Effects of Color and Size in Generating Intellectual Activity in Booth Spaces

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Abstract
This paper aims to clarify what kinds of design elements in environments stimulate mental activity. The study examined the effects on brain activity when wearable optical topography was worn in different booths having different sizes and color environments. The subjects' mental activity in the prefrontal cortex was measured during working memory tasks conducted in four kinds of different booth: a small white booth, large white booth, small yellow booth, and large yellow booth. Physiological and psychological analyses revealed the following results. 1) The large yellow booth activated mental activity the most. 2) The booth size and color of the booth have an effect on the information processing activity of information processing. 3) The size of the booth has an influence on the physiological state. 4) Activation of brain activity has an effect on the affected reaction rate and percentage of correct answers.

Keywords: brain science; cerebral blood flow; intellectual activity; color; booth size

1. Introduction
How can an environment stimulate the mental activities of human beings? This question is relevant to research in the behavioral sciences aimed at finding ways to increase the efficiency of "workers" in various environments. Studies on this topic have mostly been concerned with improving the work environment and have been conducted primarily in the field of "human engineering." In particular, they have examined the effects of the work environment on physical human behavior.

In his book, Post-Capitalist Society\(^3\), the economist P. F. Drucker describes how the productivity of industrial workers was dramatically improved by Frederick Winslow Taylor's scientific management. However, he also states that the challenge from here on is improving the productivity of knowledge workers. Applying knowledge to knowledge will be essential to achieving this goal.

Therefore, what is needed today is to improve mental activity-related work efficiency. What is sought is not just improving the productivity of human beings' physical labor, but also the productivity of their mental activities. If the physical environment can support workers' ability to perform mental activities, then how should the physical environment be designed? Much research on human beings' mental activities in physical environments belongs to the field of environmental engineering, wherein there have been studies on the effects of sound, lighting, temperature, etc. One of these studies\(^4\), has shown that color is an element of environmental design that supports individuals' mental activities.

In this study, we focus on color and size as elements that make up a space and use a method of measuring brain activity to elucidate how different environments stimulate subjects' mental activities.

2. Research Background
In Japan today, the decline in the birth rate and the aging of its society are accelerating due to the effects of the recession. The working age population has been decreasing, and the production capacity of Japan is expected to fall greatly in the future. To prevent such a reduction in production capacity, measures should be taken to increase the production capacity of individual workers.

Regarding such measures, the idea of creating an optimal architectural space to improve production capacity in a knowledge-based society is a new topic in the field of architecture. It is, however, an aspect of what architects have long sought to do in one manner or other, i.e., improve the physical environment that surrounds human beings. At the same time, active research is required.
This necessity is especially noticeable when it comes to office environments. Seeking to establish guidelines for the design of offices that promote intellectual productivity, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) established the Intellectual Productivity Commission in 2007. The Commission recognizes that improving intellectual productivity is required to realize sustainable economic development despite the decline in the Japanese population.

3. Purpose of this Research
The purpose of this research is to study color and space (its size) as environmental elements that make up a space to determine desirable environmental designs that support an individual's mental activity.

To obtain detailed results from the evaluation of subjective impressions, this study used the "kansei" (emotional sensitivity) semantic differential of direct feelings. In addition, it used near-infrared spectroscopy to investigate the effects of different combinations of color and size of a space on brain activity. It clarified the physical environmental design that promotes mental activity. It also clarified what colors and space sizes stimulate individuals' mental activities the most.

4. Mental Activities in this Experiment
The Intellectual Productivity Commission established by MLIT defines architectural space and a hierarchical model of mental activities as indicators of mental activity.

In this experiment, we focused on the first level of the model, "mental activities related to information processing." This level, is the most basic domain of mental activities and is the foundation for a variety of mental activities.

The experiment used calculation problems as the mental task. The problems involved regular processing of knowledge-related information and were suitable as information processing work.

The brain activity associated with the calculation problems representing mental activity of information processing is related to the function called working memory. This activity has been reported to be involved with the prefrontal cortex.

Therefore, it can be considered that the calculation problems used in this study increase prefrontal cortex activity.

5. Purpose of the Experiment
The purpose of this experiment was to clarify the combinations of color and size of a space that stimulate individuals' mental activity by conducting an analysis that combines subjective evaluations and measurements of information processing within the brain. A cerebral blood flow measurement device was used to measure cerebral blood flow during mental activities, a method of measuring brain activity. An impression evaluation survey was also conducted using the kansei semantic differential, as was a survey of subjects' fatigue level and mood before and after the experiment.

6. Description of Tests
The first test measured cerebral blood flow during mental activities by using near-infrared spectroscopy. For the test, four booths were prepared. The booths were of different combinations of color (yellow and white) and size (large and small). We know from previous research that yellow is conducive to the mental activity involved in information processing, while white serves as a reference color.

Subjects entered the booths and carried out mental tasks in them.

The second test consisted of surveys of the subjects. Cerebral blood flow measurements were also conducted on them during these surveys.

The surveys were in two types. The first was an impression evaluation survey using the kansei semantic differential. The second survey examined subjects' fatigue level and mood before and after the experiment.

6.1 Experimental Space
There has been a growing trend in office layouts for workers to freely choose their desk placements in the hope of facilitating better communication. On the other hand, there is also a need for space in which individuals can concentrate on their work without distraction.

Thus, for the experimental space, we focused on booths as places in which individuals perform mental tasks. The four booth spaces used in the experiment are shown in Fig.1. The experiment took place in a lecture room at a university. The booths were placed...
in the center of the classroom. The experiments took into account the effects of the surroundings, so measurements were conducted in one booth, at a time. The light source within the room was automatically maintained at a constant level. The room's temperature was set at 28°C. Also, blinds were pulled over the windows so that there were no effects due to sunlight.

The floor plan of the lecture room in which the experiment was conducted is shown in Fig.2.

6.2 Experimental Summary
A summary of the impression surveys and the cerebral blood flow measurement is presented below:
Location of experiment: lecture room in a university
Dates of the experiment: June 8 – August 31, 2015 (total of 42 days)
Subjects: 50 students (25 men, 25 women)
Equipment used: stimulus presentation system, monitor, cerebral blood flow measurement device and controller
Measurement positions: 16 areas on forehead
Impression evaluation survey: survey using kansei semantic differential
Experimental space: The experiment was carried out in four booths made of wood. The booths were painted white or yellow. The booths were of two sizes, large and small. The four booths covered the different combinations of color and size.

In the same manner as the experiment titled "Research on the effects on information processing activity of different color environments," we constructed small booths measuring 1,000 mm wide x 1,200 mm deep x 1,800 mm high, which we know from our previous study is sufficient space for subjects to perform mental tasks. We also built large booths that were double the width of the small booths. In other words, the large booths measured 2,000 mm wide x 1,200 mm deep x 1,800 mm high. The objective was to investigate the impact of the different booth colors and different booth sizes on the mental activity of the subjects.

Work desks (700 mm (H)) and chairs (400 – 450 mm (H)) were installed in the booths. Their dimensions were the same as typical office furnishings. A monitor and controller for the subjects to carry out the mental activity tasks were set up on each desk.

6.3 Experimental Tools
The tools of the study were as follows. Cerebral blood flow measurement device: This device (Fig.3.) uses near-infrared spectroscopy to detect hemoglobin and thereby measure the flow of blood. The blood flow is an indicator of the amount of prefrontal activity in the brain. The experiment used, a device from Hitachi, Ltd. that measures 16 prefrontal locations.

Impression evaluation surveys: Fig.4. illustrates the survey using the kansei semantic differential (Fig.4.). In the semantic differential method, subjects use a slope-shaped analog evaluation scale to record their direct feelings. The scores are statistically tabulated. Note that the conventional semantic differential presents subjects with five to seven pairs of opposing adjectives. Subjects circle the adjectives that correspond to their feelings. During this process of circling, the subjects must convert their emotions (limbic system information) into logical information processed by the cerebral cortex. As a result, subjects may become confused when converting (mapping) their feelings (kansei) into logical thoughts, and hence, it is believed that "many things and aspects are lost during a kansei evaluation." Thus, our survey used an analog evaluation scale and more opposing adjective pairs to obtain more detailed impressions.

6.4 Experimental Method
First, the subjects filled out a survey that assessed their level of fatigue and mood on that day. Next, each subject sat at a fixed position (at a viewing distance of 75 cm from the monitor screen) in an arbitrarily chosen booth (Figs.5. and 6.). The cerebral blood flow measurement device (Fig.3.) was then fitted on the forehead of the subject.
After the connection with the equipment was confirmed, instructions were given to the subject so he or she could quickly answer the (four-operation) calculation problems by using the controller. After the experiment began, the subjects answered the calculation problems for 15 minutes. The cerebral blood flow measurement device was removed after the subject finished the task. The subject was then given a survey on his or her fatigue level and mood and a survey on his or her subjective impressions of the booth space. The experiment was thus concluded (Fig.7.).

The subjects were 50 currently enrolled university students. We considered that they had general competence in the calculations of the task which combined four types of arithmetic operations on four single-digit numbers. Moreover, the authors, who belong to the same age group as the students, performed the calculation problems beforehand and set the level of difficulty such that "the problems could be solved if one concentrates" (Fig.8.).

The sequence of the four-operation calculation problems was as follows: A white "+" mark was shown in the center of the black monitor screen for 20 seconds. This was used as a rest screen to calm the brain activity. Then, the calculation problem slide was displayed for three seconds, and the answer selection slide was shown after that for three seconds. This rest – problem – answer selection sequence was repeated for 15 minutes (34 times), during which changes in cerebral blood flow were measured (Fig.9.).

7. Results
7.1 Accuracy Rate
The rate of correct answers to the calculation problems for each type of booth is shown in Fig.10. The average rates of correct answers were as follows: small white booth (87.7%), large white booth (89.5%), small yellow booth (90.3%), and large yellow booth (92.8%). Of the four booths, the small white one had the lowest rate and the large yellow one had the highest rate.

The rate of correct answers by gender is shown in Fig.11. While the average correct response rates differed between men and women, the ranking of the booths did not differ between genders. Thus, for both genders, the lowest correct answer rate was for the small white booth and the highest correct answer rate was for the large yellow booth.

7.2 Impression Questionnaire Survey
The impression evaluation survey was conducted after the mental task. It employed the kansei semantic differential method using 15 adjectives. The survey asked each subject to respond to each adjective on a
scale of 0 to 100 points. The results of the subjects' evaluation of their impressions for each booth are shown in Fig.12. In this way, adjectives common among the booths and adjectives specific to each booth were clarified.

Four adjectives ("Calm," "Unstimulating," "Closed," and "Intense") gave strong impressions (value exceeding ±20 of the reference value of 50) for each booth. The large white booth gave strong impressions of "Unstimulating" and "Bright." The small yellow booth gave the following five impressions: "Stimulating," "Closed," "Narrow," "Bright," and "Bold." The large yellow booth gave strong impressions of "Stimulating," "Bright," and "Bold."

Summarizing the results, we can see that common adjectives with strong impressions are as follows: For the white booths, the common adjective was "Unstimulating." For the yellow booths, the common adjectives were "Stimulating," "Bright," and "Bold." For the small booths, the common adjective was "Closed." For the large booths, the common adjective was "Bright."

These results indicate that special characteristics associated with yellow and special characteristics associated with size could be discerned.

Next, a principal component factor analysis was conducted. Varimax rotation was used to extract the factors.

The extracted factors for each adjective are summarized in Table 1.
Factor analysis was applied to the 15 adjectives used in the impression evaluation survey. The four extracted factors were given the names "Livability," "Spaciousness," "Ability to form mental images," and "Situational."

For the factor "Livability," comfort in the booth space could be perceived. For "Spaciousness," different responses to the elements of the physical environment could be seen. For "Ability to form mental images," different responses to images depending on color could be observed. For "Situational," different reactions based on the situation could be discerned.

The results of the factor analysis indicate that the white booths were affected primarily by the "Livability" factor, and the yellow booths were primarily affected by the "Ability to form mental images" factor. Moreover, the small booths were primarily affected by the "Spaciousness" factor, and the large booths were greatly influenced by the "Ability to form mental images" factor.

7.3 Fatigue and Mood Questionnaire Survey

The survey on subjects' fatigue level and mood before and after carrying out the mental tasks used five-item scales. For the evaluation of the fatigue level, the five-item scale consisted of "Very energetic," "Energetic," "Normal," "Tired," and "Very tired." The evaluation of subjects' mood used the five-item scale of "Very good," "Good," "Normal," "Bad," and "Very bad."

The average values of the 50 subjects are shown in Table 2., and the changes in fatigue and mood before and after the task are shown in Figs.13. and 14. for each booth pattern. The results reveal that color and size affected the subjects' fatigue level and mood. The changes in subjects' fatigue before and after the experiment were as follows: small white booth (-0.26), large white booth (-0.44), small yellow booth (-0.54), large yellow booth (-0.22). These results show that compared with other types of booths, the small yellow booth easily worsened subjects' fatigue when they performed the information-processing task. The changes in subjects' mood before and after the experiment were as follows: small white booth (-0.06), large white booth (-0.18), small yellow booth (-0.42), and large yellow booths (-0.10). These results show that the small and large white booths and the large yellow booth had almost no changes in subjects' mood due to the performance of the information-processing task. In contrast, the subjects' mood changed significantly in the small yellow booth.

7.4 Cerebral Blood Flow Measurement

We focused on the prefrontal area (16 points on the forehead), which is associated with working memory, because cognitive activity is produced by performing information processing tasks.

Fig.15. shows brain activity maps of the average values of all 50 subjects and time-series waveforms five seconds before presentation of the problems and 15 seconds after selection of the answers.
Brain activity began to settle down a few seconds after presentation of the answer choice slide, and gradually fell to normal values afterwards. The timing of the changes differed for each type of booth, and there were also areas where local stimulation of brain activity could be seen.

The brain activity of the subjects in the yellow booths began to settle down immediately after the subjects answered the problem. In contrast, the brain activity of the subjects in the white booths tended to rise for a while after the subjects had answered the problem.

The average response times for each type of booth were as follows: large yellow booth (1273.13 msec), small yellow booth (1274.51 msec), large white booth (1375.64 msec), and small white booth (1479.19 msec). These results show that regardless of the booth’s size, the response times in the yellow booths were shorter than in the white booths.

8. Discussion

The rates of correct answers to the calculation problems showed that in terms of color, yellow showed better results regardless of the size of the booth. We thus believe that yellow is an environmental color for supporting information processing mental activities.

Focusing on booth size, because large booths had better results regardless of color, we can conclude that the large size is better than the small size in this case. These results suggest that color and size affect mental activities. Accordingly, we next focused on combinations of color and space size. Large yellow booths had the highest correct answer rate, suggesting that the combination of color and size has an effect on information processing in the brain.

The results of the impression evaluation survey revealed that the common adjectives of yellow booths were "Unpleasant," "Uneasy," "Excited," "Stimulating," "Bold," and "Anti-intellectual." The common adjectives of large booths were "Liberating," "Spacious," and "Bright." Thus, these adjectives may affect mental activities.

The results of the survey on subjects’ fatigue and mood showed that their level of fatigue and mood changed significantly when they were in the small, yellow booth. In particular, the small yellow booth seemed to worsen their physiological conditions. On the other hand, the change in physiological conditions was not as large for the large yellow booth. Thus, the size of the space can be considered to be a factor that affects physiological conditions and a larger space may lessen the physiological burden.

The results of the cerebral blood flow measurements showed that, when the brain is stimulated, there is a trend in the improvement of the correct answer rate. Thus, it can be considered that brain activity has an effect on the correct answer rate. Moreover, comparing the average response times, the time required to reach answers was short for both large and small yellow booths. On the other hand, the time it took to reach answers in the small white booth was the longest. It can thus be considered that in yellow booths, the time for the brain activity to return to normal levels is shortened.

9. Conclusions

In this study, cerebral blood flow in the prefrontal area of the brain was measured in 50 subjects (university students) performing information processing-related mental tasks while sitting in booths distinguished by their color and size. An impression evaluation survey was also carried out using the kansei semantic differential after the task had been completed. Moreover, surveys on subjects’ level of fatigue and mood were carried out before and after the tasks. The following results were obtained by analyzing the data on information processing in the brain and the surveys.

(1) Regardless of color, changing the size of the booth space changed the correct answer rate of the calculation problems. In particular, of the two sizes of booth—large and small—used in the experiment, the larger size tended to improve the correct answer rate.
The correct answer rate varied with each type of booth. Thus, it is possible that the combination of color and space affects information processing mental activities in the brain. In particular, the large yellow booth activated mental activity the most.

The results of the physiological condition survey showed that regardless of color, changing the size of the space changed both fatigue and mood. Thus, it is possible that the size of the space affects physiological conditions before and after information processing mental activities.

The results of the impression evaluation survey showed that the positive adjectives of "Stimulating," "Bright," and "Bold"—adjectives common to yellow booths and large booths, which were associated with cerebral blood flow measurement results and higher correct answer rates to the problems—may improve information processing mental activities.

The cerebral blood flow measurement results and correct answer rates to the calculation problems showed that it is possible that stimulation of brain activity has an effect on the correct answer rate and reaction speed.

10. Future Prospects

This research study was conducted for the purpose of improving individuals' mental activities.

Going forward, there is a need to research not only the mental activities of individuals, but also those of people in group settings.

Furthermore, while this study examined first-level information processing activities, which make up the foundation of the hierarchical model of mental activities, there remains a need to focus on higher levels in the model, including the second-level knowledge processing activities and third-level knowledge creation activities.

In addition, this study examined two color patterns—white and yellow—and two sizes of space—large and small—for a total of four patterns.

Going forward, we believe it is necessary to increase the number of patterns for both color and size of space to elucidate the environmental elements that most improve information processing mental activities, as well as consider the shape of spaces.

The calculation problems that subjects attempted to solve were information processing mental activities carried out in a short 15-minute period. There is the need to study mental activities while increasing the time for tackling the calculation problems and to study what kinds of environment most improve information processing mental activities for each work period.

We plan to elucidate these issues in the future.

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References

1) P.F. Drucker "Post-Capitalist Society," Diamond. Inc, 1993.
2) Isshi, T., Watanabe, A., Obata, A., and Usui, S. "Research on the effects on information processing activity of different color environments- -A study on physical environmental design for supporting individual mental activity 1-," J. Archit. Plann., AIJ, Vol. 81, No. 720, pp.293-301, Feb. 2016.
3) "Intellectual creation and the workplace," Ed. Institute for Building Environment and Energy Conservation, Cooperation: Intellectual productivity Research Consortium: Intellectual productivity committee, pp.9-11, 2010.
4) D'Esposito, M., et al., "The neural basis of the central executive system of working memory," Nature, (6554), 279-261, (1995).
5) Ash E., et al., "Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography," Psychol. Sci. 7(1), pp.25-31, (1996).
6) Gotou, Y., Watanabe, A., Iizuka, S., and Ogawa, K. "A proposal to design partitions of workplace entering information with reassurance," (Transactions of AIJ), Vol. 71, No. 605, pp.79-84, 2006.7.
7) Hisao, S. "A consideration of qualitative research in evaluations of kansei- How should loss in quantitative kansei evaluations be compensated? Japan Society of Kansei Engineering, Vol. 10, No. 4, pp.210-218, 2011.10.
8) Ichimura, H., Ishimura, M., Kohno, H., Kawamura, T. L. A., Marques Kameda, T., Katsumata, Y., and Yoshino, J. "A proposal of questionnaire method for kansei oriented evaluation based on SD method using ICT," Bulletin of Hosen College of Childhood Education, Vol. 3, Mar. 2012.