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ORIGINAL ARTICLE

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Physiological effects in humans induced by the visual stimulation of room interiors with different wood quantities

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Abstract To clarify the visual effects of room interior with wooden materials on humans, pulse rate, blood pressure, and brain activity were measured while the subjects were exposed to visual stimuli using actual-size model rooms. The wood ratios (the ratio of the area covered with wooden material to the whole area of the ceiling, walls, and floor) of the rooms were 0%, 45%, and 90%. Subjective evaluation was also conducted. In the 0% room, diastolic blood pressure decreased significantly, but the observed change in the autonomic nervous activity was relatively small. In the 45% room, a significant decrease in the diastolic blood pressure and a significant increase in pulse rate were observed. This room tended to have the highest scores in subjective "comfortable" feeling. The 90% room caused significant and large decreases in systolic blood pressure and diastolic blood pressure at the beginning of the test, but the large coverage of wood appeared to cause a rapid decrease in brain activity and an increase in pulse rate. The present study demonstrated that a difference in wood ratio in the interior caused different physiological responses, especially in the autonomic nervous activity, by using actual-size rooms for the first time.

Key words Physiological response · Wooden interior · Visual stimulation · NIRS

Introduction

The livability of wooden houses has been studied from the aspect of the physical properties of houses or the wooden members that construct them. As summarized in several review articles,[1–3] there have been many studies on the thermal and sound insulation efficiency and humidity control properties of wooden houses.

In investigations of the influence of wood used in dwelling environments on people, the subjective feelings of participants were mainly investigated, and attempts were made to connect these with the mechanical properties of the materials. Harada et al.[4] showed that the sensory warmth when touching wood for 10 s had a negative correlation with the logarithm of the thermal conductivity, and also with the heat-flow rate between the hand–material interface. Yasuda et al.[5] extracted three factors: roughness, regularity, and distinctness, from the sensory evaluation of the visual and tactile feel of the hardwood samples. They concluded that the roughness factor was highly correlated with the root mean-square roughness calculated from the surface profile of the material. Nakamura and Masuda[6] focused on the relationship between the visual characteristics of a wood surface and its psychological image. They found that the interval of grooves that gave an "agreeable" image was near 1/6 to 1/10 of the geometrical average of the vertical and horizontal sizes of wall panels, and when there were ribbon figures on full-size panels, the interval most preferred was widened. They also investigated the influence of shadings in edge-grain patterns on subjective "natural" feelings and revealed that a clear, regular pattern in shading spoiled the natural image.[7] A new numerical description of shadings in consideration of the human visual properties was devised in the study.

The investigations from the human side as described above give us much useful information to consider the "livability" of wooden houses. Besides the studies on the subjective feelings or sensory evaluations, physiological investigations are increasingly conducted in the related fields of the dwelling ability or livability of houses, including aspects such as lighting.[8,9] Recent studies, including physiological measurements as well as psychological ones, have even clarified that there were cases in which subjective feelings or sensory evaluation do not necessarily correspond with the physiological responses. In the study of Yamaguchi

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et al.,[10] the image of a deep forest on a high-resolution color display was felt to be "relaxing," but half of the subjects who evaluated the scenery as "very relaxing" showed a significant increase in regional cerebral blood flow and a tendency for the systolic blood pressure to increase. This indicated that their bodies were led to an excited state, in contrast to their subjective declarations. Tsunetsugu et al.[11] reported that there were cases in which the subjects showed different physiological responses to the visual stimuli by the two different types of room interior, while they showed no significant difference in the subjective evaluations. Considering these facts, physiological measurements are thought to be essential to discuss the livability of wooden houses from the human side.

In this study, the physiological responses of people to the visual surroundings in rooms with wooden interiors were investigated. To elucidate if the wood quantity in the interior had an influence on physiological responses, three rooms with different wood ratios (i.e., the ratio of the area covered with wooden material to the whole area of the ceiling, walls, and floor) were compared.

Materials and methods

Three actual-size model rooms of 13 m^2 were prepared. The interiors of the rooms are shown in Fig. 1. The 0% room contained no visible wooden materials. The floor was covered by white carpet, and the walls and the ceiling were covered by white wallpaper. The room with 45% wood ratio had a wooden floor and a waist-high wooden wall. Almost all of the wall and the entire floor and ceiling were covered with wooden materials in the 90% room. For walls and floors, sliced veneer of oak was used. Besides these three rooms, another room of the same size was prepared as a practice room for the subjects so that they could become used to the procedure of the experiment. Each subject started with the practice room, and then continued to the other three rooms with different wood ratios in random order. The ambient conditions in these rooms were controlled at 21°–23°C, 50%–60% relative humidity (RH), and 40 lx. The air was changed before every subject's experiment to eliminate the influence of odors in the rooms. The wind speed in the rooms was considered to be almost zero and the effect of the wind was negligible.

Three physiological indices were measured continuously from the beginning of the experiment. Pulse rate and blood pressure were measured on the left middle finger (Finapress, Ohmeda model 2300) as indices of autonomic nervous activity.[12] Changes in the total hemoglobin concentration [tHb] were measured as an index of central nervous activity on the right side of the forehead (NIRO-300; Hamamatsu Photonics) by using near-infrared spectroscopy (NIRS).[13,14] The changes in the hemoglobin concentrations measured in the present experiment are considered to reflect the cerebral activity mainly in the prefrontal area.[15,16] These two methods (Finapress and NIRS) are noninvasive, and data for every second are available.

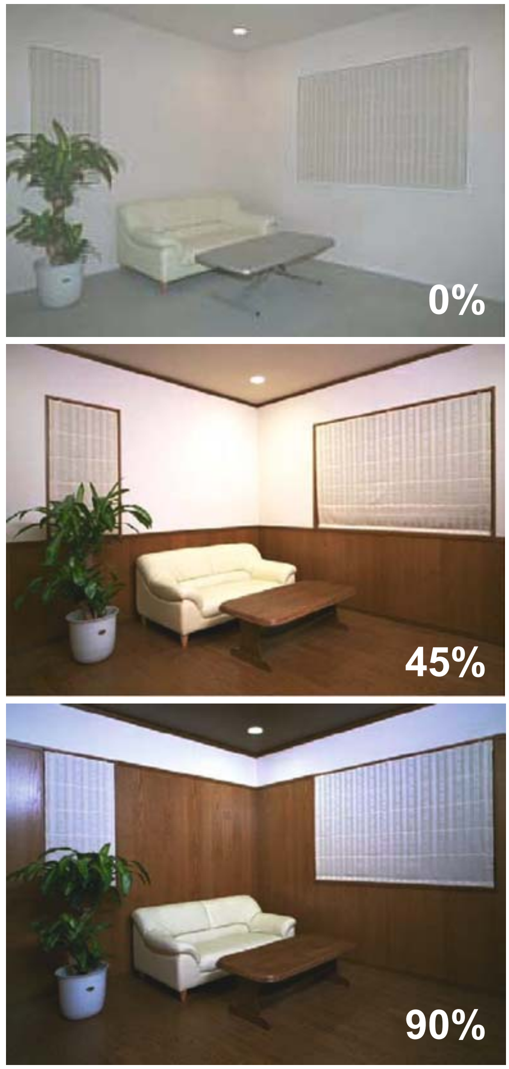

Fig. 1. Interior designs of rooms created for the experiment. *Top*, room with 0% wood ratio; *middle*, room with 45% wood ratio; *bottom*, room with 90% wood ratio

The subjects were 15 male students aged 19–28 years old. Before the measurement, sufficient information about the purpose and the procedure of the experiment was provided to the subjects. The whole process of the experiment was conducted with the subjects sitting in a wheelchair, which was custom-made for the experiment. After the sensors for the physiological measurements were attached, each subject was instructed to close his eyes, and the experimenter then pushed the wheelchair and subject into one of the rooms. The experimenter then immediately left the room quietly. After the physiological indices had recovered to a stable state, the experimenter gave an instruction from the outside the room for the subject to open his eyes. The subject was exposed to the visual stimulation of the room interior for the following 90 s. Subjective ratings on "comfortable–uncomfortable," "natural–artificial," and "restful–unrestful" feelings were subsequently performed using 13-point scales. Temporal mood states were also investigated by using POMS (profile of mood states).[17] The approximate time required for these tests was 5 min. The subject was then instructed to close his eyes again and was moved to the next room.

Data analysis

For the physiological data, some were excluded from the analysis because of artifacts. The least data appropriately obtained were those of ten subjects for the hemoglobin concentration, so we analyzed the data of those ten subjects for all measures.

To eliminate the effect of individual differences in baselines, the physiological data were processed as follows. The values of pulse rate and blood pressure for each second were converted to a percentage of the average value over 10 s before stimulation. The value of [tHb] of each second was converted to the difference from the average value over 10 s before stimulation. One sample t-test was performed to compare the physiological data during the stimulation with 100 for pulse rate and blood pressure, and with 0 for the [tHb]. To avoid type-I error, the following was considered. The rate that significant differences between N out of 90 data and 100 (or 0) would be found by error (the rate that N significant differences would be detected despite the fact that there are no significant differences) can be calculated by using binomial distribution,

$$ {}_{90}C_N(0.05)^N(0.95)^{(90-N)} $$

when the significance level is 0.05. The calculated rate becomes <0.05 when N is equal to or larger than 8. Therefore, it was considered that if there were more than 8 significant differences out of 90 data during the stimulation, the change in the physiological index as a whole was significant.

The scores for the questionnaire for the sensory evaluation were obtained by converting the points the subjects had marked into scores of −6 to +6. Scores of +2 (−2), +4 (−4), and +6 (−6) were slightly comfortable/natural/restful (slightly uncomfortable/artificial/unrestful); moderately comfortable/natural/restful (moderately uncomfortable/artificial/unrestful); and very comfortable/natural/restful (very uncomfortable/artificial/unrestful) in the questionnaire sheet, respectively. The scores of POMS were calculated in accordance with the method. One-way analysis of variance (ANOVA) was used to investigate the effect of the kinds of rooms on the subjective evaluations. A Tukey-Kramer post-hoc test was performed to compare the rooms when the main effect of the rooms was significant in the ANOVA.

Results and discussion

Figure 2 shows the average scores for the subjective “comfortable” feeling for rooms with different wood ratios. Three rooms were all evaluated as slightly or moderately comfortable. The 45% room tended to be evaluated as the most comfortable. Figure 3 shows the scores for the “natural” feeling, and Fig. 4 shows the scores for the “restful” feeling. The 0% room was evaluated as between slightly and moderately artificial, whereas the 45% and 90% rooms were evaluated as slightly natural. The main effect of the

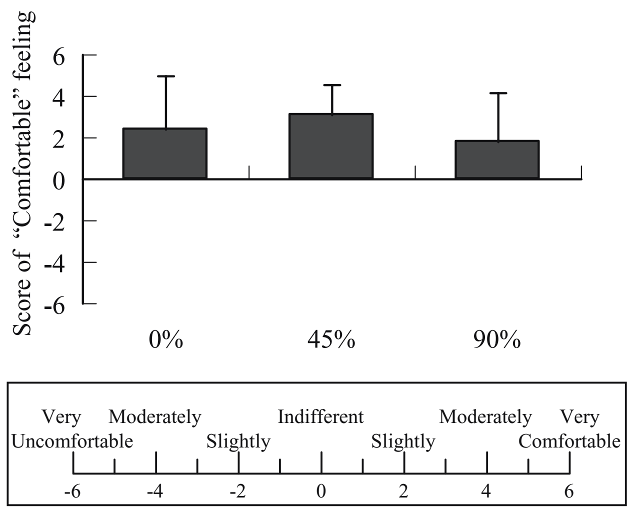

Fig. 2. Scores of “comfortable” feeling for rooms with different wood ratios presented as mean ± SD (n = 10)

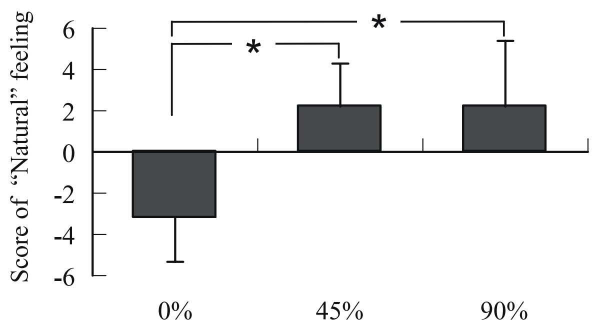

Fig. 3. Scores of “natural” feeling for rooms with different wood ratios (n = 10). *Asterisk*, $P < 0.05$ by Tukey-Kramer multiple comparison test. Score system analogous to that shown in Fig. 2

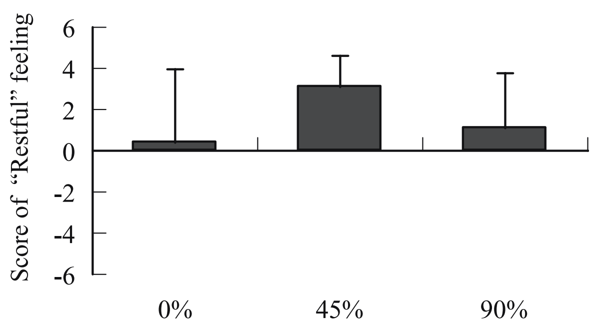

Fig. 4. Scores of “restful” feeling for rooms with different wood ratios. Score system analogous to that shown in Fig. 2

Table 1. Results of one-way analysis of variance on "natural" feeling in rooms with different wood ratios

	df	Sum of squares	Mean square	*F*-value	*P*-value
Kind of room	2	194.400	92.200	13.755	<0.001**
Residual	27	190.800	7.067		

** $P < 0.01$

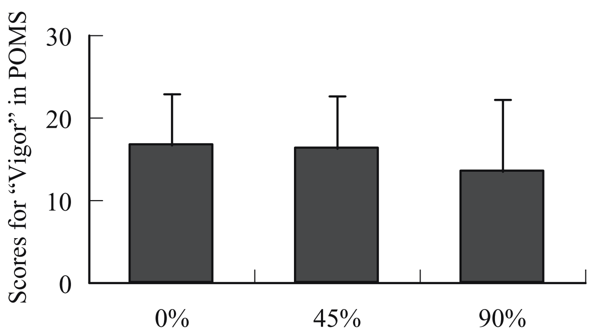

Fig. 5. Scores of "vigor" in profile of mood states (POMS) for rooms with different wood ratios given as mean ± SD

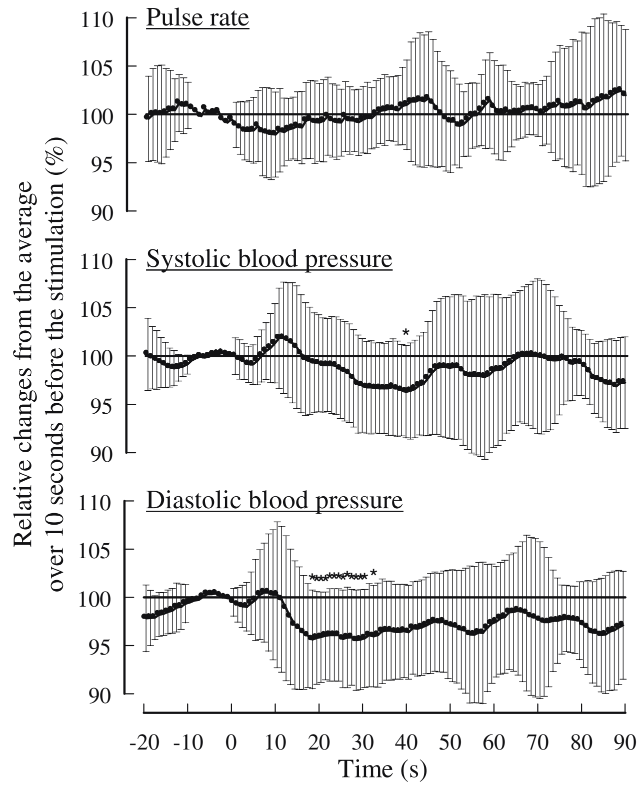

Fig. 6. Time-series variations in pulse rate and blood pressure in room with 0% wood ratio. Data given as mean ± SD (n = 10). *Star*, $P < 0.05$

room type on the natural feeling was significant in one-way ANOVA (Table 1), and there were significant differences ($P < 0.05$) between the 0% and 45% rooms, and between the 0% and 90% rooms. No significant difference was observed in the restful feeling, but the 45% room tended to be evaluated as the most restful. The scores of the "vigor" in the POMS are shown in Fig. 5. There was no significant difference between the three rooms. In the subjective evaluations by the questionnaires, the 45% room tended to have the highest scores for comfortable and restful feelings. An excessive wood ratio was less preferred, and it was assumed that there might be an appropriate wood quantity in which many people felt comfortable.

Figure 6 shows the time-series variations in pulse rate and blood pressure for the 0% room; it can be seen that the pulse rate of the subjects did not change for the entire exposure. Similarly, systolic blood pressure did not show a significant change. Diastolic blood pressure decreased significantly after 19s to 31s and stayed below the baseline. Figure 7 shows the time-series variations in pulse rate and blood pressure for the room with 45% wood ratio. A significant decrease in the diastolic blood pressure was observed between 16 and 31s, and between 45 and 53s. The pulse rate in the 45% room gradually increased after the subjects opened their eyes, and the increase became significant after 54s. The increase in the pulse rate might be compensation for the decrease in the blood pressure. The trend in the systolic blood pressure was similar to the diastolic blood pressure, but no significant difference was observed. Figure 8 shows time-series variations in pulse rate and blood pressure for the 90% room. Both systolic blood pressure and diastolic blood pressure showed a significant and large decrease from approximately 20s (systolic blood

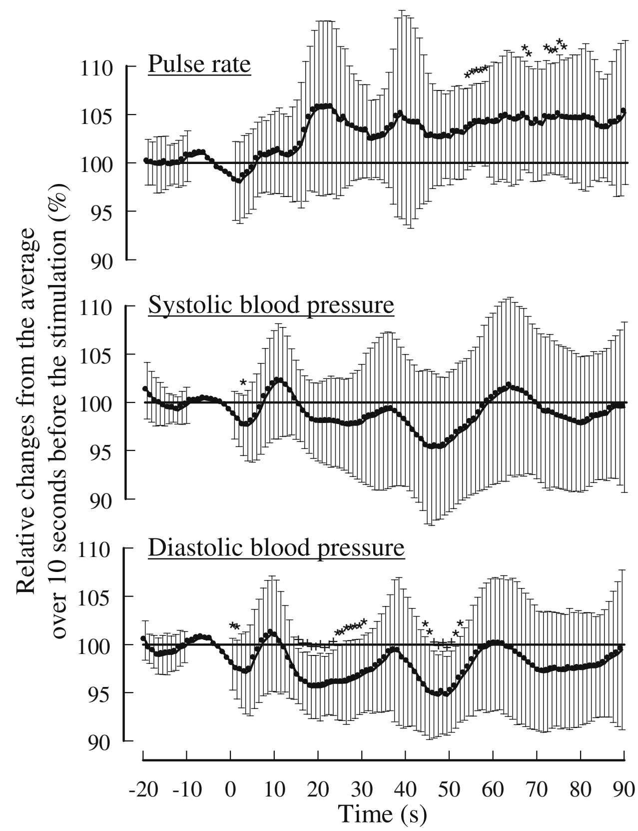

Fig. 7. Time-series variation in pulse rate and blood pressure in room with 45% wood ratio. Data given as mean ± SD (n = 10). *Star*, $P < 0.05$; *plus sign*, $P < 0.01$ by one-sample t-test

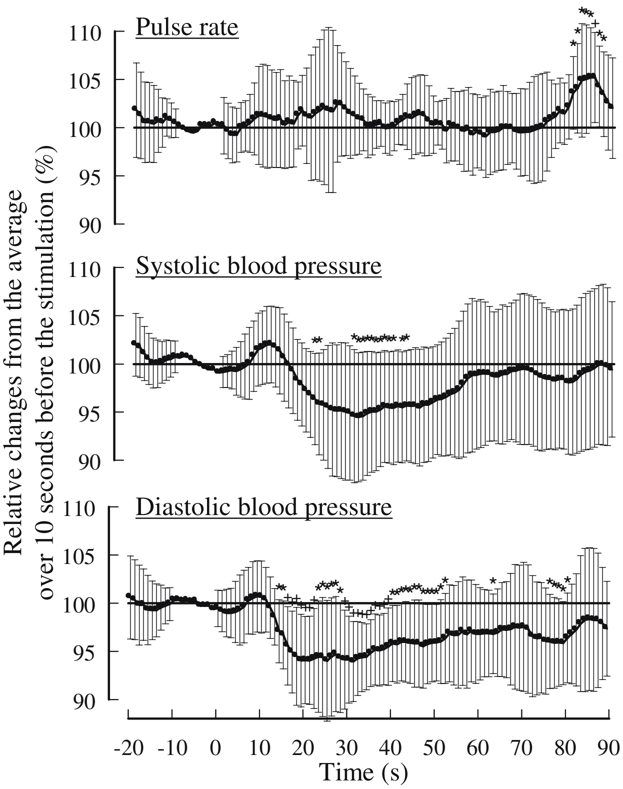

Fig. 8. Time-series variations in pulse rate and blood pressure in room with 90% wood ratio. Data given as mean ± SD (n = 10). *Star*, $P < 0.05$; *plus sign*, $P < 0.01$ by one-sample t-test

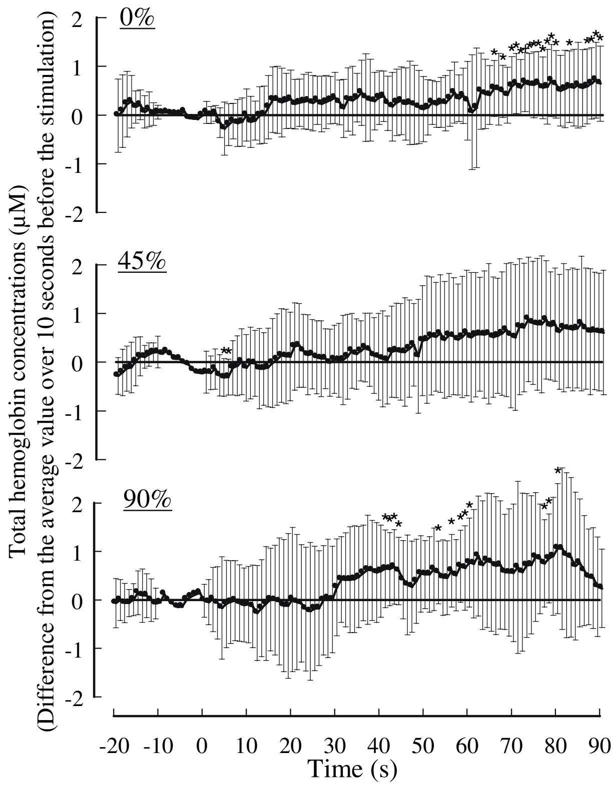

Fig. 9. Time-series variation in total hemoglobin concentrations in the right frontal lobes for subjects exposed to rooms with different wood ratios. Data given as mean ± SD (n = 10). *Star*, $P < 0.05$; *plus sign*, P < 0.01 by one-sample t-test

pressure from 22s and diastolic blood pressure from 17s), which was interpreted to mean that the parasympathetic nervous activity was dominant for at least the first half of the stimulation. The pulse rate did not change significantly, except for a sudden increase after 81s.

Figure 9 shows the time-series change in the total hemoglobin concentration in the right prefrontal lobe for the 0%, 45%, and 90% rooms. In the 0% room, the [tHb] changed little during the initial 10s of the exposure, but tended to increase afterward to reach a significant increase. The [tHb] tended to increase especially in the latter part of the exposure in the 45% room. In the 90% room, a significant increase in the [tHb] was observed intermittently between 42 and 81s, but the [tHb] showed a sudden drop in the last 10s. The results for [tHb] indicated that regional cerebral blood flow (rCBF) and cerebral activity of the measured area basically increased, regardless of the interior wood ratio. This may be because the subjects had interest in the interior design or the surface patterns of the wooden materials, and tried to collect the information from their surroundings. The increase in rCBF of the frontal area when the subjects declared a comfortable feeling has often been observed in our previous studies.[18] A sudden decrease in [tHb] in the 90% room, however, was considered to show that the subjects became tired of the large coverage of wood in the room.

The 0% room caused little change in pulse rate and systolic blood pressure, and less change in diastolic blood pressure than the other two rooms. The physiological responses here may be reflected in the subjective evaluation that the 0% room was slightly artificial and almost indifferent in restful feeling. The 45% room tended to be rated as the most comfortable and restful among the three rooms and significantly natural when compared with the 0% room. Because the score of "vigor" in the POMS for the 45% room was not high, the significant increase in pulse rate in the second half of the test seemed to be compensation for the decrease in blood pressure. In the 90% room, the rCBF rapidly decreased after 81s, despite the significant increase from 42 to 80s The results seemed to indicate that the subjects became tired of the large coverage wood in the 90% room and gave up information collection. The pulse rate also significantly increased in the last 10s. These physiological responses may have a connection with the results of the subjective evaluation, in which the 90% room had relatively low scores in comfortable and restful feelings.

In our previous study,[19] we found that a room with 30% wood ratio caused a significant decrease in pulse rate and diastolic pressure. The findings in the present study, together with those of the previous study, demonstrate that differences in wood quantity in the room interior obviously caused different physiological responses. Further studies would make it possible to design rooms to fit the intended use by considering their effects on the physiological function. Although studies addressing physiological mechanisms and individual differences are required to explain the implication of the physiological responses in the present study, it has been clarified that consideration of the physiological effects is essential when designing room interiors.

Conclusions

By investigating the physiological responses of humans to the visual stimuli of room interiors with different quantities of exposed wood, the following results were obtained:

1. In the 0% room, diastolic blood pressure significantly decreased, but the observed change in the autonomic nervous activity was relatively small. These responses might be reflected in the subjective evaluation for which the 0% room had relatively low scores for natural and restful feelings.
2. In the 45% room, a significant decrease in the diastolic blood pressure and a significant increase in pulse rate were observed. This room tended to have the highest scores in subjective comfortable and restful scores. It was assumed that there might be an appropriate and moderate wood quantity with which many people felt comfortable.
3. The 90% room caused significant and large decreases in systolic blood pressure and diastolic blood pressure at the beginning of the test, but the large coverage of wood was thought to provide too much information for the subjects and caused a rapid decrease in their cerebral activities and an increase in pulse rate at the end of the exposure.

In the present study, diastolic blood pressure decreased significantly in all three rooms with different wood quantities. However, the pulse rate increased significantly in the 45% room, systolic blood pressure significantly decreased in the 90% room, and these two indices were unchanged in the 0% room. It was clarified that visual stimuli by room interiors with different wood quantities caused different responses in autonomic nervous activity.

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References

1. Suzuki M (1987) Studies on the livability of wooden house (in Japanese). Mokuzai Gakkaishi 33:829–836
2. Suzuki M (1988) Wooden residence – habitability (in Japanese). Mokuzai Kogyo 43:67–73
3. Haishi T, Norimoto M (1997) Sensory and emotional characteristics of wood V: temperature–humidity environment and wood (in Japanese). J Soc Mater Sci 46:1335–1341
4. Harada Y, Nakato K, Sadoh T (1983) Thermal properties and sensory warmth of wood surfaces (in Japanese). Mokuzai Gakkaishi 29:205–212
5. Yasuda A, Sadoh T, Nakato K (1983) Visual and tactile roughness of hardwood surfaces relating to physical roughness (in Japanese). Mokuzai Gakkaishi 29:731–737
6. Nakamura M, Masuda M (1990) Influence of grooves in wall panels on psychological images I. Influence of groove intervals (in Japanese). Mokuzai Gakkaishi 36:930–935
7. Nakamura M, Masuda M (1995) Visual characteristics of shadings in edge-grain patterns (in Japanese). Mokuzai Gakkaishi 41:301–308
8. Kuller R (1986) Physiological and psychological effects of illumination and colour in the interior environment. J Light Vis Env 10:33–37
9. Kobayashi H, Sato M (1992) Physiological responses to illuminance and color temperature of lighting. Ann Physiol Anthropol 11:45–49
10. Yamaguchi M, Hatakeyama E, Suda R, Kikuchi T, Miyazaki Y, Sato M (2001) Effect of visual stimulation of natural scenery on central and autonomic nervous systems (II). In the case of poor correlation between sensory evaluation and physiological responses (in Japanese). Jpn J Physiol Anthropol 6:86–87
11. Tsunetsugu Y, Miyazaki Y, Sato H (2002) The visual effects of wooden interiors in actual-size living rooms on the autonomic nervous activities. J Physiol Anthropol 21:297–300
12. Boehmer RD (1987) Continuous, real-time, noninvasive monitor of blood pressure: Penaz methodology applied to the finger. J Clin Monit 3:282–287
13. Villringer A, Chance B (1997) Non-invasive optical spectroscopy and imaging of human brain function. Trends Neurosci 20:435–442
14. Shaw RA, Mansfield JR, Kupriyanov VV, Mantsch HH (2000) In vivo optical/near-infrared spectroscopy and imaging of metalloproteins. J Inorg Biochem 79:285–293
15. Villringer K, Minoshima S, Hock C, Obrig H, Ziegler S, Dirnagl U, Schwaiger M, Villringer A (1997) Assessment of local brain activation. A simultaneous PET and near-infrared spectroscopy study. Adv Exp Med Biol 413:149–153
16. Hoshi Y, Tamura M (1993) Dynamic multichannel near-infrared optical imaging of human brain activity. J Appl Physiol 75:1842–1846
17. Yokoyama K, Araki S, Kawakami N, Takeshita T (1990) Production of the Japanese edition of the Profile of Mood States (POMS): assessment of reliability and validity (in Japanese). Nippon Koshu Eisei Zasshi 37:913–918
18. Suda R, Yamaguchi M, Hatakeyama E, Kikuchi T, Miyazaki Y, Sato M (2001) Effect of visual stimulation of natural scenery on central and autonomic nervous systems (I) – in the case of good correlation between sensory evaluation and physiological response (in Japanese). Jpn J Physiol Anthropol 6:84–85
19. Tsunetsugu Y, Sato H, Miyazaki Y (2005) Visual effects of interior design in actual-size living rooms on physiological responses. Build Environ 40:1341–1346