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An Analysis of the Effect of Integrated Thermal Control on Cognitive Task Performance Using Time-Series Changes in Intellectual Concentration

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ABSTRACT

In order to improve the performance of knowledge and intellectual work, which has become more important in the advanced information society, the authors have proposed integrated thermal control, which combines controlling the environment during work and rest. Our previous studies have suggested that integrated thermal control has some potential to improve workers' intellectual concentration on work, which is thought to be correlated with workers' performance. In this study, a clustering analysis of time-series change of workers' intellectual concentration was conducted to examine in more detail the effects of integrated thermal control using airflow (ITC-A). The results showed that the ITC-A condition might not improve concentration in cases when one's concentration showed a continuous downward trend in the Control condition.

Keywords: Workplace environment, Cognitive task performance, Airflow, Answering time analysis

INTRODUCTION

In today's developed information society, improving the performance of knowledge work and intellectual work is considered important not only for increasing corporate profits but also for improving occupational health, including improving work-life balance. Since the workplace environment is known to affect work performance (Al Horr et al. 2016), many researches evaluate the effect of various environmental factors during work especially about thermal factors (Oseland 1999, Wargocki et al. 2000), or break (Amano et al. 2012). Based on the knowledge from those studies, the authors have proposed "integrated thermal control", which combines and controls both the environments during work and break. Authors have been examining the effect of the proposed control on work performance.

In our previous studies (Ueda et al. 2018, Kawamoto et al. 2018, Ueda et al. 2017), it was shown that the performance-enhancing effect of integrated thermal control using airflow (ITC-A) throughout the day based on the

evaluation using the concentration time ratio (CTR), which is a performance evaluation index of the ratio of time when workers concentrated on their work during their working time. However, although performance during work changes moment by moment due to accumulation of fatigue and other factors, time-series changes in intellectual concentration during work was not examined, and the details of the effects of integrated thermal control on performance remain unclear.

Therefore, the objective of this study was to analyze and evaluate the effects of integrated thermal control on work performance in more detail by focusing on the time-series changes in concentration on cognitive task performance. Clustering analysis of time-series data is generally applied to find major patterns in large amount of data and to forecast combining other time-series analysis method (Saeed et al. 2015). By conducting clustering analysis of time-series data on the degree of concentration on intellectual tasks, the effects of integrated thermal control can be estimated on each pattern of change in concentration. It was also expected to obtain knowledge for individual adaptive control of integrated thermal control.

METHODS

For the analysis, we used the response time data of a cognitive task for intellectual concentration assessment (Ueda et al. 2016), which was designed to require cognitive activities of numerical and verbal semantic comprehension, comparative judgment, and information integration. These data were obtained from 44 participants performing 4 sets of 30 minutes each in the integrated thermal control and control conditions. Participants were all male university students with the age of 21.0 years (SD = 2.0).

Calculation of Concentration Rate

Based on the three-state model during performing cognitive task proposed by Uchiyama et al. (Uchiyama et al. 2013), the answering time data of a cognitive task to evaluate intellectual concentration forms a lognormal distribution when answered with concentration, when the task consists of multiple questions of constant difficulty. Based on this, the expected answering time E for one question when answering with concentration was calculated by fitting analysis of all sets of answering time data in each participant. Concentration and non-concentration were assigned to each time point in each set as shown in Figure 1 using each participant's expected answering time E. Answers with an answer time of E or less were assumed to have been answered by continuing to work with concentration, while answers with an answer time longer than E were assumed to have been answered after interrupting work for a while and then concentrating for E. Then, the percentage of time spent concentrating in the last 500 seconds at each time point was used as the concentration rate at that time. In this study, the time window was set to 500 seconds, which is relatively long, to find a rough pattern of change in concentration by clustering based on the long-term trend within each set.

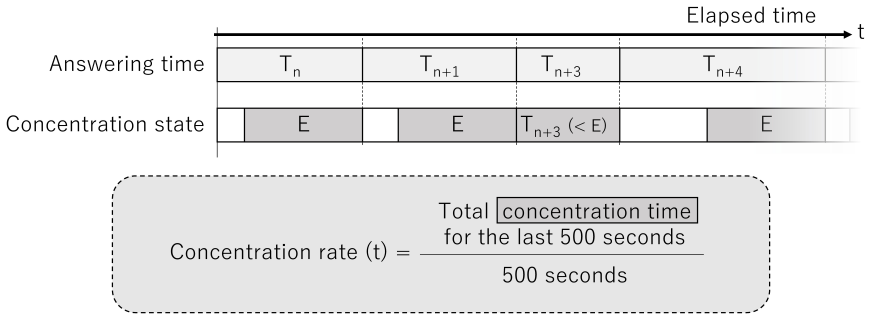


Figure 1: Allocation of concentration time and calculation of concentration rate.

Clustering Method

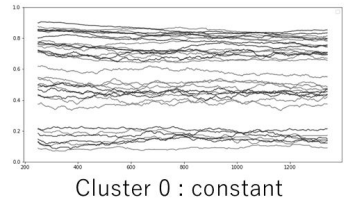
In this analysis, correlation value was used as a distance function for clustering to find the pattern of time-series change of concentration. The Ward method, which is a hierarchical clustering method that allows us to examine the number of clusters based on the dendrogram was applied.

However, when correlations are used as the distance function, it is difficult to successfully discriminate patterns whose concentration rate is of a constant as the same cluster. Therefore, we set a threshold value for the variation of the degree of concentration based on the pre-clustering and separated the data of constant type in advance. In pre-clustering, clustering analysis was conducted with using the all participants data with 8 dummy data representing the major change pattern of concentration rate we found out from our previous data, such as down-constant trend which shows downward trend in the first half and constant trend in the latter half. The threshold value for the variation degree of concentration rate was set based on the variation of the corresponding part of the data classified into the same cluster as the dummy data containing the part of constant trend.

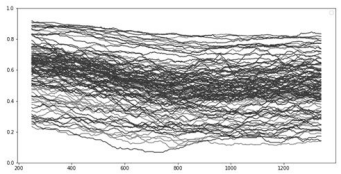
After omitting the data that were defined as constant from the overall data, clustering was applied again to the remaining data. Based on the dendrobium, the number of clusters was set to four in this analysis. Including the constant type that was separated beforehand, the time-series changes in concentration in each task set were classified into a total of five clusters.

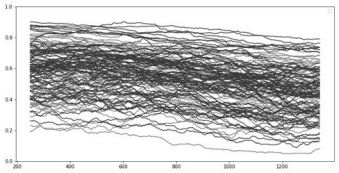
RESULTS AND DISCUSSIONS

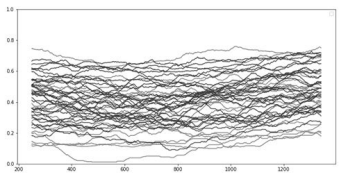
The results of the clustering are shown in Figure 2. Cluster 0 was a constant type which was separated beforehand, Cluster 1 had a downward trend in the first half and a constant trend in the second half, Cluster 2 had a downward trend throughout the set, Cluster 3 had a constant trend in the first half and an upward trend in the second half, and Cluster 4 had a constant upward trend. In contrast to cluster 3 and 4, which contain patterns of increasing trend of concentration ratio, the numbers of cluster 1 and 2 was larger. Since cluster 1 and 2 contain decreasing trend of concentration rate, this suggests that it would be difficult to maintain a certain level of concentration when working continuously due to fatigue accumulation.



	ITC-A	Control
Cluster 0	14	20
Cluster 1	56	55
Cluster 2	59	65
Cluster 3	27	21
Cluster 4	20	15







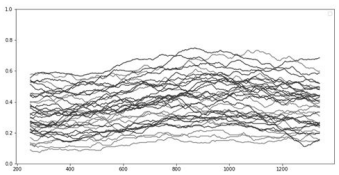


Figure 2: Separated data of each clusters and the list of separated numbers of sets in each cluster.

Table 1 shows a summary of which clusters the same set was classified into in the Control and ITC-A conditions. The same set means the set of cognitive tasks performed by each participant during the same time period. While many sets belonged to the same cluster, there was a distinctive difference in the number of sets classified as Cluster2 in the Control condition and Cluster1 in the ITC-A condition, and vice versa. Cluster 1 was the pattern with a down-constant trend, while Cluster 2 is with a continuous downward trend. It was suggested that ITC-A might suppress the decline of concentration rate after the middle part of the set for those whose concentration rate had continuous downward trend.

To examine the difference in the effect of ITC-A for each pattern of change in concentration rate, the average values of concentration rate in the Control and ITC-A conditions for the data classified into each cluster in the Control condition. Table 2 shows the results. The data belonging to most clusters have a higher average of the concentration rate in ITC-A, while only cluster 2 has almost same average values both in ITC-A and Control conditions. Cluster 2 was a group of data that has a continuous downward trend during the 30 minutes task set. The results in Table 1 indicate that the downward trend may have been suppressed, but it may not have led to an improvement in the overall concentration rate of the set based on Table 2. It suggests that for those whose concentration tended to go downward during the task set, it may have suppressed the downward trend but did not lead to an improvement in concentration for the entire set.

Table 1. Clustering results of the same set for each condition.

Control \ ITC-A	Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Cluster 0	4	3	8	4	1
Cluster 1	7	18	17	10	3
Cluster 2	1	**26**	25	4	9
Cluster 3	1	7	5	5	3
Cluster 4	1	2	4	4	4

Table 2. Average concentration per condition. for data classified into each cluster by Control condition.

Control set	Average Concentration rate under Control	Average Concentration rate under ITC-A
Cluster 0	0.56±0.23	0.62±0.21
Cluster 1	0.48±0.15	0.51±0.16
Cluster 2	**0.53±0.14**	**0.53±0.14**
Cluster 3	0.37±0.16	0.41±0.16
Cluster 4	0.34±0.14	0.39±0.15

CONCLUSION

As a result of calculating the time-series change data of intellectual concentration from the answering time data and conducting clustering, it was suggested that for the group whose concentration tended to decrease during the 30-minute work period, the ITC-A might suppress the decrease in concentration, but it did not lead to an improvement in the average of the overall concentration. In the future, we would like to conduct further studies by combining the results with subjective evaluations and by comparing the results with those obtained when the time window for calculating the degree of concentration was changed.

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