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An Experimental Study on Intellectual Concentration Influenced by Indoor Airflow

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***Abstract*—In order to improve intellectual concentration, few studies have verified the effect of indoor airflow among the thermal environment conditions, and the differences of the season in effects have not been studied. In this study, in order to investigate the influence of the airflow in winter on the intellectual concentration, an evaluation experiment was conducted. In the previous study, an effective airflow in summer was proposed and the improvement of intellectual concentration by evaluation experiment was confirmed. Therefore, an airflow profile in winter was proposed with reference to the airflow profile in summer. The airflows are a combination of a simulative airflow and mild airflow. An experiment has been conducted to investigate the influence of a room airflow in winter on intellectual concentration. As a result of comparison with no airflow condition, no significant difference was found. Based on the results, it is a future task to ask preliminary preference in advance and to establish a mechanism that can provide controllable airflow for each individual, taking into account the preference for airflow to be different for each individual.

***Keywords*—Intellectual concentration, airflow, winter, experiment.

I. Introduction

THE attempts to improve intellectual productivity and intellectual concentration have been actively studied by controlling the indoor environment in recent years, and particularly to office environments. There are many factors such as temperature, lighting, noise, etc. affecting intellectual productivity and intellectual concentration of office workers in the office. Several studies have shown that the thermal environment (temperature, humidity, airflow, thermal radiation) has a large influence on intellectual productivity and intellectual concentration[1]-[5]. And, some experiments in the studies have been conducted to measure the influence of temperature and humidity. However, focusing on the influence of indoor airflow on intellectual productivity and intellectual concentration, no study has been quantitatively analyzed with the basis of experimental results.

A profile of room airflow was proposed to improve intellectual concentration in a previous study[6]. The experimental results showed that intellectual concentration was improved by an average of 6.5% points when using the proposed airflow by comparing with an environment without airflow.

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The experiment was conducted in a summer season, however there are fluctuations in temperature and humidity throughout the year in Japan and especially in summer and winter the thermal environment is quite different. Also, basal metabolism is larger in winter than summer[7], and the cloths and comfortable feeling by room temperature are different in summer and winter. Therefore, it is assumed that the way people feel is different in summer and winter, and there is a possibility that appropriate environmental conditions may be different.

For the above reasons, the purpose of this study is to verify the effect of airflow on intellectual concentration in winter. There is a possibility that the airflow that improved intellectual concentration in summer may have the same effect as in winter. On the other hand, it is assumed that there are differences on airflow in summer and winter due to the difference in seasonal temperature and humidity. For this reason, an evaluation experiment is conducted to confirm the change of intellectual concentration due to airflow in winter compared with a condition without airflow.

II. Related Research

In order to evaluate the influence of airflow, Zhai *et al.* have considered subjective evaluation of thermal comfort in an uncomfortable indoor environment of high temperature and high humidity[8]. As a result, it has been shown that the airflow has the effect of maintaining thermal comfort in an indoor environment with high temperature and high humidity. As a study showing one of the effects of airflow, Morito *et al.* conducted an experiment to examine the influence of a cold airflow of air conditioning on sleep of participants [9]. As a result, it has been shown that direct exposure by the cold airflow would cause the prevention of sleep through reduction in the skin temperature. From the result, it is considered that there is a possibility that direct exposure of the airflow would cause the arousal.

As an influence of air quality, Wyon *et al.* showed that a poor air quality degrades work performance [10]. It seems that there is a possibility that improving an air quality would improve intellectual productivity of office workers.

In addition, focusing on differences in individual feelings, there are some studies using thermal controllable environmental conditions. Akimoto *et al.* suggested that the use of individually controllable air conditioning has an effect affecting fatigue and psychological aspects and that there is a possibility of maintaining comfort [11].

Tanabe *et al.* developed a task unit of isothermal airflow that enables workers to control the specifications of airflow around each worker and measured the effect of the subjective thermal comfort[12]. As a result, the comfortable feeling was improved by using the task unit. The above-described research by Zhai *et al.* used an airflow that can be controlled individually, and showed that the thermal comfort of the workers would be maintained even if the room temperature rises[8].

In these studies, the comfort and arousal level are subjectively measured as the influence of the thermal environment. And, they do not consider on seasonal differences. In the effect of the thermal environment, it is confirmed in a previous study that an airflow improves intellectual concentration in summer[6]. On the other hand, different results may be showed in winter. Therefore, in order to propose an appropriate utilization of an airflow according to the season, this study aims at confirming the effect of an airflow in winter and analyzing the factor.

III. Proposal of an Airflow in Winter

In this study, the summer airflow proposed in the previous study is explained at first. Then, with reference to the summer airflow, a preliminary experiments using the airflow in winter is conducted and an airflow is proposed to improve intellectual concentration in winter.

A. Airflow used in the experiment in summer

The airflows proposed in the previous study are a combination of a simulative airflow and a mild airflow [6]. A simulative airflow was expected to improve awareness with the basis on the suggestion of the possibility that cooling airflow would impede sleep [9]. On the basis of the experimental result on the influence of indoor air quality performance[10], a mild airflow circulating the air was expected to improve intellectual concentration by improving air quality. Then, preliminary experiments were conducted to consider the wind speed, blowing time, interval of the airflow blowing, the impression to the airflow, the arrangement of the air purifier, the position to expose the airflow, etc. In the simulative airflow, the winds were exposed directly to the back of the participants at regular intervals (wind speed 1.6 ms, once every 10 minutes for 20 seconds). The mild airflow continued to expose a weak wind to the upper body of the participants (wind speed 0 to 0.4 ms, cycle of 120 seconds). The conditions of the simulative and mild airflows as airflow profiles was compiled and evaluation experiments were conducted to measure intellectual concentration using the airflows of the airflow profile. The number of the participants was 28 , and the period of the experiments was from August to September 2014 (summer season in Japan). In the condition with the airflows, the effect of the airflows was confirmed by using the airflows with the proposed airflow profile, compared with the condition without airflow. The task was a receipt classification task[13], and the intellectual concentration was measured using the concentration time ratio (CTR)[14]. The CTR is an index showing how long the worker is concentrated during the work time from the answer time per a question of cognitive task. As a result, intellectual concentration under the condition with the airflows was improved by an average of 6.5 % points compared with a condition without airflow (paired two-tailed t test, $p < 0.001$).

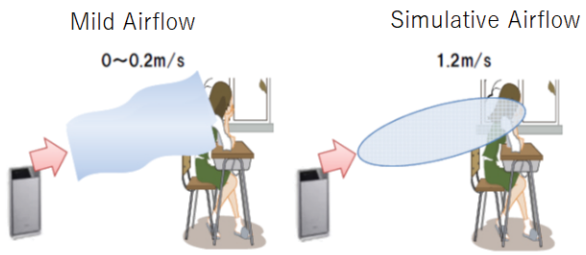

Fig. 1 An airflow profile in winter

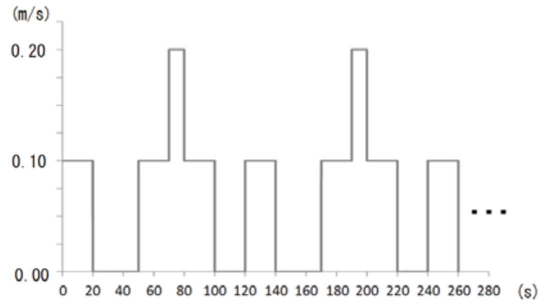

Fig. 2 Change in airflow speed

B. Airflow profile in winter

In this study, an airflow profile is considered to improve intellectual concentration in winter. First, it was assumed that the airflow profile which improved intellectual concentration in summer might improve intellectual concentration even in winter. On the other hand, in winter with different amounts of metabolism and clothing, the airflow profile in summer may be different in feeling and impression. Then, preliminary experiments were conducted to examine the wind speed and the position to expose the airflow in order to ask the impression on the airflow in an interview. Preliminary experiments with 16 participants were conducted in a laboratory room in Kyoto University from November to December 2014. An air cleaner for exposing the airflow was placed for each participant, and the participants were provided instructions to do receipt classification task [13]. Because there were many opinions that exposure of the same airflow as in summer provided a feeling of coldness by the airflow, it was considered to adjust the wind speed at both the simulative airflow and the mild airflow and change the exposure position with reference to the summer airflow profile. Then, an airflow profile was set up to improve intellectual concentration in winter. The proposed airflow profile in winter is shown in Fig. 1. Fig. 2 shows an example of how to control the fluctuation of the wind speed during the mild airflow.

Fig. 3 Experimental situation of a participant

TABLE I
ENVIRONMENTAL CONDITION IN THE EXPERIMENTAL ROOM

Room temperature	23 ± 0.5 ℃
Humidity	45 ± 5%
CO_2 concentration	Less than or equal to 800 ppm
Noise levels	Less than or equal to 48.7 dB
Desk surface illumination	400-500 lux

- **An simulative airflow** exposes brief and high wind directly to the back of the worker at regular intervals (wind speed 1.2 m/s, once every 10 minutes for 20 seconds)
- **A mild airflow** adjusts the wind direction over the worker's head and does not directly expose to the worker' s body (wind speed 0 - 0.2 m/s, cycle of 120 seconds)

IV. Evaluation Experiment with Airflows in Winter

A. Purpose

In this experiment, the effect of airflow is examined on intellectual concentration in winter. For the purpose, an experiment is conducted using airflows with the airflow profile (Fig. 1) combining the simulative airflow and the mild airflow proposed in Chapter 3. In the experiment, the condition to be compared as the reference is without airflow, and the condition without airflow and the condition with airflow are compared.

B. Indoor environmental conditions

The experiments were conducted in a laboratory in Kyoto University from December 2014 to January 2015. Fig. 3 shows an experimental situation of a participant in the experiment.

The environmental conditions of the laboratory are shown in Table I. In order to prevent the influence of environmental conditions on intellectual concentration other than the airflows, the environmental conditions such as temperature, humidity, desktop illuminance were controlled to be constant. An air purifier (F-VXJ90-WZ, by Panasonic Co., Ltd.) was used to blow the airflows. An example of change in the wind speed during the experiment is shown in Fig. 4. In order to reduce th influence by the difference of the temperature in tops and bottoms[15], the air was stirred using three circulators. The direction of the airflows was adjusted so that the air from the air conditioning did not hit the participants directly. In order to make it hard to feel coldness caused by the airflow, a hot carpet was installed as a countermeasure against cold feet.

C. Participants

Participants in the experiment were 28 healthy university students (14 males and 14 females). Screening was conducted

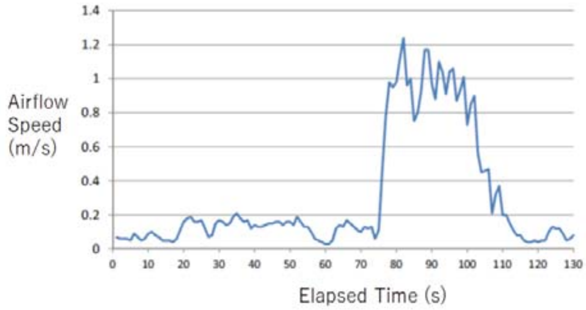

Fig. 4 Change in airflow speed in the experiment

Fig. 5 Cloths of the participants

so that the participants' Body Mass Index would be 18.5 to 25.0 so that no difference in sensitivity to the environment due to differences in body shape would occur. In order to control clothes to 1.2 clo, participants were asked to switch to T-shirt, shirt, fleece, trousers, socks and slippers shown in Fig. 5. They were provided an instruction to utilize a lap blanket if necessary. Here, clo is defined as the thermal insulation performance of clothes that human beings can maintain comfort physiologically and psychologically, For example, the combination of underwear, shirt, trousers, jacket, and socks will be 1.0 clo [16].

D. Procedure

The experimental protocol is shown in Fig. 6. The first day was taken as the practice day and it was decided to take a counterbalance of the order effect with/without airflows in the second and third days. Therefore, as one condition per day, a condition with airflows and another condition without airflow were assigned respectively. The experimental time in one day was from 9 o'clock to 17 o'clock each day. Participants received an explanation of the experiment on the first day and practiced the tasks. After that, on the 2nd and 3rd day, the receipt classification task [13] was executed and the answer time per question of the receipt classification task for 45 minutes was measured. In addition, because the task becomes monotonous only with the receipt classification task, Sudoku task was performed as a dummy task so as not to reduce the motivation.

In each SET of SET 1 to SET 3 in Fig. 6, the receipt classification task in 45 minutes, Sudoku task in 20 minutes

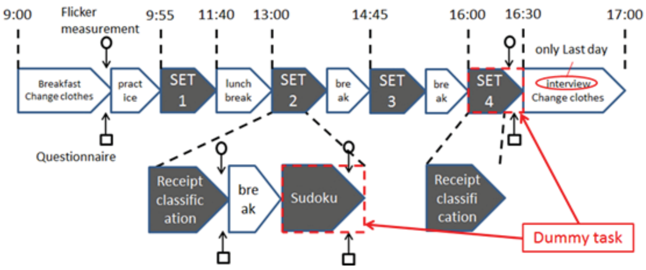

Fig. 6 Experimental protocol

and questionnaires after each task were conducted. Also, at the beginning of each task, an instruction was provided to the participants: "Please work at a pace that is not fatigued, assuming you are working from 9 o'clock to 17 o'clock." The instruction was for preventing intellectual concentration from changing due to a significant change in motivation to work. Since there is a terminal effect that improves work motivation at the end of the day, SET 4 which is the last task is 30 minutes and it is excluded from the measurement target. On the third day which is the last day, an interview was conducted on the indoor environment through 3 days and the physical conditions of participants. The participants were not told in advance to conduct the interview, however, the period of SET 4 was set as the time to perform as on the second day. The following instructions as a life control were provided so that participants' physical conditions would not change through 3 days.

- Because of distributed breakfast, lunch and drinking water,do not eat foods and drinks other than those prepared by the experimenter during the experimental period.
- Do not eat foods including caffeine during the experiment.
- Get a distributed activity meter to be worn outside the laboratory during the experiment, and have a regular life in mind.

E. Measurement items

In this experiment, in order to examine the effect on intellectual concentration due to presence/absence of airflows, (1)intellectual concentration, (2)physiological brain fatigue, (3)subjective fatigue, (4)subjective assessment of indoor environment, (5)personal characteristics were measured and (6)interviews were conducted.

(1) CTR[14] was used to measure intellectual concentration. In this experiment, the CTR at the time of the receipt classification task was calculated.

(2) To measure the physiological brain fatigue, the flicker value[17][18] was measured immediately before the start of the experiment, immediately after the termination of the receipt classification task and Sudoku task, and at the end of the lunch break. The change in the flicker value was used as an estimation of physiological brain fatigue. In this experiment, a descent method of lowering the frequency (Hz) was used. Three consecutive values were measured at a time and the median value was used .

TABLE II
RESULTS OF CTR IN THE RECEIPT CLASSIFICATION

	Condition without airflow (% points)	**Condition with airflows** (% points)
Average	65.7	66.7
SD	14.8	14.1

(3) To measure subjective fatigue, questionnaires of subjective complaints named "Jikaku-sho Shirabe"[19][20] were used. They are devised by the Working Group for Occupational Fatigue of Japan Society for Occupational Health.

(4) To measure the subjective evaluation of the indoor environment, questionnaires for environmental evaluation were conducted.

(5) To measure personal characteristics, KG's type daily life questionnaire[21], STAI (State-Trait Anxiety Inventory-JYZ)[19], Morningness-Eveningness Questionnaire[22] were conducted. The KG's type daily life questionnaire evaluates the activity of daily life and the results are classified into type A (aggression, time urgency, competitiveness, accomplishment effort, etc.) and type B (other than type A)[23]. The STAI measures and evaluates "state anxiety"(current anxiety) and "characteristic anxiety"(anxiety from usual)[19]. The results of the Morningness-Eveningness Questionnaire are classified into five types: super morning type, morning type, intermediate type, evening type, super evening type[22]. The morning type is in good condition in the morning and the evening type makes you feel better from noon.

(6) The interviews were conducted at the time corresponding to SET 4 on the third day, The questions were the awareness of the simulative airflow, the awareness of the mild airflow, the impression of the simulative airflow, the air volume, the blowing time and interval of the simulative airflow.

F. Results

A total of 12 participants was excluded from the 28 participants, because they were inadequately controlled due to poor physical condition or late arrival and/or did not work as instructed with remarkably few answers, sixteen participants were the target of analysis. The results of 16 participants are described below.

(1) Intellectual concentration

The results of the condition without airflow and with airflows are shown in Table II. The CTR of the condition with airflows was 66.7% points and the CTR of the condition without airflow was 65.7% points, however, the difference of CTR between the two conditions was not significantly shown (paired two-sided t test; $p = 0.47$).

(2) Physiological brain fatigue

In order to compare the condition with airflows and without airflow, the difference in average of flicker value was confirmed for each time period (pairwise two-sided t test). Only at the completion of Sudoku task of SET 1, there was a tendency that the condition without airflow was larger than the condition with airflows ($p < 0.05$). In other tasks, there was no significant difference of flicker values.

(3) Subjective fatigue

In the receipt classification tasks(SET 1 - SET 3), the differences between the conditions without airflow and with airflows were not significantly shown on sleepy feeling and blurred feeling on the basis of "Jikaku-sho Shirabe"(pairwise two-sided t-test; $p < 0.05$).

(4) Subjective evaluation of indoor environment

With respect to the subjective evaluation of the indoor environment, a pairwise two-sided t-test was performed for each item by comparing the conditions without airflow and with airflows. The items with a significantly higher evaluation in the condition with airflows are "feeling wind pressure" ($p < 0.001$), "the air is circulatin" ($p < 0.001$), "The air movement is comfortable ''($p < 0.01$),"the whole room is comfortable"($p < 0.05$) and "the humidity is comfortable"($p < 0.05$). The items with a significantly higher evaluation of the condition without airflow are "hot in the whole body" ($p < 0.01$), "the humidity is wet" ($p < 0.05$) ,"I like the room environment" ($p < 0.05$). In the other items, the differences were not significantly shown.

(5) Personal characteristics

As a result of type judgment using the KG daily life questionnaire, nine participants were classified as type A, and seven were classified as type B. For STAI, one participant could not be measured, and 15 people were targeted. As a result, the state anxiety was 41.6 (N = 15) and the characteristic anxiety was 50.4 (N = 15). As a result of the Morningness-Eveningness Questionnaire, three were night type, one was morning type, and 12 were intermediate type.

(6) Interviews

The results of the interviews are shown in Table III. The number of respondents is shown in parentheses, and those without a number indicates that there is one respondent. One participant may answer more than one.

From the results of the interview, responses were obtained for the mild airflow "not noticed" (9 participants) and for the stimulative airflow "noticed" (14 participants). While the stimulative airflow was answered "waking up"(5 participants), the answers of "prevented the work" were obtained (2 participants).

(7) Summary

As a measurement result of intellectual concentration, it was 66.7% points in the condition with airflows from Table II, and the difference was not shown significantly compared with the 65.7% points of the condition without airflow (in the summer experiment it was 6.5% points improvement). With respect to physiological brain fatigue and subjective fatigue, the difference between the conditions with airflows and without airflow was not shown significantly. Subjective assessment of the indoor environment showed results showing the influence of airflows in several items related to the airflows. A specific relationship could not be found between personal characteristics and intellectual concentration. With the basis on the interview results, more than half of the participants answered that they were not noticed during the work on the mild airflow. On the other hand, about 90% of participants answered that they noticed the simulative flow.

TABLE III
RESULTS OF THE INTERVIEW

Awareness of the mild airflow
"I did not notice". (9)
"I do not remember."（3）
"I feel the wind is occasionally. Eyes were dry regardless of the wind".
"The room temperature was low and the wind was blowing."
"I sometimes felt a strong wind and thought it was cold."
"I felt the circulation of the air with a strong wind from time to time."
"I was aware, I felt like I had been out for three days."
Awareness of the stimulative airflow
"I noticed".(14）
"I felt it when I was hit directly, I did not feel anything else besides that."
"I did not feel it in particular."
Impression of the stimulative airflow
"I woke up by the wind".（5）
"It felt good".（2）
"When I was concentrated and the wind was blowing, it hampered work".（2）
"The wind was cold."（2）
"There is no effect on work."
"The concentration returns and sleepy awakens, but the impact will last only a little."
"When the wind came up, I felt comfortable. I refreshed.
"When I am not sleepy and the wind is blowing , I do not mind."
On the air volume, the blowing time, and interval of the stimulative airflow
"Strength is just right".（6）
"The wind should be stronger when I am sleepy".（3）
"When the wind is more weaker, I would be concentrated".（2）
"The interval should be more frequent".（2）
"Since the body was burning, it is good to have the wind hit."

V. CONCLUSION

In this study, in order to investigate the influence of the airflow in the winter on the intellectual concentration, the evaluation experiment was conducted. In the previous study, an effective airflow in summer was proposed and the improvement of intellectual concentration by evaluation experiment was confirmed. Therefore, an airflow profile in winter was proposed with reference to the airflow profile in summer. The airflows are a combination of a simulative airflow and mild airflow. Then a evaluation experiment was conducted in winter. As a result of comparing the effects between without airflow and the condition with airflows, the difference was not shown significantly.

Based on the results, it is a future task to ask preliminary preference in advance and to establish a mechanism that can provide controllable airflow for each individual, taking into account the preference for airflow to be different for each individual.

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