A Study on Integrated Thermal Control to Improve Intellectual Work Performance

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Abstract

In a developed information society such as ours, intellectual work such as office work has been increasing as a share of the total work of human beings. The performance of office work is linked directly to company profits. Work performance improvement can also engender work time reduction, which can improve workers' health and well-being. It can also be expected to reduce energy consumption because of shortened working time spent using computer equipment and air conditioning. Given that background, efforts to improve intellectual work performance have been actively undertaken.

Traditionally, office work has been done in office buildings. However, the recent COVID-19 epidemic has led many companies to introduce remote work as a measure to prevent infection. Even before the 20th century, the benefits and shortcomings of remote working were discussed. Some successful cases have been reported. However, in some cases, work performance was decreased because of the lack of preparation and increased mental strain under remote work situations. A sudden shift to remote work from conventional work styles because of the crisis situation, but without sufficient preparation of some equipment or worker skills is a concern underlying work performance reduction. It is probably meaningful to investigate means of improving work performance not only of conventional office working styles but of remote work in households.

Thermal control methods used for this study have emphasized improvement of work performance. Devising a thermal environment can be implemented in a workplace, irrespective of the working contents, so that one can find high potential for installation into various workplaces. Targeting many workers in various workplaces including office buildings and households is also expected to be possible. Especially among environmental factors, thermal factors have been explored frequently. Their effects on work performance, as shown from many conventional studies, are thought to be considerable. In addition, in Japan, air conditioning equipment is widely distributed both among office buildings and households. Therefore, installing thermal controls in a workplace is thought to present less difficulty. Designing a thermal controlling method for a workplace demands consideration of energy consumption while improving work performance because about 30% of energy consumption, both of households and businesses, is attributable to cooling and heating.

For this study, the integrated thermal control (ITC) method was proposed as a thermal control method to improve work performance. It was designed to be implementable both

in office working situations and household remote working situations. The ITC method comprises three thermal controls: – making thermal sensations cooler to improve work performance during work hours – making thermal sensations warmer to improve relaxation and fatigue recovery during break times – thermal sensation differences between situations of working and taking breaks to change workers' mood smoothly when starting to take a break or restart working. Many reports have discussed effects of thermal environments during working on work performance. Many studies have indicated improved work performance by devising thermal environments in work situations. However, fewer studies have examined how thermal environments during break times affect work performance. A novel trial is designing thermal environment changes depending on worker work hours and break situations to improve work performance throughout a day.

To produce thermal sensation changes based on the ITC method concept, two thermal factors were specifically examined for temperature and airflow. Temperature is controlled by air conditioners, which are popular thermal control devices that are used in business and household sectors. Moreover, much knowledge exists in conventional studies that have elucidated effects of temperature variation on work performance, which can be referred when implementing ITC. For this study, ITC implemented by temperature control is called temperature-based integrated thermal control (ITC-T). Airflow is controlled by fans, which are inexpensive and which are also spread widely, so that it is easy to install them both in business and household sectors. Moreover, controlling airflow is expected to require less energy consumption than temperature control. For this study, ITC implemented by temperature control is designated as airflow-based integrated thermal control (ITC-A).

To evaluate ITC effects on work performance, the concentration time ratio (CTR) was applied. It can evaluate the ratio of time, showing how long workers concentrate on their work during working times. An important advantage is that CTR can evaluate work performance quantitatively and objectively. Its results are not influenced by learning effects.

As a first trial, the ITC-T was evaluated by an experiment conducted in summer. In light of the increasing trend of energy consumption for cooling because of global warming and because the comfort range of thermal sensation is more fit to the ITC in summer than in winter, the experiment was scheduled to be conducted in summer. Two experiment rooms were prepared as a room for working and for breaks because the room temperature was difficult to control and change in a short time in one space depending on the workers' work or break situation. The temperature was controlled in two rooms to make participants' thermal sensation slightly cool during work and warm or neutral during breaks. Furthermore, the thermal sensation difference was emphasized by making the temperature of the room for work cooler about 10 min after restarting work. In the experiment, the ITC was evaluated by comparison with the control condition, which was designed to be a unified thermal sensation both under work and break situations as a typical office. In the experiment, 38 men participated; 22 participants'

data were validated. The average CTR of the ITC condition was significantly higher for 3.2% than in the control condition. Higher CTR represents a longer concentration time, so that the CTR results suggest that the ITC-T can improve work performance throughout the day during summer. However, results of the subjective questionnaire suggest some negative effect of the ITC-T: subjective sleepiness was found to be significantly higher; subjective lassitude and lethargy tended to be higher under the ITC-T condition.

Results obtained from the ITC-T evaluation experiment in summer suggest that the ITC-T had an improvement effect on work performance. Nevertheless, the mechanisms of work performance improvement under ITC-T remain unclear. Moreover, following the ITC-T evaluation experiment in summer, an experiment was conducted in winter. Results of the winter experiment showed no difference between CTR of the ITC-T and the control conditions, which suggest a different tendency from that shown by the summer results, as described above. Differences of the results between summer and winter can not be discussed based on these results. Therefore, to clarify how ITC-T affected work performance in summer and winter experiments, an analysis of mechanisms was conducted.

Results of the mechanism analysis suggest that ITC-T affected work performance through environmental perception, subjective impressions of workplace environments or mood. It also affected subjective fatigue both in summer and winter. However, it is difficult to identify similarities from results of this analysis. Similarities must be determined carefully based on further data. Based on the mechanisms model obtained using the analysis, weak relations between ITC-T implementation and environmental perception, and between subjective fatigue and work performance are reasons why work performance was not affected significantly by the ITC-T condition in winter evaluation experiment. Presumably, the mechanism model can help meliorate the temperature settings of ITC-T to make ITC-T more effective for work performance improvement and to reduce its negative effects on fatigue.

The next experiment was conducted to evaluate ITC-A effects on work performance in summer. Compared to ITC-T, which requires control of the temperatures of at least two rooms, ITC-A can be implemented in one place without any relocation because the airflow can be controlled to change thermal sensations individually merely by changing the airflow velocity exposure. It was also expected to limit energy consumption more than ITC-T implementation was able to. The ITC-A program was implemented using three airflow control methods: Steady airflow was provided to cool thermal sensations during work to improve work performance; slight and fluctuating airflow was provided to make the thermal sensation warmer to improve relaxation and fatigue recovery; and strong airflow was provided for just 2 min after restarting work to make the thermal sensation cooler and thereby change the mood smoothly. Through the experiment, ITC-A was evaluated by comparison with the control condition without any airflow exposure.

In the experiment, 48 men participated; 38 participants' data were validated. Results of

CTR under ITC-A were significantly higher for 2.8% than under the control condition. These results suggest that ITC-A can improve work performance. Subjective evaluation results also showed a tendency of lassitude reduction under the ITC-A condition, which also implies positive effects of ITC-A. The electrical consumption of ITC-T and ITC-A were also simulated and compared. Two situations were assumed when calculating the simulated electricity consumption: an unified working time situation and a unified amount of work situation. In overviews of each assumed situation, results showed that the ITC-T required more than 20% higher electrical consumption than the control condition. However, the increment of the electrical consumption in the ITC-A from the control was less than 10%. Put succinctly, results suggests that ITC-A can improve work performance, with the salient implication that ITC-A can decrease subjective fatigue and in addition, with decreased electricity necessary for implementation.

For this study, the ITC method for improving work performance was proposed and evaluated for this study. Results of the evaluation experiment conducted by particularly addressing two thermal factors implied that ITC has improvement effects on work performance throughout each working day. An analysis of mechanisms was also conducted. The results suggest that a similar structure of change mechanisms of work performance by ITC-T, irrespective of seasons. Actually, ITC was designed for implementation both in office buildings and households for remote working. Therefore, the findings are expected to be useful both for conventional working styles and for remote working situations, which are becoming popular in such a crisis situation of COVID-19. The findings of this study suggest a new aspect of workplace environment design, to change environmental control depending on workers' work and break situations. Results also implied the possibility of coexistence of improved work performance and energy conservation. More evaluation under various situations is expected to be necessary to supervise the installation of ITC methods in an actual workplace environment.