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

SUBJECTIVE EXPERIMENT ON CAUSAL RELATIONSHIP BETWEEN INDOOR TEMPERATURE AND OCCUPANTS' PERFORMANCE MEDIATED BY AROUSAL STATE

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SUMMARY

In the present study, a subjective experiment was done to validate the causal relationship between indoor environment and occupants' performance mediated by their arousal state. Indoor temperature was selected as the environmental parameter, and controlled at three levels (22, 25, 28^{o}C). The subjects' performance was evaluated with three types of tasks (detecting wrong pairs of numbers, inputting numbers, and Sudoku). The results were obviously dependent on the tasks. When subjects engaged in either detecting wrong pairs of numbers or inputting numbers, there were almost no differences in both arousal state and performance among three indoor temperatures. However, in the case of Sudoku, the EA at 22^{o}C was significantly higher than 28^{o}C ($p<0.05$) and the TA at 22^{o}C was significantly lower than 28^{o}C ($p<0.05$). A difference in performance on Sudoku was also found between 22^{o}C and 28^{o}C at the ending of the session ($p<0.1$). As the reason of the dependence on the tasks, it was considered that both EA and TA subsided due to the simplicity and monotony of the tasks except for Sudoku. Thus the EA and TA became lower regardless of the indoor temperature and no differences were caused in the performance.

INTRODUCTION

Many studies have shown the impacts of indoor environment on occupants' performance. However, degrees of the impacts are different among the studies, and besides, some studies have shown little impacts. In order to explain such differences, we are studying the mechanism of the causal relationship between indoor environment and performance with focusing on occupants' arousal state. Based on some studies in psychology (Matthews et al., 1990; Shirasawa et al., 1999), we consider that the arousal state consists of two components, i.e. energetic arousal (EA) and tense arousal (TA).

In our previous study (Goto et al., 2015), we had done two subjective experiments. One was to investigate the influence of indoor environment on subjects' arousal state, and showed poor indoor environment lowered EA and raised TA. The other was to

investigate the influence of subjects' arousal state on their performance, and showed high EA caused high work performance but high TA caused low work performance. Therefore, arousal state must be an intermediary factor of causal relationship between indoor environment and occupants' performance.

In the present study, we have carried out a subjective experiment to validate the causal mechanism mentioned above. We selected indoor temperature as the environmental parameter, and subjects' arousal state and work performance were investigated.

METHODOLOGIES

This experiment was conducted in an experimental room at Yamaguchi University, from August to September 2012. 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, and outdoor air (OA) supply rate and illumination intensity were kept at a constant level. Table 1 shows the experimental cases. Humidity was not controlled.

The subjects' performance was evaluated with three types of tasks, i.e. detecting wrong pairs of numbers, inputting numbers and Sudoku (Figure 2). Figure 3 shows the schedule of an experimental session. During the first 30 minutes, subjects adapted to the environment while watching a video lecture about geoscience. Then, the subjects engaged in three sets of 20 min task. Only one of the three tasks was adopted in an experimental session, thus the subjects done the same task repeatedly three times. Questionnaires about arousal state were answered between the task periods as well as beginning and end of the session. The other questionnaires about indoor environment were answered before the first task period and after the third task period. Each subjects participated in each of three experimental sessions of different experimental cases, but with an identical task. The experimental cases were assigned to the subjects in a randomized order.

Twenty-four or twenty-two subjects participated as volunteers regarding each task (Table 2). They were all university students, and paid for their participation. In addition, some rewards were paid to the subjects depending on the task performance. To reduce the effects of circadian rhythm, experiments of each subject were done in the same time frame (10:00-11:50 or 14:00 -15:50). 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 3, as the questionnaire to evaluate subjects' arousal state. From this questionnaire, energetic arousal (EA) and tense arousal (TA) were evaluated in the same manner of our previous study (Goto et al., 2015). We also measured skin conductance (SC) as an objective evaluation of arousal state. It was measured continuously during each experimental session.

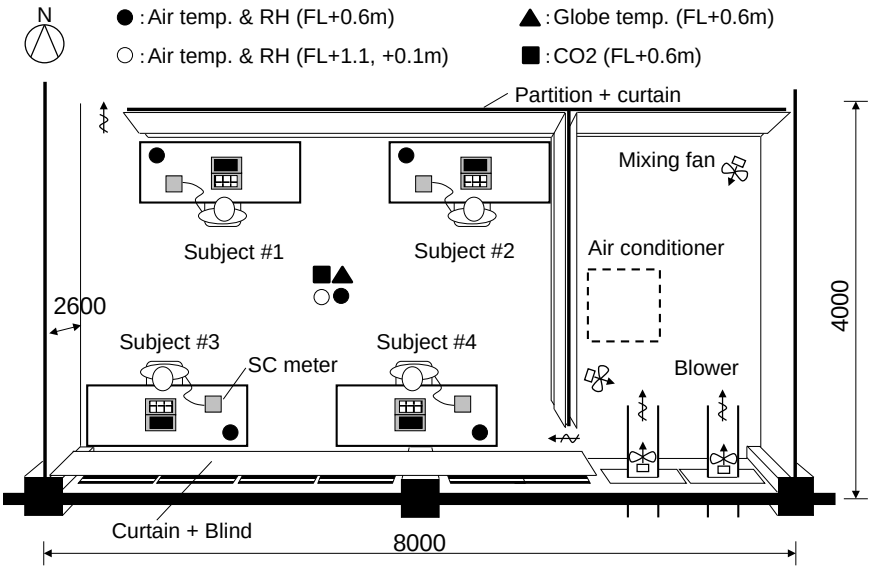
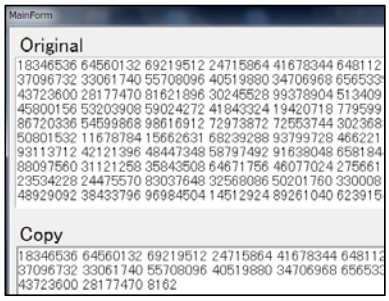


Figure 1. Experimental room.

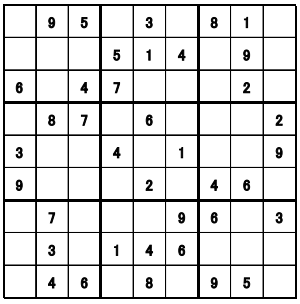
Table 1. Experimental cases.

	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	25				
Case 3	28				

Task A: Detecting wrong pairs of numbers

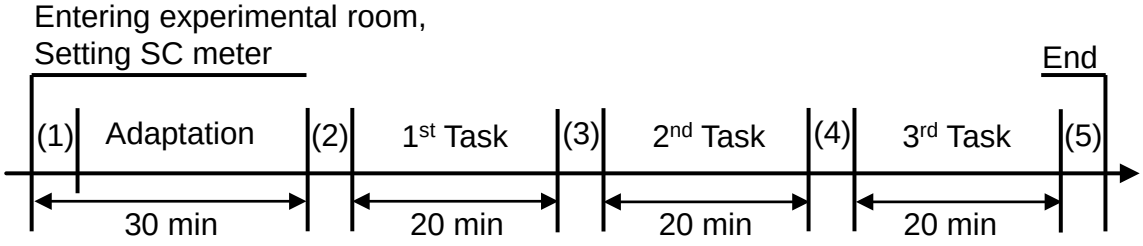


Task B: Inputting numbers



Task C: Sudoku

Figure 2. Types of Tasks.



(1) Questionnaire: Physical condition, Environmental satisfaction and Arousal
(2), (5) Questionnaire: Arousal, Environmental satisfaction
(3), (4) Questionnaire: Arousal

Figure 3. Schedule of experimental session.

Table 2. Experimental subjects

	Number	Average age
Detecting wrong pairs of numbers	22 (Male 20, Female 2)	20.6
Inputting numbers	24 (Male 19, Female 5)	21.0
Sudoku	24 (Male 20, Female 4)	21.1

Table 3. 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

RESULTS AND DISCUSSION

Table 4 shows the time average and standard deviation of indoor environment measurements. The temperature in Case 1 was slightly higher than the target value because of the insufficient cooling capacity of air conditioner. But the temperature in the other cases was satisfactorily controlled. Relative humidity decreased along with temperature. It is because the air was dehumidified when it was cooled by the air conditioner, and no intentional control was done regarding humidity.

Subjects' average thermal satisfactions are presented in Figure 4. Regarding each type of tasks, those in Case 3 were significantly lower than the other cases (paired t-test), while those in Cases 1 and 2 were almost the same.

Table 4. Indoor environment measurements.

		Air temp. [^{o}C]	Globe temp. [^{o}C]	Relative Humidity [%]	CO2 [ppm]
Task A	Case 1	22.5±0.2	22.5±0.2	53±3	733±128
	Case 2	25.2±0.3	25.2±0.3	70±5	674±127
	Case 3	27.9±0.2	27.9±0.2	74±2	688±139
Task B	Case 1	22.5±0.3	22.4±0.4	53±2	675±112
	Case 2	25.2±0.3	25.2±0.3	59±4	694±122
	Case 3	28.0±0.2	28.0±0.3	76±3	654±133
Task C	Case 1	22.6±0.2	22.6±0.2	49±3	696±125
	Case 2	25.2±0.3	25.2±0.4	55±3	683±134
	Case 3	28.1±0.3	28.1±0.2	74±2	682±132

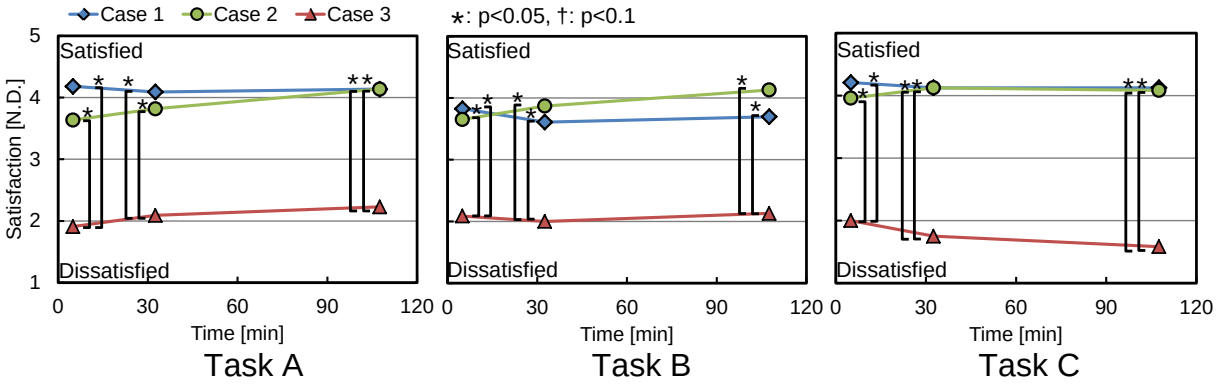


Figure 4. Satisfaction with thermal environment.

Figures 5 and 6 show subjects' averages of EA and TA evaluated with JUMACL. According to paired t-test, there were almost no differences within Task A (detecting wrong pairs of numbers) and Task B (inputting numbers). It was not expected but can be explained by the characteristics of these tasks. Both EA and TA were considered to be subsided by simplicity and monotony of the tasks. Thus, the EA and TA became lower regardless of the indoor temperature. On the other hand, there were some significant differences in both EA and TA within Task C (Sudoku). The EA in Case 1 was significantly higher than that in Case 3, and the TA in Case 1 was significantly lower than that in Case 3. The EA in Case 2 also tended to be higher than Case 3. Additionally, it was found that both EA and TA of Task C once fell during adaptation period, and then rose together with starting the task. The reason must be that the EA and TA were subsided by watching video lecture during the adaptation period.

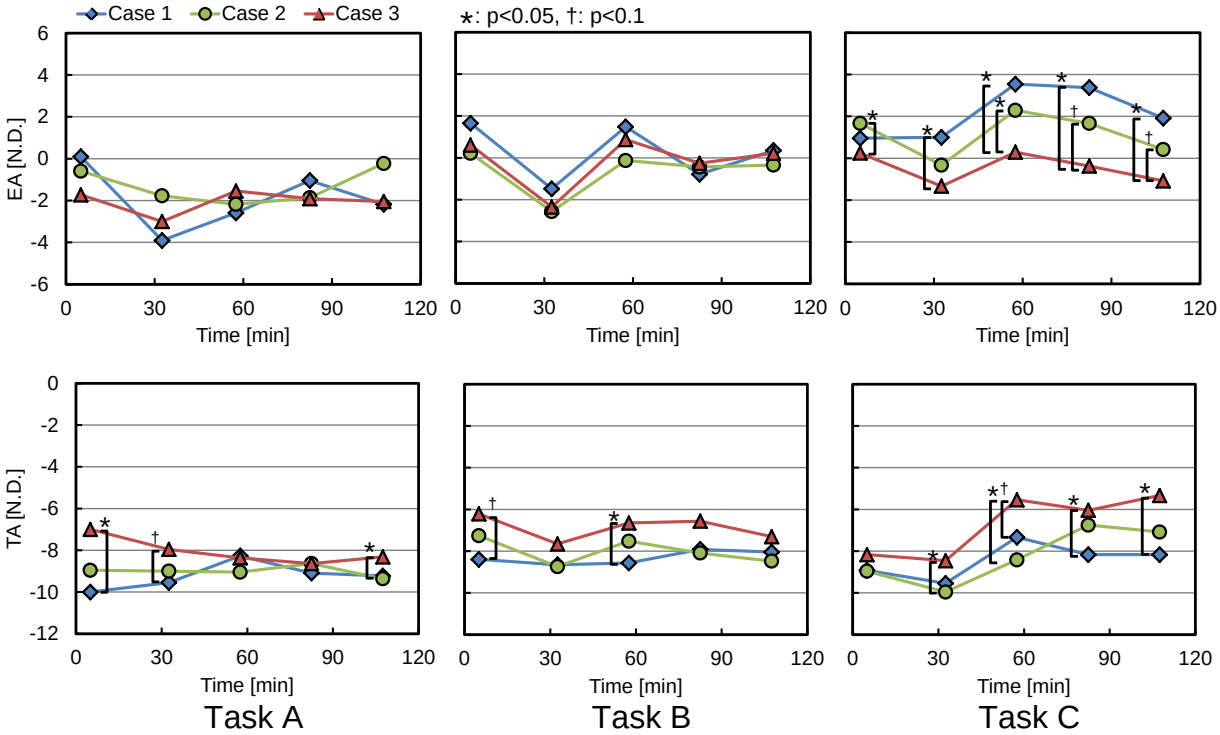


Figure 5. Energetic arousal (EA) and tense arousal (TA).

Subjects' averages of SC during each period, i.e. adaptation, 1st task, 2nd task and 3rd task, were presented in Figure 6. Low SC level typically indicates low arousal level. The SC of Task C was significantly higher in Cases 1 and 2 than in Case 3, while almost no differences were found in that of Task A. Furthermore, the SC was lower during adaptation period than during task periods. These tendencies were well consistent with the results of EA.

Figure 7 shows the average performance in every case with three types of tasks. Regarding Tasks A and B, no differences were found among the cases. It was reasonable because the subjects' arousal state was not different among these cases. On the other hand, a difference in the performance was found in Task C. At the 3rd period, the performance in Case 1 was higher than that in Case 3. It was consistent with the results of EA and TA mentioned above, and also agreed with our previous study (Goto et al., 2015).

Meanwhile, the p-value of this difference was slightly high ($p<0.08$). It must be attributed to the individual differences in sensitivity. In a few subjects, their arousal state was less affected by indoor temperature, and thus their performances were not different between the cases. Figure 8 shows the average performance on Task C excluding three subjects whose amounts of arousal change were in the bottom 25% regarding both EA and TA. The p-value was found to be smaller than that in Figure 7.

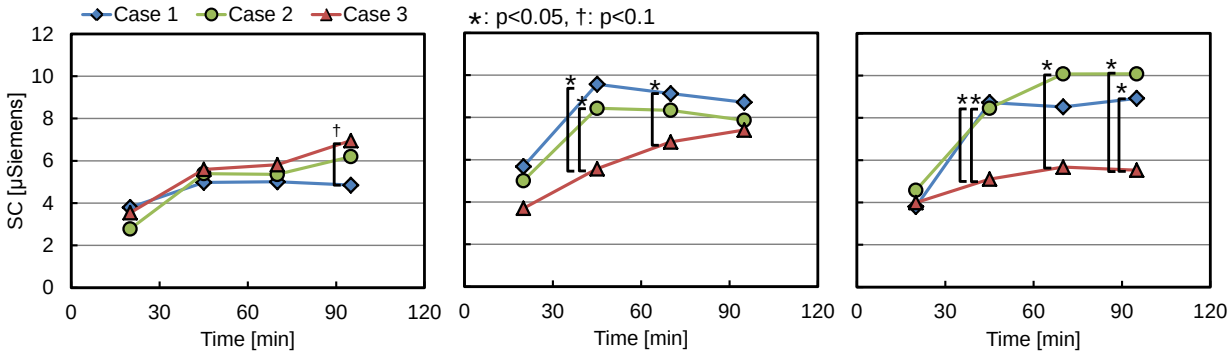


Figure 6. Skin conductance (SC).

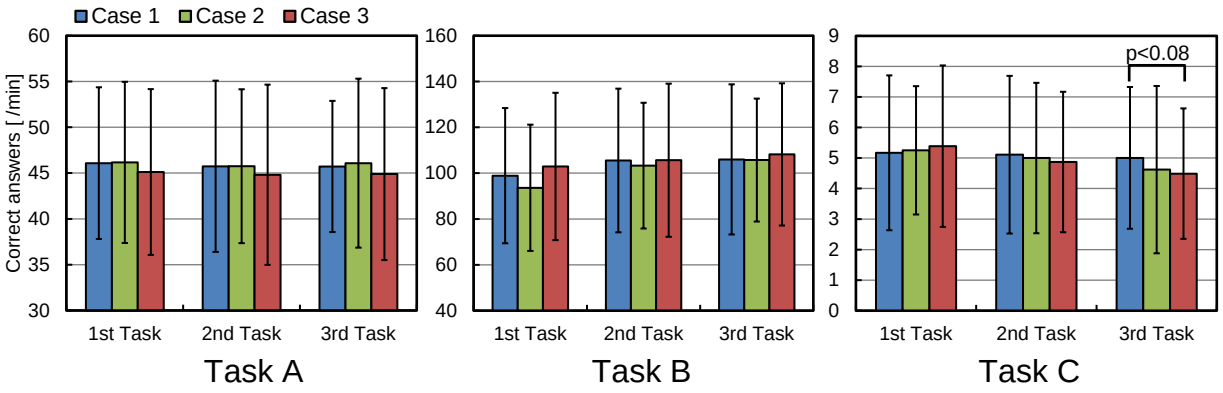


Figure 7. Work performance (number of correct answers per min).

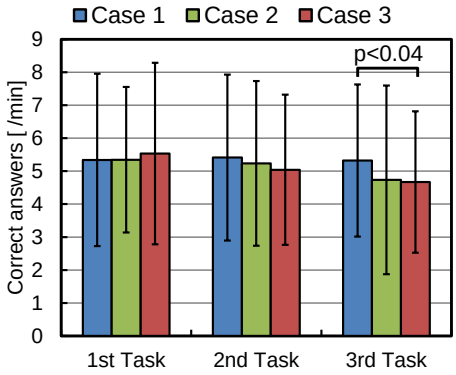


Figure 8. Work performance on Task C (excluding three subjects).

CONCLUSIONS

When subjects engaged in Sudoku, EA was significantly higher at 22°C than at 28°C and TA was significantly lower at 22°C than at 28°C. A difference in the performance was also found between 22°C and 28°C. However, when subjects engaged in either detecting wrong pairs of numbers or inputting numbers, there were almost no differences in both arousal state and performance among three indoor temperatures. This must be because subjects' arousal state calmed down due to the simplicity and monotony of those tasks. Thus, both EA and TA became lower regardless of the indoor temperatures and no differences were caused in the performance. These facts indicate that the arousal state is one of the key factors in the mechanism of causal relationship between indoor environment and occupants' performance.

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