Individual control of air velocity for increasing productivity

Naoe Nishihara*, Shin-ichi Tanabe

Department of Architecture, Waseda University, Tokyo, Japan

ABSTRACT
Subjective experiments were conducted in a climatic chamber to evaluate the effect of individual control of air velocity on productivity. For the condition of constant air velocity (CAV) subjects were not allowed to control air velocity and for the condition of preferred air velocity (PAV) they were allowed to control it. The chamber was conditioned at air temperatures of 31°C, mean radiant temperature of 31°C, and relative humidity of 50%. Several computer tasks were given to the subjects to evaluate task performance. There was no significant difference in task performance between PAV and CAV subjects. According to the evaluation of subjective symptoms of fatigue, the subjects complained of mental fatigue more at CAV than at PAV. It was found that providing individual control of air velocity was able to reduce subjective feelings of mental fatigue. Evaluation of fatigue is useful to evaluate productivity.

INDEX TERMS
Productivity; Fatigue; Individual control; Air velocity; Task performance

INTRODUCTION

Recently, personal ventilation, which can provide individual control over environmental conditions, has been the focus of attention from the aspect of energy conservation, thermal comfort, and productivity. Productivity is defined as the extent to which activities have provided performance in terms of system goals (Parsons, 1993). There are many studies on the effect of personal control on thermal comfort, but few studies focused on the effect of fatigue. In this study, experiments were conducted in a climatic chamber to evaluate the effect of individual control of air velocity on productivity. In this study, not only task performance but also subjective fatigue was measured. Two conditions, one with constant air velocity (CAV) and the other with preferred air velocity (PAV), were compared. For the CAV conditions subjects were not allowed to control air velocity and for the PAV conditions they were allowed to control it.

METHODS

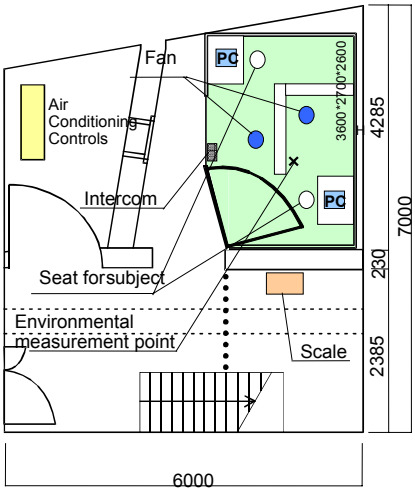
To evaluate the effect of individual control of air velocity on productivity, subjective experiments were conducted in a climatic chamber at the Waseda University during July and August 2001. The plan of the chamber and experimental set up are shown in Figure 1. Twenty-one male subjects of college-going age participated in the experiments. They participated in the experiment four times in total at intervals of 1 week. All subjects were volunteers and they were paid at a fixed rate for their participation. To investigate the effect of individual control of air velocity on productivity precisely, it is required to control subjective motivation at the same level as much as possible. However, it is very difficult to neutralize subjective motivation because it is related to the health condition, mood, etc. In this study, in order to increase their motivation to the same level, they were informed that the top 10 performers of the computer tasks could earn one hour's worth of bonus. Therefore, it could be assumed that subjects were highly motivated.

* Corresponding author. E-mail: nishihara@tanabe.arch.waseda.ac.jp

The experimental conditions are shown in Table 1. The average value of SET* (Gagge *et al*., 1986) was calculated. The fans were able to adjust air velocity to three levels—'Soft', 'Medium' and 'Powerful'. The fans were set at a point 1.3 m to the left side from the midpoint of subject and at a point 0.7 m above the floor. The air velocities at 0.1, 0.6, 1.1 and 1.7 m above the floor were measured using an ultrasonic anemometer (KAIJO OA —60TC1). The vertical distributions of air velocity at the midpoint of subjects are shown in Figure 2. The CAV conditions were set at the air velocity level 'Medium'. For the CAV conditions they were not allowed to control air velocity and for the PAV conditions they were allowed to control it by using a remote controller. The chamber was conditioned at air temperatures of 31°C, mean radiant temperature of 31°C and relative humidity of 50%.

Table 1 Experimental conditions (mean ± standard deviation)

Condition (0.71 clo, 1.1 met)	Air temperature (°C)	Mean radiant temperature (°C)	Relative humidity (%RH)	Air velocity (m/s)	SET* (°C)
Practice	28.2 ± 0.07	28.2 ± 0.08	50 ± 0.6	0.10 ± 0.10	29.0
Control	28.3 ± 0.10	28.2 ± 0.12	51 ± 0.6	0.10 ± 0.10	29.1
CAV	31.0 ± 0.19	31.0 ± 0.20	50 ± 0.6	1.44 ± 1.33	28.4
PAV	31.2 ± 0.13	31.2 ± 0.14	49 ± 0.6	1.82 ± 1.71	28.3



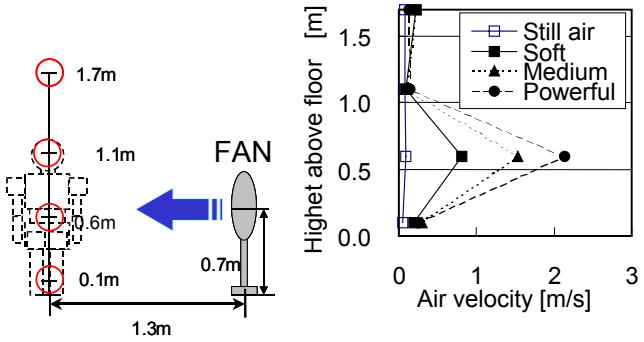


Figure 2. The vertical distributions of air velocity at the midpoint of subjects

Figure 1. The plan of the chamber and experimental set up

As a control (Control), subjects were exposed to the condition at air temperatures of 28°C, mean radiant temperature of 28°C and relative humidity of 50%. Subjects experienced these three conditions in balanced order. Before these three conditions, they participated in a practice session under the same conditions as in the Control situation. Up to two subjects could enter the climatic chamber at a time and subjects occupying the same chamber simultaneously experienced the same experimental conditions. Air velocities in the table are measured at a point 0.4 m to the left of the midpoint of the subject and at a point 0.7 m above the floor. Subjects wore typical office clothing ensembles, which were provided by us. Thermal insulation was estimated at 0.71 clo using a thermal manikin (Tanabe and Hasebe, 1993).

The experimental procedure is shown in Figure 3. After changing clothes and entering the climatic chamber, subjects stayed there in a sedentary state for 30 min, and then they voted on their first thermal sensation in the chamber and feeling of fatigue. Two kinds of computer tests were carried out to evaluate the task performance: the text typing test for 30 min and the Walter Reed Performance Assessment Battery test (PAB) (Thorne *et al*., 1985) for about 15 min before and after the text typing test. The PAB test consisted of seven tasks; two-letter search, four-choice serial reaction time, interval production, manikin, code substitution, matching to sample and

running memory. The interval production task was evaluated by a subjective estimated time of 1 s. The other task performances were evaluated using the number of correct answers per minute. There was no significant difference in task performance between PAV and CAV. After each test, an intermission of 10 min was allowed and then the subjects were asked to record their thermal sensation, sensation about air velocity, feeling of fatigue and evaluation of task load.

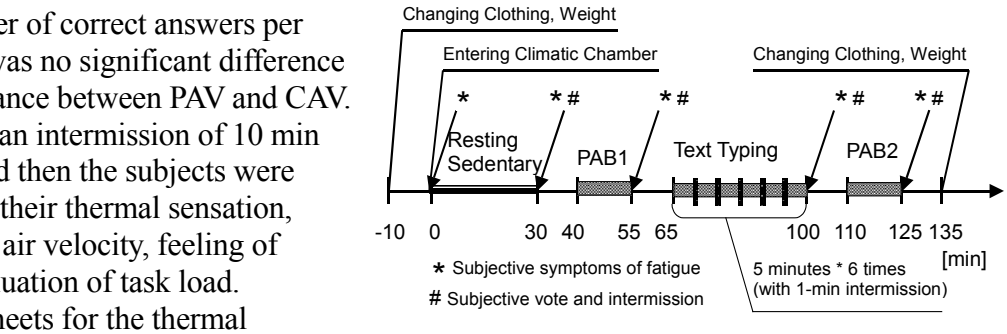


Figure 3 Experimental procedure

The voting sheets for the thermal environment and air velocity are shown in Figure 4. NASA-TLX National Aeronautics and Space Administration Task Load Index is the scale for subjective evaluation on mental work load (Hart and Staveland, 1988). The Japanese version by Miyake (Miyake and Kumashiro, 1993) was used for experiments. NASA-TLX consists of six component scales; 'mental demand', 'physical demand', 'temporal demand', 'performance', 'effort' and 'frustration level'. The subjects indicate the performance by a mark on each line segment, on the leftmost end for 'good (0)'and on the rightmost end for 'poor (100)', or on the leftmost end for 'low (0)' to the rightmost end for 'high (100)' for the other scales. For a comprehensive evaluation of the mental workload, RTLX (Raw TLX) proposed by Miyake was used. RTLX were calculated by averaging ratings of six components. Subjects rated NASA-TLX after each task.

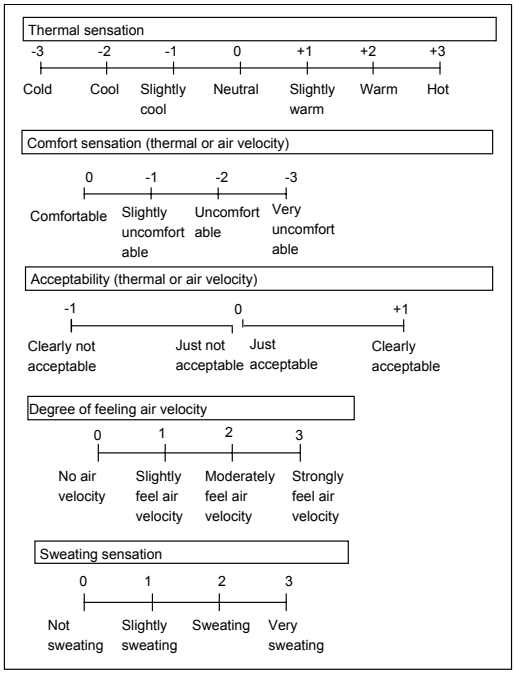


Figure 4. The voting sheet on thermal environment and air velocity

To evaluate the feeling of fatigue, subjects filled in the sheets of 'Evaluation of Subjective Symptoms of Fatigue' suggested by the working group for occupational fatigue of the Japan Society for Occupational Health (Yoshitake, 1973). This evaluation method is used in the field of labour science and ergonomics in Japan. It consists of three categories; group I consists of 10 terms about 'drowsiness and dullness', group II consists of 10 terms about 'difficulty in concentration', and group III consists of 10 terms about 'projection of physical disintegration'. Three categories of subjective symptoms of fatigue are shown in Table 2. Based on Yoshitake's method, the rate of complaints was calculated using equation (1). According to the order of the rate of complaints among three categories, three types of fatigue feelings were suggested (Yoshitake, 1973): General pattern of fatigue: 'I > III> II', typical pattern of fatigue for mental work and overnight duty: 'I > II > III', and typical pattern of physical work: 'III >I > II'. 'General rate of complaints' was defined as the rate of complaints about all 30 symptoms. Subjects were asked to fill symptoms in the sheets five times during each experiment—namely, just after entering the climatic chamber, after remaining sedentary, after PAB test 1, after the text typing test and after the PAB test 2.

Table 2 Three categories of subjective symptoms of fatigue

Group I	Group II	Group III
Feel heavy in the head	Feel difficulty in thinking	Have a headache
Whole body feels tired	Become weary of talking	Feel stiff in the shoulders
Legs feel tired	Become nervous	Feel a pain in the back
Yawning	Unable to concentrate	Feel opressed in breathing
Feel the brain is hot or muddled	Unable to have interest in things	Feel thirsty
Become drowsy	Get forgetful	Have a husky voice
Feel strain in the eyes	Lack of self-confidence	Feel dizzy
Become rigid or clumsy in motion	Anxious about things	Have a spasm on the eyelids
Feel unsteady while standing	Unable to straighten up in a posture	Have a tremor in the limbs
Want to lie down	Lack patience	Feel ill

$$\text{Rate of complaints (\%)} = \frac{\text{Total number of a corresponding fatigue symptom of total subjects}}{\text{Total number of symptoms on the evaluation sheet} \times \text{Total number of subjects}} \times 100 \quad (1)$$

Mean differences in the results between CAV and PAV were tested for significance using the paired *t*-test. For the analysis of task performance, the correct answer rate per minute for each task was calculated. To evaluate subjective symptoms of fatigue, the rate of complaints for each subject was calculated and those were compared between CAV and PAV.

RESULTS AND DISCUSSION

Subjective Vote for Thermal Environment and Air Velocity

The average value ± standard deviation of the thermal sensation vote, comfort sensation vote, thermal acceptability and sweating sensation vote are shown in Table 3. There was no significant difference between CAV and PAV. The results of sensation about air velocity are shown in Figure 5. After the PAB test 2, the average values of degree of feeling the air velocity were 2.01 in the PAV condition, which was significantly higher than that in the CAV condition of 1.73 ($p < 0.05$). After the text typing task, the sensation about air velocity in PAV also had a tendency to be higher than that in CAV ($p < 0.1$). The acceptability of air velocity of PAV was significantly higher than that of CAV after remaining sedentary, after the text typing task and after the PAB test 2 (after resting, after PAB test 2: $p < 0.05$, after text typing test: $p < 0.01$).

Task Performance

It was difficult to evaluate the productivity only by the task performance. The reasons for it might be that the following: subjects were highly motivated; as shown in Table1, subjects in CAV and PAV conditions were exposed to almost identical levels of thermal stress and the difference in thermal stress between this and the control condition was small; and the 21 subjects in our study were less than the 30 subjects in previous experiments that succeeded in demonstrating the effects of quite large environmental differences on text typing but not on the PAB (e.g. Wargocki *et al*.,1999).

Table 3 Subjective vote about the thermal environment

	Thermal sensation vote	Comfort sensation vote	Thermal acceptability	Sweating sensation vote
Practice	1.9 ± 0.8	−1.5 ± 0.6	−0.1 ± 0.7	1.3 ± 0.5
Control	1.5 ± 0.7	−1.2 ± 0.6	0.0 ± 0.4	1.0 ± 0.8
CAV	0.9 ± 1.1	−1.0 ± 0.7	0.0 ± 0.5	0.9 ± 0.5
PAV	0.7 ± 1.2	−1.0 ± 0.6	0.2 ± 0.5	0.8 ± 0.4

(+$p < 0.1$; *$p < 0.05$; **$p < 0.01$: significant differences)

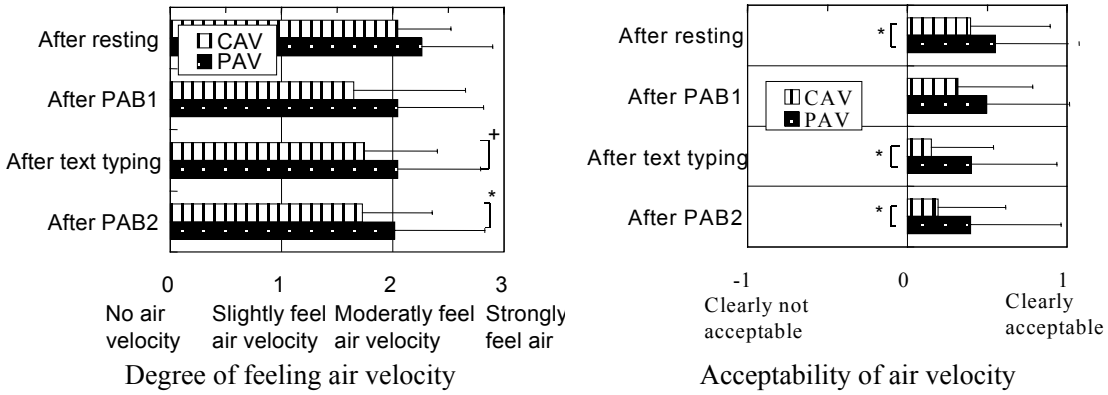


Figure 5 Subjective vote about air velocity

NASA-TLX

The results of RTLX after the PAB test 1, the text typing task and the PAB test 2 are shown in Figure 6. There was no significant difference between CAV and PAV. The value of RTLX of the text typing test was significantly higher than the PAB test. The text typing test involved a higher mental workload than the PAB test.

Evaluation of Subjective Symptoms of Fatigue

General rate of complaints and the order among the three categories of the subjective symptoms of fatigue are shown in Table 4. General rate of complaints of PAV were the lowest in all experimental conditions. In the PAV condition, the order among three categories of the subjective symptoms of fatigue was I>III>II, and it was categorized as 'General pattern of fatigue'. On the other hand, in Practice, Control and CAV conditions, it was I > II > III and they were categorized as 'Typical pattern of fatigue for mental work and overnight duty'.

The rate of complaint of each group was compared for the CAV and PAV conditions. There were no significant differences between groups I and III. Therefore, the rate of complaints of group II is shown in Figure 7. After resting sedentary and the text typing task, the rate of complaints of group II in PAV were significantly lower than that in CAV ($p < 0.05$). According to the evaluation of subjective symptoms of fatigue, the subjects complained of mental fatigue more at CAV than that at PAV. It was found that providing individual control of air velocity was able to reduce the subjective feeling of mental fatigue. In our previous study, the effect of moderately hot environment on productivity was also evaluated and the subjects complained of mental fatigue more at an operating temperature of 33°C than 25 and 28°C (Nishihara *et al*., 2002). In the real workplace, it is regarded that the negative effects of fatigue on performance will be much larger than they could possibly be in an experiment that lasted only about 2 h. Evaluation of fatigue might be useful to evaluate productivity.

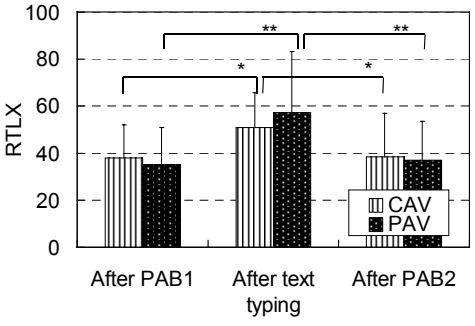


Figure 6 RTLX

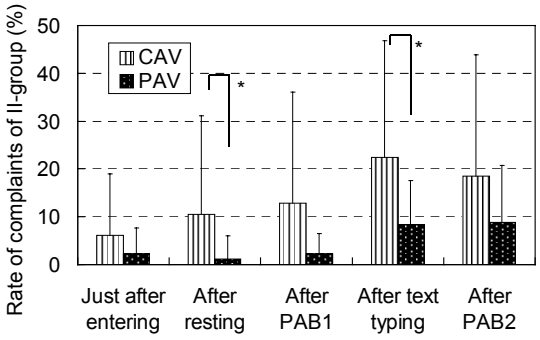


Figure 7 Rate of complaints of group II.

Table 4 The order among the three categories of the subjective symptoms of fatigue

Conditions	General rate of complaints (%)	Group I (%)	Group II (%)	Group III (%)	The order among the three categories
Practice	16.3	20.5	15.7	12.9	I > II > III
Control	13.2	17.2	11.5	10.8	I > II > III
CAV	14.4	17.8	14.1	11.3	I > II > III
PAV	10.0	15.6	4.6	9.9	I > III > II

CONCLUSIONS

Subjective experiments were conducted to evaluate the effect of individual control of air velocity on productivity. In this paper, the results of task performance, mental workload and feeling of fatigue were reported.

1. There was no significant difference in task performance between PAV and CAV.
2. According to the evaluation of mental workload by NASA-TLX, there are no significant differences between CAV and PAV. The value of RTLX of the text typing task was significantly higher than for the PAB test. NASA-TLX mainly evaluated the mental workload more by task types than by environmental conditions.
3. According to the evaluation of subjective symptoms of fatigue, the subjects complained of mental fatigue more at CAV than at PAV. It was found that providing individual control of air velocity was able to reduce the subjective feeling of mental fatigue.

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