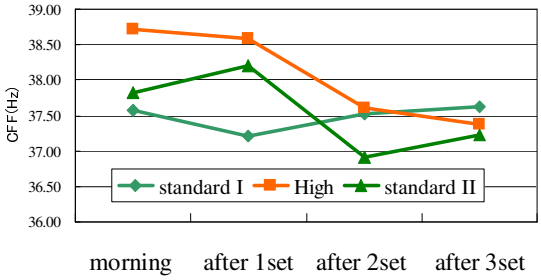

Fig.16: Result of CFF.

5.4 Discussion

While the performance improvements of the simulated tasks are 4.20% to 5.49%, the ones of CPTOP are -0.32% to 0.98%. It is supposed that this difference was caused by time pressure of each question, mental work load or task time. Among them, the time pressure seemed to influence the performance more than other factors. Although each question of CPTOP tasks has a time limit, the simulated tasks have no time limit. When subjects performed test sets of CPTOP, they were forced to answer each question quickly under the time pressure so that the space of improving performance was less than that of the simulated tasks.

The result of questionnaire and CFF could not prove adjustment of circadian rhythm in period under the high illumination condition. The subjects took enough sleep during the experiment period. Therefore, it is supposed that adjusting their circadian rhythm by the proposed lighting method did not clearly appear. In addition, being exposed on the high illumination light might give more fatigue to the subjects.

6. CONCLUSION

In this study, a lighting control method which adjusts human circadian rhythm has been proposed to improve performance of office work. The method gives high illumination in the morning and in the early afternoon to increase arousal level and adjust circadian rhythm, then reduce it in the late afternoon not to accumulate fatigue by keeping high arousal level to the next day.

In order to evaluate the effectiveness of the proposed method, an objective and quantitative evaluation method has been discussed. From the viewpoint of work performance, three test sets of CPTOP and their corresponding simulated tasks were picked up. From the viewpoint of fatigue and circadian rhythm, a subjective questionnaire and CFF were picked up.

By using these evaluation indexes, a subject experiment was conducted where 15 subjects joined for 18 days under two lighting conditions, high illumination condition as the proposed method and standard illumination condition as the control condition. The results shows that the improvement rates of the simulated tasks under the high illumination condition against the standard illumination conditions were 4.20% to 5.49%, while those of CPTOP were -0.32% to 0.98%. The difference of the improved rates might be caused by time pressure of CPTOP. The result of the questionnaire and CFF could not prove adjustment of circadian rhythm.

In the future, the authors will improve CPTOP and conduct further experiments in actual office rooms as a field study.

7. REFERENCES

[1] M.Rea, M.Figuero and J.Bullough: Circadian Photobiology: an Emerging Framework for Lighting Practice and Research, Lighting research & technology, Vol.34, No.3, 2002, pp. 177-190.

[2] Sensharma N. P. and Woods, J. E, An Extension of a Rational Model for Evaluation of Human Responses, Occupant Performance, and Productivity, Healthy Building 2000, Workshop 9.

[3] Fisk W.J. et al, Worker Performance and Ventilation, Part 1,2, Proceedings of Indoor Air, 2002, pp.784-795.

[4] Kroner W.M. and Stark-Martin J.A, Environmentally Responsive Workstation and Office-Worker Productivity, ASHRAE Transactions, Vol.100, 1994, pp.750-755.

[5] Wargocki P., et al, Productivity is Affected by the Air Quality in Offices, Healty Building 2000, pp.635-640.

[6] Fleishman, E. A. and Reilly, M. E, Handbook of Human Abilities, Consulting Psy-chologists Press, pp.1-37

[7] Fumiaki Obayashi, Misa Kawauchi, Masaaki Terano, Kyoko Ito, Hiroshi Shimoda, Hidekazu Yoshikawa, Objective Measurement Method for Productivity and Investigation on Environmental Factor, HCII2005, CD-ROM.

[8] Hiroshi Shimoda, Kazuhiro Tomita, Hirotake Ishii, Fumiaki Obayashi, Masaaki Terano, Hidekazu Yoshikawa, A Study on an Environmental Control Method to Improve Productivity of Office Workers, SEE2006, Vol.2, Paper No.E-050, 2006, pp.867-872.

[9] Japan Society of Occupational Health, Handbook of Industrial Fatigue, Roudou Chousakai, 1998.