C: Behaviour & environmental psychology
C.1. Man-environment interaction

SUBJECTIVE EXPERIMENTS ON RELATIONSHIPS BETWEEN INDOOR ENVIRONMENT AND AROUSAL STATE AND BETWEEN AROUSAL STATE AND WORK PERFORMANCE

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SUMMARY

The present study focused on arousal as one of the human physiological and psychological responses mediating the causal relationship between indoor environmental quality and performance. In order to investigate the role of arousal state, two subjective experiments were carried out. The first experiment was to verify that indoor environment affects occupants' arousal state. Indoor temperature, outdoor air supply rate and illumination intensity were changed at two or three levels (22, 25, 28^{o}C; 10, 30 m^{3}/h/person; 10, 300 lx), and six combinations of them were adopted as the experimental cases. A questionnaire was used to evaluate their arousal state with two dimensions of energetic arousal (EA) and tense arousal (TA). Skin conductance level was also used for objective assessment of their arousal state. As a result, EA tended to be low in the cases of poor IEQ, while TA tended to be high at the same time. The second experiment was to verify that arousal state affects performance. During the experiment, subjects performed three types of tasks (detecting wrong pairs of numbers, inputting numbers, and Sudoku), and indoor environment was not controlled. This experiment showed that subjects' performance became higher when EA was high, but became lower when TA was high.

INTRODUCTION

A significant number of studies have shown that poor indoor environmental quality (IEQ) causes low occupants' performance (Andersson et al., 1999). On the other hand, the degrees of observed impacts are much different among the studies, and some other studies have shown little impacts on subjects' performance (Tanabe and Nishihara, 2004). Therefore, it is still difficult to evaluate the impacts of IEQ on occupants' performance quantitatively. In order to explain such differences among the studies, we must reveal the mechanism of the causal relationship between IEQ and performance.

The most prevalent factor on occupants' performance must be their abilities. The reason why IEQ have some effects on it can be inferred that IEQ affects occupants' physiological and psychological responses, e.g. motivation, arousal and fatigue, then

those responses disturb relationship between their ability and performance. Here, we especially focused on arousal as one of the responses mediating the causal relationship between IEQ and performance. The effects of arousal state on the performance are well known in the field of psychology for a long time. The most famous study was done by Yerkes-Dodson (1908). On the other hand, some newer studies suggest the arousal state consists of two components, i.e. energetic arousal (EA) and tense arousal (TA), and each component has a different effect on the performance (Matthews et al., 1990; Shirasawa et al., 1999).

The present study investigated a role of the arousal state on the causal relationship between IEQ and performance. We considered that the relationship can be divided into two phases, and two subjective experiments were carried out corresponding to each phase. One experiment was done to verify that indoor environment affects occupants' arousal state. The other experiment was done to verify that arousal state affects performance.

METHODOLOGIES

Experiment 1

This experiment was conducted in an experimental room at Yamaguchi University, from August to September 2011. Figure 1 shows the layout of the experimental room. Curtains and blinds were closed to avoid sunlight from the windows. Outdoor air was introduced into an adjacent small room by fans, and the air temperature was controlled before flowing into the experimental room. Indoor temperature was changed at three levels. Outdoor air (OA) supply rate and illumination intensity were changed at two levels respectively. Six combinations of them were adopted as experimental cases as shown in Table 1. Humidity was not controlled.

Figure 2 shows the schedule of an experimental session. During the first 30 minutes, subjects adapted to the environment and engaged in some tasks, i.e. detecting wrong pairs of numbers, inputting numbers and calculation, at the same time. It was intended to raise their arousal state in advance and minimize the initial deviations in arousal state between different subjects and dates. Then, a video lecture was given for 90 minutes and an examination was carried out after the lecture. Questionnaires about arousal state were answered before and after the video lecture. The other questionnaires about indoor environment were answered before the video lecture and after the examination. The video lectures were about high school biology, and produced by Nippon Housou Kyoukai (NHK). Each subjects participated in each of six experimental sessions of different experimental cases, and the experimental cases were assigned to the subjects in a randomized order.

Twenty-four subjects (7 female and 17 male) participated as volunteers. They were all university students with an average age of 21.3 years, and paid for their participation. In addition, some rewards were paid to the subjects depending on the results of the examinations as an incentive to keep watching the video lectures. To reduce the effects of circadian rhythm, experiments of each subject were done in the same time frame (10:00-12:10 or 13:50-16:00). All subjects were instructed to wear as 0.7 clo.

We used the Japanese UIST Mood Adjective Checklist (JUMACL, Shirasawa et al., 1999) shown in Table 2, as the questionnaire to evaluate subjects' arousal state. From this questionnaire, subject's arousal state was evaluated with two dimensions, i.e. energetic arousal (EA) and tense arousal (TA). Each adjective was converted into the score as shown in Table 3, which was slightly modified by us from the original manner. Besides this subjective method, skin conductance (SC) was also measured as an objective evaluation of arousal state. This is a physiological method to examine a state of the emotional sweating which reflects arousal state, and low SC level typically indicates low arousal level. Thus, both EA and TA are expected to correlate to the SC level. However, we cannot distinguish EA and TA from the SC observation. The SC was measured continuously during each experimental session.

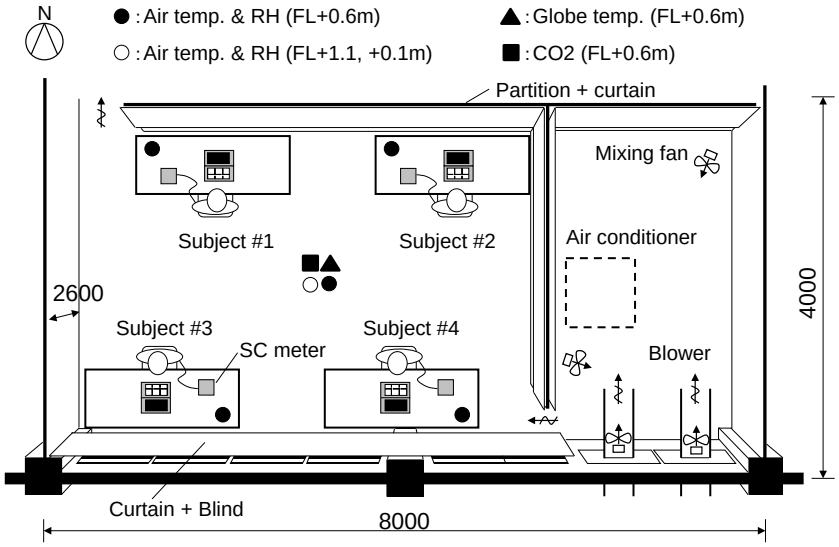


Figure 1. Experimental room.

Table 1. Experimental cases.

	Indoor temp. [^{o}C]	OA supply rate [m^3/h/person]	Illumination Intensity [lx]	Humidity	Clothing [clo]
Case 1	22	30	300	Uncontrolled	0.7
Case 2	28				
Case 3	25				
Case 4		10			
Case 5		30	10		
Case 6	28	10			

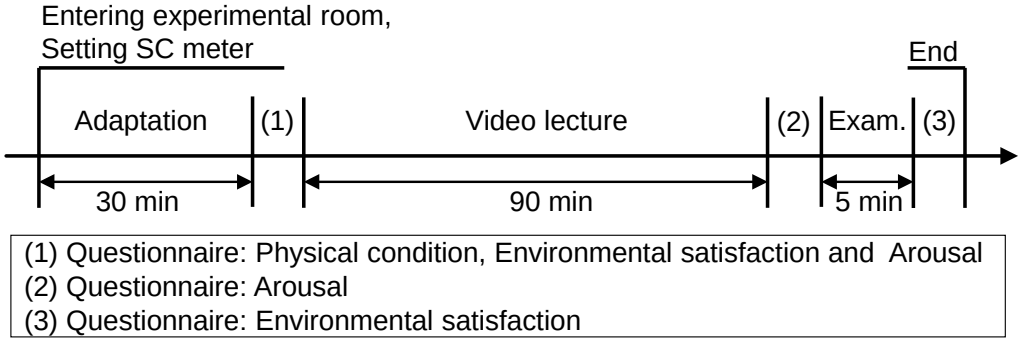


Figure 2. Schedule of experimental session (Experiment 1).

Table 2. JUMACL (Questionnaire on arousal state).

Does the adjective define your present mood? (1: Definitely, 2: Slightly, 3: Slightly not, 4: Definitely not)								
Restful	1	2	3	4	Unenterprising	1	2	3	4
Bright	1	2	3	4	Placid	1	2	3	4
Energetic	1	2	3	4	Calm	1	2	3	4
Relaxed	1	2	3	4	Dull	1	2	3	4
Nervous	1	2	3	4	Anxious	1	2	3	4
Sleepy	1	2	3	4	Vigorous	1	2	3	4
Industrious	1	2	3	4	Idle	1	2	3	4
Composed	1	2	3	4	Stirred up	1	2	3	4
Tense	1	2	3	4	Active	1	2	3	4
Passive	1	2	3	4	Jittery	1	2	3	4

Table 3. Scores of JUMACL.

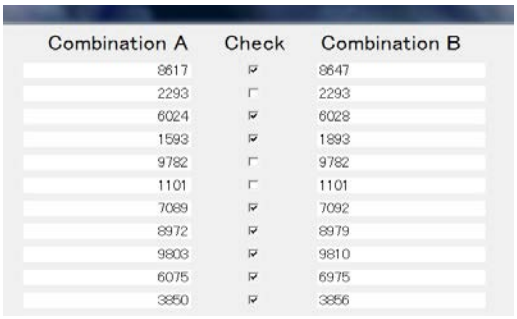
Energetic Arousal (EA)	Bright, Energetic, Active, Vigorous, Industrious	Definitely (+3), Slightly (+2), Slightly not (+1), Definitely not (0)
	Sleepy, Passive, Idle, Dull, Unenterprising	Definitely (-3), Slightly (-2), Slightly not (-1), Definitely not (0)
Tense Arousal (TA)	Nervous, Tense, Anxious, Jittery, Stirred up	Definitely (+3), Slightly (+2), Slightly not (+1), Definitely not (0)
	Restful, Relaxed, Calm, Placid, Composed	Definitely (-3), Slightly (-2), Slightly not (-1), Definitely not (0)

Experiment 2

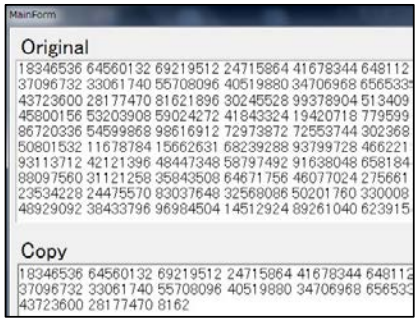
The other experiment was done to verify that arousal state affects performance. It was conducted from December 2010 to January 2011, at the same experimental room mentioned above (Figure 1). In this experiment, subjects engaged in three kinds of tasks, i.e. detecting wrong pairs of numbers, inputting numbers and Sudoku (Figure 3).

Figure 4 shows the schedule of an experimental session. The experimental session was divided into three periods, and three different tasks mentioned above were randomly assigned to these periods. Questionnaires about arousal state were answered before and after each task. The JUMACL was used as the questionnaire.

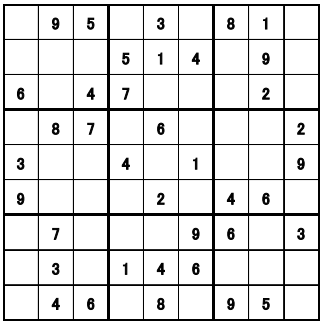
Six subjects (4 female and 2 male) participated as volunteers. They were all university students with an average age of 21.6 years, and not paid for their participation. Every subject participated in ten experimental sessions repeatedly. In order to let the subjects' arousal state spread in a wide range, indoor environment and clothing insulation were not controlled and the experiments were done on random day and time.



Task A: Detecting wrong pairs of numbers



Task B: Inputting numbers



Task C: Sudoku

Figure 3. Tasks of Experiment 2

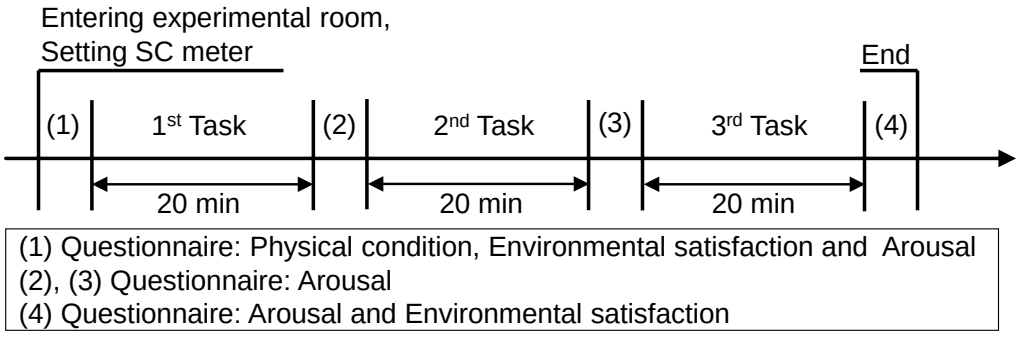


Figure 4. Schedule of experimental session (Experiment 2).

RESULTS AND DISCUSSION

Results of Experiment 1

Figure 5 shows subjects' average of EA and TA after adaptation period. Although we did not expect and intend, significant differences were observed in the arousal state after adaptation period (before video lecture). It indicates that the indoor environment had significant impacts on the arousal state, even though the exposed duration was only 30 minutes.

According to paired t-test, the EA in Case 6 was significantly lower than that in all cases except for Case 2. Moreover, EA was significantly lower in Case 2 than in Cases 1 and 3, and was lower in Case 5 than in Case 3. On the other hand, the TA in Case 6 was significantly higher than that in all cases except for Case 2, and the TA in Case 2 was significantly higher than that in Case 3. These facts indicate that both high temperature and low illumination had significant impacts on EA and TA, although the impact of low ventilation rate was not significant. The reason why the

ventilation rate did not have significant impact was because 30 min of adaptation period was not enough time to make differences in CO2 concentrations.

The EA and TA after video lecture were presented in Figure 6. Both EA and TA were tended to be lower than before the lecture, and the differences among the cases became small. It indicates that the video lecture had an effect to lower the arousal level. However, there were still some differences in the arousal state, which seemed to be caused by the indoor environment. The EA in Case 6 was significantly lower than that in Case 4, and tended to be lower than that in Case 1. The EA in Case 2 also tended to be lower than those in Cases 1 and 4. On the other hand, the TA in Case 6 was significantly higher than those in Cases 3 and 5. From these facts, it was considered that high temperature and combined poor condition had certain impacts on the EA and TA.

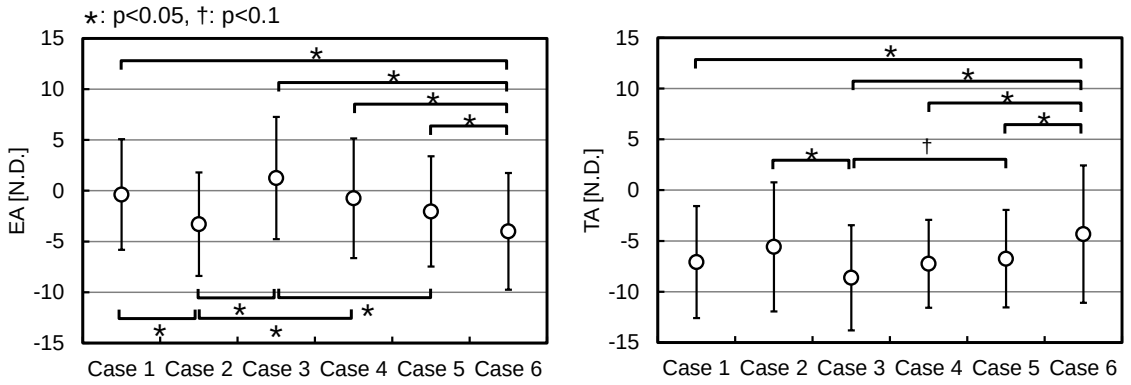


Figure 5. EA and TA after adaptation period.

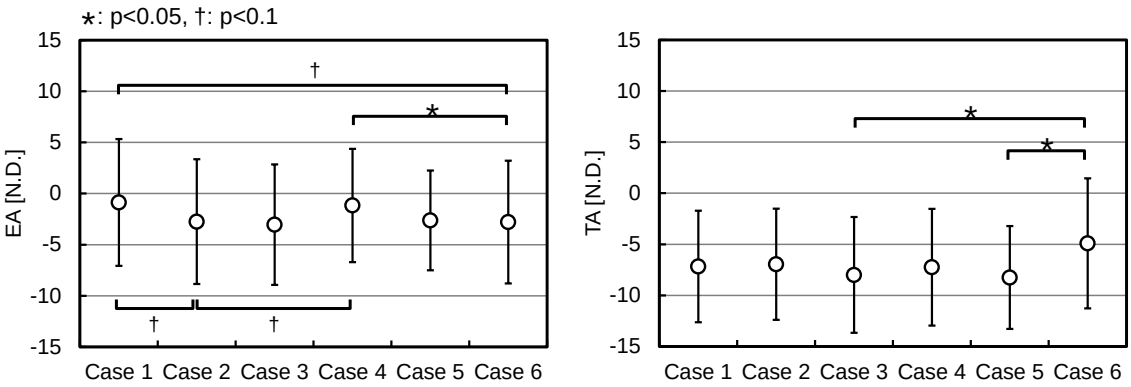


Figure 6. EA and TA after video lecture.

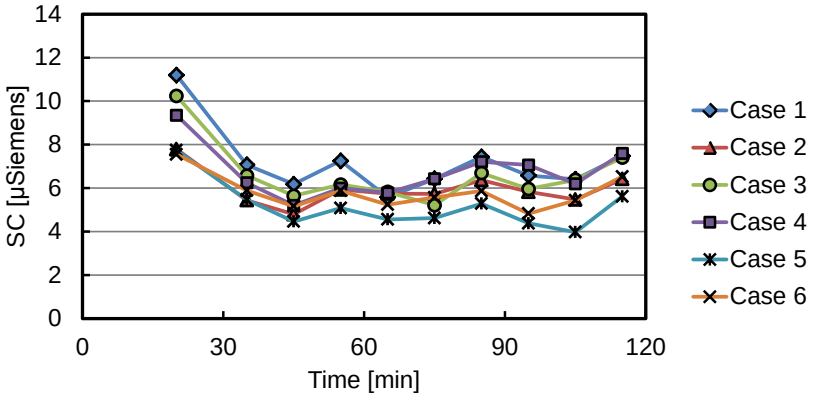


Figure 7. SC during Experiment 1.

Figure 7 shows the average SC of all subjects during the experiments. The SC during adaptation period was higher than that during watching video lecture, and this fact supported the results of EA and TA mentioned above. In addition, the SC observed in Cases 1, 3 and 4 were relatively high, while those in Cases 2, 5 and 6 tended to be low. It corresponded to the results of EA but not TA. The relation between SC and EA could be more prevalent than that between SC and TA in this experiment, because EA was much higher than TA.

Results of Experiment 2

Figure 8 shows the relationship between subjects' performance and EA. Each plot indicates the individual performance during each task period and the individual EA averaged before and after the period. The regression models did not well fit the data, but the EA was found to have significant positive impacts on the performance of all tasks ($p<0.01$). Figure 9 shows the relationship between subjects' performance and TA in the same manner. TA was also found to have significant impacts on the performance of all tasks, although the direction of the impacts was opposite.

Figure 10 shows that the EA after Task A became lower than that before. On the other hand, Figure 11 shows that the SC during Task A was lower than those during the other tasks. These facts were consistent with each other, and it was indicated that the Task A had an effect to lower subjects' EA.

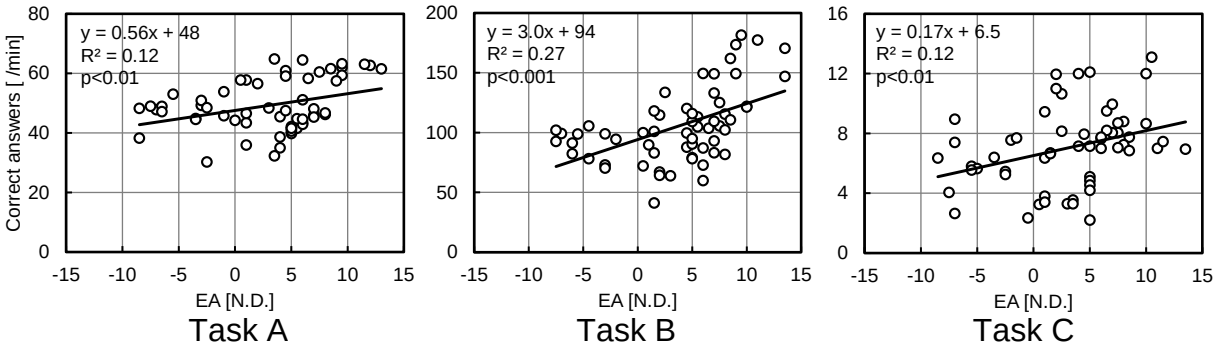


Figure 8. Relationship between EA and performance (num. of correct ans. per min).

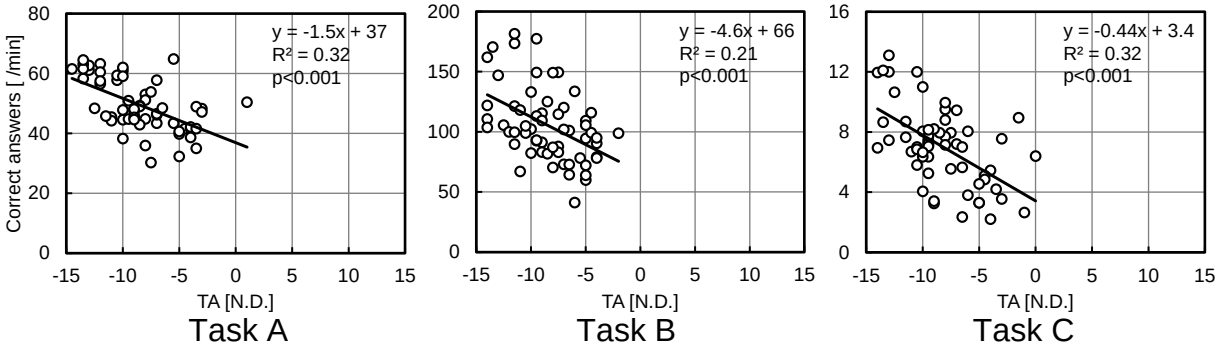


Figure 9. Relationship between TA and performance (num. of correct ans. per min).

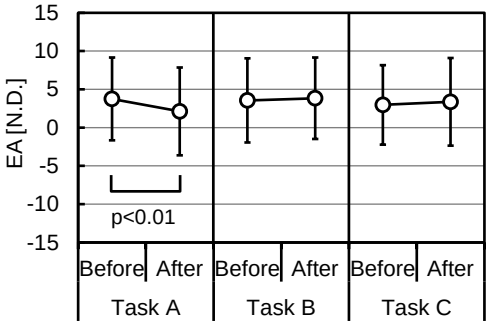


Figure 10. EA before and after task.

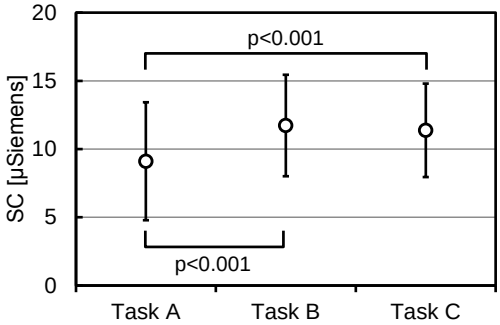


Figure 11. SC during task

CONCLUSIONS

In the present study, the first experiment showed that poor indoor environments caused low EA and high TA. The second experiment showed that low EA and high TA caused low work performance. Therefore, arousal state was considered to be one of the intermediary factors on causal relationship between indoor environment and performance. In addition, it was found that some kinds of tasks had the effects to lower people's EA and TA.

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