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# Effects and interaction of different interior material treatment and personal preference on psychological and physiological responses in living environment

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## Abstract

Japanese cedar (*Cryptomeria japonica*) wood is widely used as a traditional construction material in Japan. The relationship between an individual's perceived comfort level and a preference for Japanese cedar wood interiors is of interest. We compared volunteers' physiological responses and subjective evaluations of wooden dwelling spaces with different wood materials: planed Japanese cedar lumber, or printed grain resin sheet overlay boards. Eighty-three subjects were asked to stay in each room for 30 min. We evaluated salivary stress markers, blood pressure, the profile of mood states-brief form (POMS), and a questionnaire that used the semantic differential method to evaluate the subjects' feeling state for both rooms. The concentrations of the volatile organic compounds in both rooms were also quantified after the experiment. The results demonstrated that the subjects' evaluation of each room was highly dependent on their preference; each room was evaluated more positively by subjects who preferred it. Although the subjects' feelings were also influenced by their preference, the room with Japanese cedar did not elicit negative feelings, even from the subjects who disliked it. The subjects' physiological responses were totally independent of their preferences. Their blood pressure decreased in the Japanese cedar room, and their salivary alpha-amylase activity was repressed in both rooms. These results indicated that the subjective evaluations were influenced in part by the subjects' preferences, while their physiological responses were not affected. Regardless of which room the subjects preferred, the Japanese cedar room reduced the subjects' blood pressure compared to the room with artificial materials.

**Keywords:** Japanese cedar, *Cryptomeria japonica*, Preference, Physiological response, Psychological response

## Introduction

Wood has been used as a material in construction and interior decoration in Japan since ancient times. The smell and appearance of wood materials were recently reported to affect humans' physiological and psychological responses [1–7]. The smell of wood materials is

thought to contribute to a room's perceived comfort level. Subjects who inhaled the smell of Japanese cedar (*Cryptomeria japonica*) described a 'natural' and 'peaceful' feeling; their pulse rates also decreased slightly. That study's authors concluded that the Japanese cedar smell has a relaxant effect on humans [5]. It has also been shown that inhaling Japanese cypress wood oil can reduce the oxy-Hb concentration in the right prefrontal cortex of human subjects while enhancing parasympathetic nervous activity [8].

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Other researchers asked subjects to do arithmetic in rooms with and without the smell of Japanese cedar, and they observed that during and after the completion of the arithmetic only in the room without the Japanese cedar smell, the ratio of the low-frequency (LF) component to the high-frequency (HF) component (LF/HF) of the subjects' heart rate variability (HRV) was increased, and their salivary alpha-amylase (SAA) levels were increased [6]. When people were exposed to Japanese cedar chips, their frontal activity was reduced and their blood pressure declined [9]. A later study described how the smell of wood suppressed the activities of the sympathetic nervous system and promoted the feeling of a 'natural' environment [10]. Many studies, including those mentioned above, indicated that the effects of wood-derived stimulation can provide multiple physiological and psychological benefits such as stress reduction, task performance improvement, blood pressure reduction, and more. However, different types and concentrations of a woody smell can influence the level of subjective comfort. Several research groups have reported that the relationships between the concentration of smells and various emotions are complex; for example, some researchers found that inhaling a high concentration of  $\alpha$ -pinene triggers a feeling of discomfort [10, 11].

In addition, the effects of the smell of wood on physiological responses do not necessarily correspond to individual preferences. Subjects' SAA activity and blood pressure were lower in a room with limited wood material compared to one with more wood, and these values did not correspond to the results from the subjects' evaluations, which indicated that they preferred rooms with more wood [2]. The effect of a woody smell on people's physiological and psychological responses depended on the smell's concentration [10]. However, even subjects who reported disliking the smell of Japanese cedar showed no increase in blood pressure with exposure to the smell [3].

As one of the varieties of construction materials, printed grain resin sheet overlay boards have been widely used as imitation wood. The appearance of the room using these boards as the interior material is almost the same as that of the room using the real wood. However, the composition of printed grain resin sheets is quite different from real wood. The volatile organic compounds (VOCs) in the room with the imitation-wood grain vinyl covering as an interior material were, thus, suspected to be different from the VOCs in the room with real wood, and they may elicit different physiological and psychological responses.

We, therefore, performed a quantitative analysis of VOCs in the rooms, and we compared the psychological and physiological human responses between the rooms

with two different types of wood interior coverings: planed Japanese cedar lumber and printed grain resin sheet overlay boards.

## Materials and methods

### Experimental rooms

Two interiors were constructed at Kyushu University in October 2012 (Fig. 1). The rooms were the same size and had almost the same lighting conditions (floor space, 10 m<sup>2</sup>; ceiling height, 2.4 m; room interior volume, 24 m<sup>3</sup>). Room A had planed Japanese cedar lumber as the interior material; this lumber, dried at 50–60 °C, was used for the floor (thickness 15 mm), the four walls, and the ceiling (thickness 12 mm). The room's foundation, pillars, crossbeams, and beams were composed of planed Japanese cedar lumber dried in a drying set at 120 °C and then under reduced pressure at 50–60 °C. The inside and outside surfaces of the door of Room A were covered by wood grain sheets.

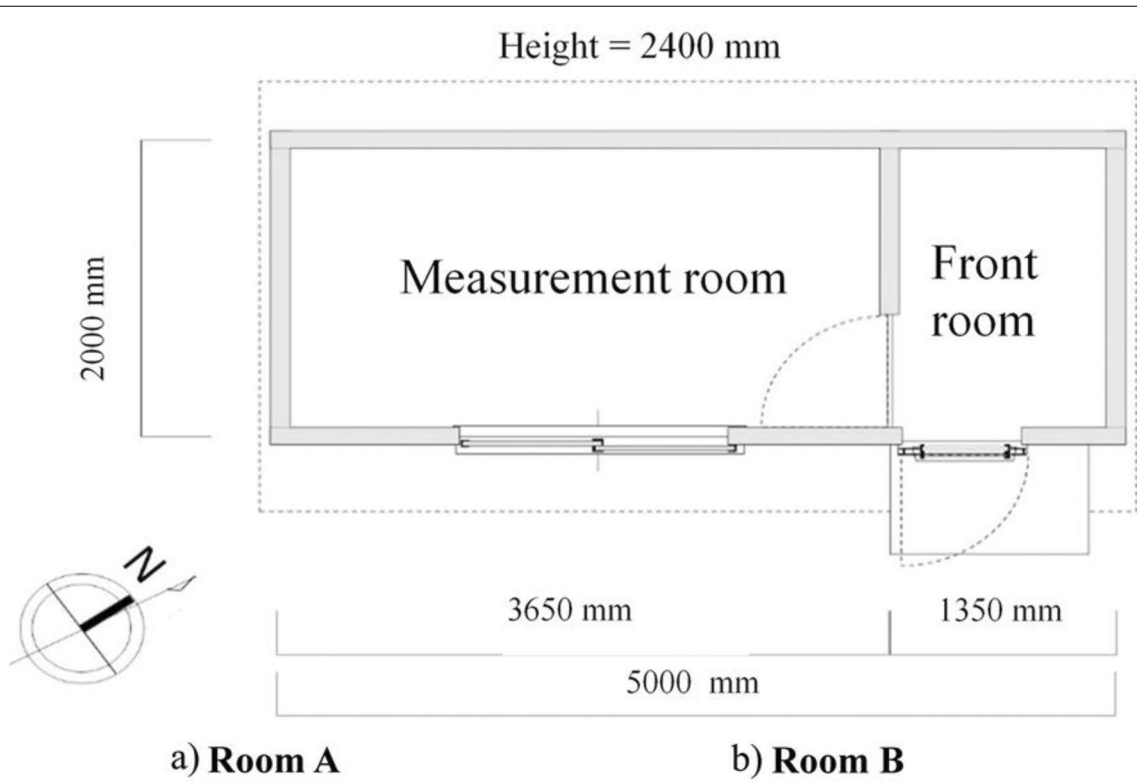
As interior materials, Room B had wood-based materials covered with an imitation-wood vinyl covering and painted interior sections. Medium density fiberboard (MDF) (thickness 6 mm) with a UV coating was used for the floor (7.3 m<sup>2</sup>). Particleboard was used as the substrate material for the walls (thickness 12.5 mm) and the ceiling (9.5 mm), and the surfaces were covered with an imitation-wood vinyl covering. The material of the foundation, pillars, crossbeams, and beams was Japanese cedar lumber dried at high temperature (90–120 °C for 6 days). The inside of the door of Room B was covered by the same wood grain sheets as used for the door of Room A, and its outside surface was covered by wood grain sheets.

All of the materials used in both rooms emitted an amount of formaldehyde conforming to F☆☆☆☆ (Japanese Industrial Standard, formaldehyde emission limit: 0.5 mg/L) [12]. It has been demonstrated that the main atmospheric VOCs of the two rooms were essentially the same [13]. Room A had a higher level of VOCs (mainly terpenes) compared to Room B.

The door of Room A had a wood grain sheet on both sides, and the door of Room B had the same wood grain sheet as that used for the Room A door on its inside surface but a plain sheet on the outside.

### The subjects

The human research protocols for the study were approved by the Ethics Committee of the College of Agriculture at Kyushu University (No. 21). Eighty-three healthy adults (mean age  $\pm$  standard deviation: 37.1  $\pm$  14.7 years) were recruited for the study: 32 males (38.9  $\pm$  16.4 years) and 51 females (36.0  $\pm$  13.5 years). None of the subjects reported having any abnormal physical or mental health conditions. All subjects were



**Fig. 1** The layout of the experimental houses and photos of (a) Room A, and (b) Room B at Kyushu University. The interior of Room A was composed of planed Japanese cedar lumber, and Room B had printed grain resin sheet overlay boards

informed about the study's purpose (i.e., to investigate the effects of the smell of wood) so that the subjects were expected to pay more attention to the smell of the room's atmosphere rather than its visual features; the researchers did not mention the differences in interior materials used in the two rooms. Written informed consent was obtained from all subjects. The subjects were asked to refrain from taking medications or supplements, consuming foods or beverages containing alcohol or caffeine, or participating in vigorous sports 1 day before and on the day of the experiment. The subjects received compensation after completing the experiment. All of the subjects select their responses themselves. All of the experiments were performed in January or February of 2014.

## Measurements

### *Temperature, humidity, and volatile organic compounds (VOCs)*

The temperature and humidity in each room were recorded by a hygrothermograph (Data Logger TR-72Ui; T&D Corp., Matsumoto, Japan) after each subject's entrance and before his or her exit from the room. After all of the experiments were finished in March 2014, three pumps attached to sorbent tubes (Tenax TA; Gerstel, Linthicum, MD) were set in the two rooms and started simultaneously to collect VOCs (flow rate: 0.15 L/min, amount: 9 L, duration: 60 min). Sorbent tubes were thermally desorbed to a gas chromatography–mass spectrometry system (GC/MS; 7890A/5975C, Agilent Technologies, Santa Clara, CA) with a thermal desorption unit (TDU) (Gerstel). Samples were injected in the splitless mode. The GC/MS was equipped with a DB-5MS column (30 m × 0.25 mm; 0.25- $\mu$ m film thickness; Agilent Technologies). Cryo-injection (from – 100 to 40 °C in 15 min) allowed VOCs to enter the injection port of the GC/MS system. The oven temperature program was 60 °C for 5 min and was increased to 230 °C at 3 °C/min, then held at this temperature for 30 min. Helium was used as the carrier gas at a flow rate of 1 ml/min.

For the quantitative analysis, 1  $\mu$ L of benzaldehyde solution (200  $\mu$ L/L, acetone) was added as the internal standard. A calibration curve was prepared using  $\beta$ -caryophyllene (one of the sesquiterpenes) to determine the concentration of each volatile component as the  $\beta$ -caryophyllene equivalent. The limit of quantification (LOQ) was determined as the concentration with a signal-to-noise ratio (S/N) of 10. We focused on sesquiterpenes, which are the main VOCs of Japanese cedar wood. We identified the sesquiterpenes contained in the VOCs by comparing the mass spectrum with the National Institute of Standards and Technology mass spectral library (NIST 11.0). We determined the Kovats retention index

(RI) using Aroma Office software ver. 7.0 (Nishikawa Keisoku, Tokyo).

### *Physiological responses*

The subjects' salivary alpha-amylase activities were measured as a stress marker after they entered and before they exited each room (Salivary amylase monitor CM-2.1; Nipro Corp., Osaka, Japan). To determine whether the changing ratio of SAA differed between the two rooms, we calculated the changing ratio of SAA using the following formula:

$$\text{Changing ratio} = (\text{score before exit} - \text{score after entrance}) / \text{score after entrance}.$$

Blood pressure and pulse rate were also measured twice after the subjects entered the rooms and twice before exiting (Terumo Electronic Sphygmomanometer P2000; Terumo Corp., Kakamigahara, Japan) to reduce the measurement error by averaging.

### *Subjective evaluations*

For the assessment of their overall subjective feelings associated with the rooms (including aroma and interior design), the subjects were asked to fill out a questionnaire using a semantic differential (SD) method [14]. Based on the previous studies [10, 15], the following 17 pairs of adjectives were used in this study: comfortable–uncomfortable, bright–dark, natural–artificial, warm–cold, bright–dark, soft–hard, calm–tense; (visual) light–heavy, (visual) natural–artificial, (visual) refreshed–unrefreshed, (smell) light–strong, (smell) refreshed–unrefreshed, (smell) light–heavy, (smell) natural–artificial; accessible–inaccessible, cold–warm, simple–intricate, not tired–tired, secure–insecure, (feel can do work) well–not well. A visual analog scale (VAS) was used to identify the position of each word along a continuous line (0–100 mm) between the two end-points. The subjects were asked to make a mark on the line that fit their intuitive feeling in response to the room.

To investigate the distinct perceptions of the smell in the room, we administered a questionnaire containing the following nine words, each on a visual scale of 0–100 mm: sweet, sour, perfumed, soft, spicy, bitter, fresh, refreshing, and calm. For the evaluation of the emotional feeling regarding each room's odor, we administered a questionnaire containing seven pairs of words: like (0)–dislike (100), cozy (0)–not cozy (100), not tired (0)–tired (100), balmy (0)–violent (100), calm (0)–rough (100), unrefreshing (0)–refreshing (100), and light (0)–strong (100) in the VAS format. The VAS scores were measured using a ruler.

To assess the subjects' mood states, we used the short form of the Profile of Mood States (POMS-SF) [16]. The

subjects were asked to check a five-point scale ranging from ‘not at all’ to ‘extremely’ for all 30 questions on the POMS-SF before leaving either room. The POMS-SF questions were assigned to six different subscales of mood: Tension–Anxiety (T–A), Anger–Hostility (A–H), Vigor (V), Fatigue (F), Depression (D), and Confusion (C). T-scores were calculated according to the POMS manual, and mood states were assessed quantitatively [16]. For the identification of each subject’s preferences, each was asked to disclose their preferred room and to state the reason(s) why they preferred the room after they had finished their stays in both rooms.

**Experimental procedure**

For each room, an air conditioner and humidifier were used to set the temperature in the range of 16–18 °C and humidity in the range of 40–50%. The air conditioner, humidifier, and ventilating fan were turned off during the experimental period. A passive ventilation system was adapted via a 15-cm-diameter hole in one wall. After the subject arrived at the test site, he or she was asked if their physical condition was good. The subject was also asked to use the restroom before entering a room, to avoid the need to leave the room during the experiment. Although the inside surfaces of the doors of both rooms were covered by the same type of wood grain sheet, the door of Room B had a subtly different surface compared to Room A, and the subjects were asked to evaluate the interior smell of each room before entering the room. Once in the room, the single subject was asked to sit on a chair for 10 min to rest and evaluate the room. After the evaluation, the subject’s blood pressure and pulse rate were measured twice.

The SAA activity was measured after the blood pressure was measured the second time. The tip of the salivary meter was put under the subject’s tongue to immerse it in saliva for 30 s, and SAA activity was measured by salivary amylase monitor. The subject was then instructed to fill out a POMS-SF form and the three questionnaires. After these were finished, the subject’s salivary alpha-amylase activity, blood pressure, and pulse rate were measured again. Each subject stayed in each room for approx. 30 min. To avoid sequential effects, the order of the room exposure was randomly determined. Each subject went

from the ‘first’ room to the ‘second room’ after a 1-week interval. Finally, the subject was asked to choose his or her preferred room (Table 1).

**Statistical analyses**

We used paired *t*-tests to compare the rooms’ VOC concentration, temperature, and humidity. Data from the three questionnaires regarding the subjects’ feeling about the rooms, the rooms’ distinct perceptual characteristics, and the rooms’ smells were subjected to a factor analysis to extract factors (maximum-likelihood method, promax rotation, eigenvalues > 1). Logarithmic transformation was performed for the salivary alpha-amylase activity to approximate a normal distribution. All subjects were assigned to one of the two groups, depending on their room preference: The W group (wood was preferred) liked room A (*n* = 49), and the L group (laminare preferred) liked room B (*n* = 34). A multivariate repeated-measures analysis of variance (MANOVA) followed by Bonferroni post hoc tests were conducted using the mean blood pressure, mean pulse rate, and salivary alpha-amylase activity, using all of the subjects’ data. The between-subjects factor was groups (W group vs. L group), and the within-subjects’ factors were timing (after entrance, before exit) and room (room A, room B).

A two-way repeated-measures ANOVA followed by Bonferroni post hoc tests was conducted on the T-score of the POMS-SF and the factor scores of all questionnaires. The between-subjects factor was group (W vs. L), and the within-subjects factor was room (A vs. B). In all cases, the significance level was set at *p* < 0.05. The effect size is shown by partial eta-squared ( $\eta p^2$ ) defined by the following formula.

$$\eta p^2 = SS_{\text{effect}} / (SS_{\text{effect}} + SS_{\text{error}}).$$

where SS represents the sum of squares of analysis of variance. We used the values of 0.01, 0.06, and 0.14 to indicate small, medium, and large associations between the variables, respectively [17, 18]. All statistical analyses were performed with SPSS ver. 19.0 (IBM, Armonk, NY). The statistical powers for each post hoc analysis were calculated using R ver. 3.5.1. All of the data are shown as the mean ± 95% confidence interval (CI).

**Table 1 Time schedule of experimental procedure**

1	2	3	4	5	6	7
Sit and calm down	Blood pressure pulse rate	Salivary amylase activity	POMS	Impression evaluation	Salivary amylase activity	Blood pressure pulse rate
10min	2min	2min	5min	7min	2min	2min

## Results

### Physiological responses

The analysis of the subjects' systolic blood pressure (SBP) revealed that regardless of the subjects' preference, the SBP of 76.0% ( $n=63$ ) of the 83 subjects (W group,  $n=37$ ; L group,  $n=26$ ) decreased by an average of 7 mmHg after they stayed in room A. The SBP of 22.9% ( $n=19$ ) of the 83 subjects (W group,  $n=12$ ; L group,  $n=7$ ) increased by an average of 4 mmHg after they stayed in Room A. One subject's SBP did not change (in either room).

In the case of Room B, a decrease in SBP by an average of 7 mmHg occurred in 69.0% ( $n=57$ ) of the 83 subjects (W group,  $n=36$ ; L group,  $n=21$ ); whereas, an increase in the SBP by an average of approx. 8 mmHg was observed in 30.1% ( $n=25$ ) of the subjects (W group,  $n=12$ ; L group,  $n=13$ ).

The results of statistical analysis revealed a significant main effect of timing in the case of Room A ( $F(1, 81)=7.568$ ,  $p=0.007$ ,  $\eta p^2=0.085$ ,  $1-\beta=0.776$ ). The pairwise comparisons for the main effect showed lower SBP in all of the subjects who stayed in Room A before exiting compared to the SBP after their entrance (before exiting:  $111\pm 12$  mmHg vs. after entrance:  $114\pm 13$  mmHg,  $p=0.007$ ,  $\eta p^2=0.085$ ,  $1-\beta=0.776$ ). The SBP was decreased in both the W group (before exiting:  $108\pm 15$  mmHg vs. after entering:  $112\pm 16$  mmHg,  $p=0.009$ ,  $\eta p^2=0.081$ ,  $1-\beta=0.754$ ) and the L group (before exiting:  $114\pm 19$  mmHg vs. after entering:  $119\pm 20$  mmHg,  $p=0.008$ ,  $\eta p^2=0.022$ ,  $1-\beta=0.265$ ) after they stayed in Room A; whereas, no significant change in SBP was observed after the subjects stayed in Room B.

Regarding the subjects' pulse rate, regardless of their room preference, the pulse rate of 47.0% ( $n=39$ ) of the 83 subjects (W group,  $n=26$ ; L group,  $n=13$ ) decreased by an average of 3 bpm after they stayed in Room A; whereas, an approx. 3-bpm increase in the pulse rate was detected in 48.2% ( $n=40$ ) subjects (W group,  $n=12$ ; L group,  $n=13$ ) after their stay in Room A. The remaining four subjects' pulse rates were not changed by their stay in Room A.

In the case of Room B, the pulse rate of 59.0% ( $n=49$ ) of the 83 subjects (W group,  $n=28$ ; L group,  $n=21$ ) decreased by an average of 4 bpm, and an average 3-bpm increase in the pulse rate occurred in 39.8% ( $n=33$ ) subjects (W group,  $n=21$ ; L group,  $n=13$ ). The remaining subject's pulse rate was not changed in Room B.

The results of the statistical analysis revealed a significant main effect of timing in the case of Room B ( $F(1, 81)=6.789$ ,  $p=0.011$ ,  $\eta p^2=0.077$ ,  $1-\beta=0.731$ ). The pairwise comparisons of all subjects for the main effect showed a lower pulse rate before exiting the room than after the entrance (before exit:  $69\pm 7$  vs. after entrance:  $70\pm 8$ ,  $p=0.011$ ,  $\eta p^2=0.077$ ,  $1-\beta=0.731$ ). The pulse

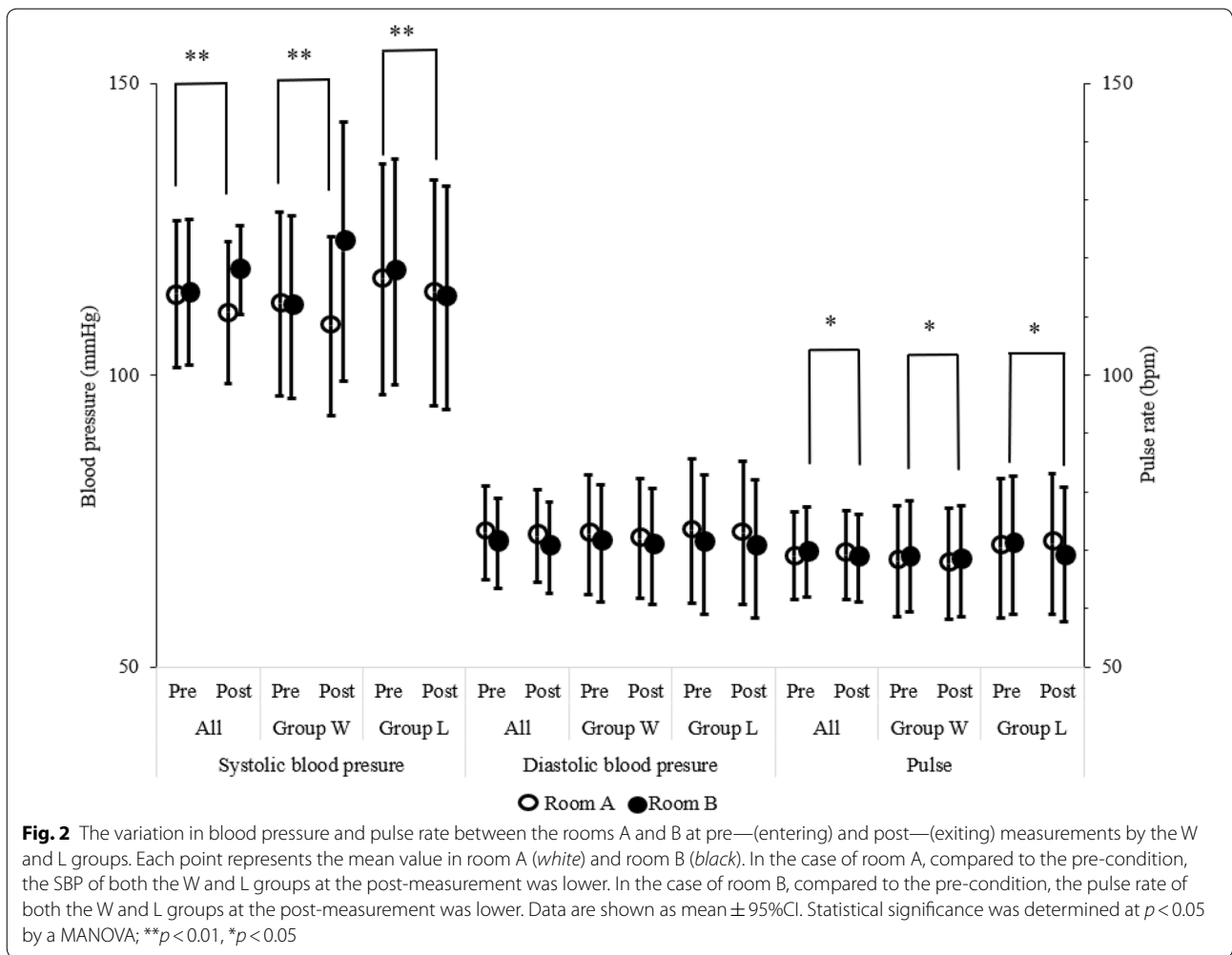
rate was decreased in both the W group (before exiting:  $68\pm 10$  bpm vs. after entering:  $69\pm 10$  bpm,  $p=0.009$ ,  $\eta p^2=0.025$ ,  $1-\beta=0.295$ ) and the L group (before exiting:  $69\pm 12$  bpm vs. after entering:  $71\pm 12$  bpm,  $p=0.005$ ,  $\eta p^2=0.056$ ,  $1-\beta=0.583$ ) after they stayed in Room B; whereas, no significant change in pulse rate was observed after the subjects stayed in Room A (Fig. 2).

For the SAA, regardless of the subjects' preference, the SAA of 56.6% ( $n=47$ ) of the 83 subjects (W group,  $n=24$ ; L group,  $n=23$ ) decreased by an average of 0.58 KU/L after they stayed in Room A. The SAA of 22.9% ( $n=36$ ) of the subjects (W group,  $n=25$ ; L group,  $n=11$ ) increased by an average of 0.42 KU/L after their 30 min in Room A.

In the case of Room B, the SAA of 60.2% ( $n=50$ ) of the 83 subjects (W group,  $n=32$ ; L group,  $n=18$ ) decreased by an average of 0.63 KU/L; whereas, that of the other 31 subjects (37.3%) (W group,  $n=15$ ; L group,  $n=16$ ) increased by approx. 0.49 KU/L. There was a significant main effect of timing in the case of Room A ( $F(1, 81)=4.190$ ,  $p=0.044$ ,  $\eta p^2=0.049$ ,  $1-\beta=0.525$ ). The pairwise comparisons for the main effect showed lower SAA in all subjects before the room exit compared to after the entrance (before exiting:  $4.27\pm 0.18$  vs. after entering:  $4.43\pm 0.16$ ;  $p=0.044$ ,  $\eta p^2=0.049$ ,  $1-\beta=0.525$ ). The SAA was decreased both in W group (before exiting:  $4.32\pm 0.22$  vs. after entering:  $4.37\pm 0.21$ ,  $p=0.016$ ,  $\eta p^2=0.03$ ,  $1-\beta=0.407$ ) and L group (before exiting:  $4.21\pm 0.30$  vs. after entering:  $4.49\pm 0.22$ ,  $p=0.002$ ,  $\eta p^2=0.060$ ,  $1-\beta=0.615$ ). The same was true of Room B ( $F(1, 81)=4.953$ ,  $p=0.029$ ,  $\eta p^2=0.058$ ,  $1-\beta=0.595$ ), in which the pairwise comparisons of all subjects for the main effect showed lower SAA before the room exit than after the entrance to the room (before exiting:  $4.15\pm 0.17$  KU/L vs. after entrance:  $4.35\pm 0.17$  KU/L,  $p=0.029$ ,  $\eta p^2=0.058$ ,  $1-\beta=0.595$ ). The SAA was decreased in both the W group (before exiting:  $4.21\pm 0.24$  KU/L vs. after entering:  $4.42\pm 0.21$  KU/L,  $p=0.016$ ,  $\eta p^2=0.043$ ,  $1-\beta=0.467$ ) and the L group (before exiting:  $4.09\pm 0.25$  KU/L vs. after entering:  $4.27\pm 0.28$  KU/L,  $p=0.009$ ,  $\eta p^2=0.021$ ,  $1-\beta=0.255$ ) (Fig. 3).

### Subjective evaluations

Regarding the T-A sub-scale of the POMS-SF, 26 subjects (W group,  $n=11$ ; L group,  $n=15$ ) gave a higher score to Room A than Room B; 35 subjects (W group,  $n=25$ ; L group,  $n=10$ ) gave a higher score to Room B, and the remaining 22 subjects gave the same score to both rooms. A significant interaction was found between room and group. The W group's T-score for Room A was lower than that for Room B. For the V sub-scale of the POMS-SF, 40 subjects (W group,  $n=31$ ; L group,  $n=9$ ) gave a higher score to Room A than Room B. 31 subjects

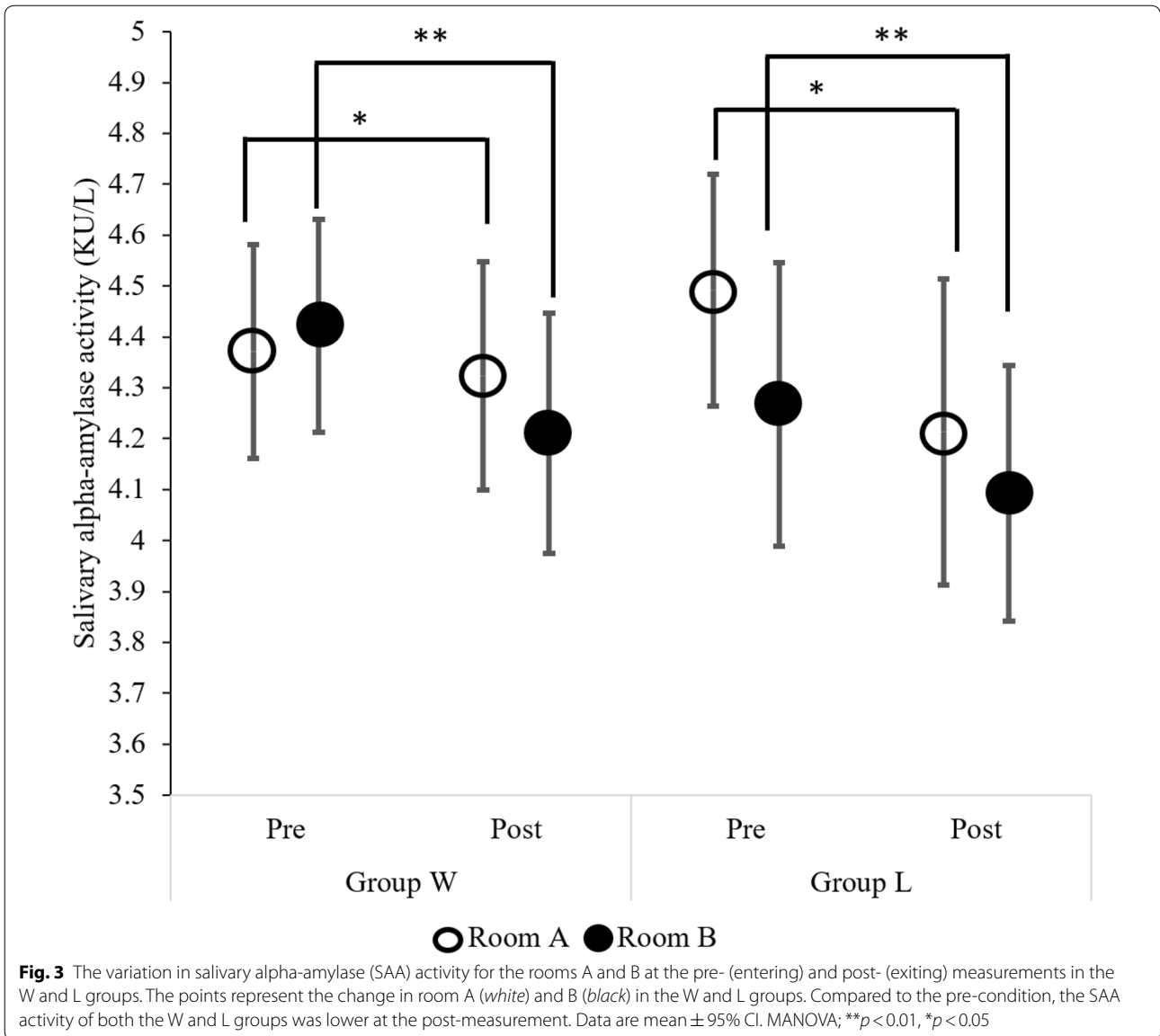


(W group,  $n = 11$ ; L group,  $n = 20$ ) gave a higher score to Room B, and the remaining 12 subjects gave the same score to both rooms. There was an interaction between room and group, with the W group having a higher T-score than Room B.

For the F sub-scale of the POMS-SF, 15 subjects (W group,  $n = 5$ ; L group,  $n = 10$ ) gave a higher score to Room A compared to Room B; 23 subjects (W group,  $n = 19$ ; L group,  $n = 4$ ) gave a higher score to Room B. Most of the subjects ( $n = 45$  total, W group,  $n = 25$ , L group,  $n = 20$ ) felt indifferent about the two rooms. The results revealed a significant interaction between room and group. The W group’s T-score for Room A was lower than that for Room B. For the C sub-scale of the POMS-SF, 31 subjects gave Room A a higher score (W group,  $n = 15$ ; L group,  $n = 16$ ); a different 31 subjects gave Room B a higher score (W group,  $n = 23$ ; L group,  $n = 8$ ), and the remaining 21 subjects gave the two rooms the same score (W group,  $n = 11$ ; L group,  $n = 10$ ). Moreover, on the D sub-scale of the POMS-SF, 13 subjects (W group,  $n = 5$ ;

L group,  $n = 8$ ) gave a higher score to Room A than Room B, and 27 subjects (W group,  $n = 18$ ; L group,  $n = 9$ ) gave a higher score to Room B. Most of the subjects ( $n = 43$  total, W group,  $n = 26$ , L group,  $n = 17$ ) gave the two rooms the same score. The statistical analysis showed a marginally significant interaction between room and group. The W group’s T-score for Room A was marginally lower than that for Room B (Table 2).

The SD questionnaire included 17 pairs of adjectives. The eigenvalue was assumed to be  $\geq 1$ . Seven repetitions resulted in the end of the rotation, and four explicable factors were extracted. Table 3 shows the extracted factors and factor loadings. The initial eigenvalues showed that factor 1 was 7.71, factor 2 was 1.53, factor 3 was 1.31, and factor 4 was 1.02. The four-factor solution explained 68.06% of the variance (Table 3). Adjectives comprising factor 1 were related to how comfortable the subjects felt in the room; thus, factor 1 was designated as the ‘level of comfort.’ Adjectives comprising factor 2 were related to the subjects’ evaluation of the sensory quality; factor



2 was thus designated as ‘texture.’ Adjectives comprising factor 3 were related to the subjects’ feelings about the room; thus, factor 3 was designated as ‘impression.’ Finally, adjectives comprising factor 4 were related to the subjects’ olfactory evaluation; factor 4 was, therefore, designated as ‘smell.’

For the SD questionnaire, in the case of the factor score of factor 1, an interaction was found between room and group. The score of the W group for Room A was higher than that for Room B, and the opposite was true for the L group. Regarding factor 2, there was a significant main effect of room; this effect shows that if we ignore the group, Room A still rated significantly higher than Room B. In addition, the W group subjects gave a higher

score to Room A than Room B. For factor 3, an interaction was found between room and group. The W group’s score for Room A was higher than that for Room B, and the opposite was true of the L group. In the case of factor 4, a marginal interaction was found between room and group. The L group’s for Room B was marginally higher than that for Room A (Table 2).

The questionnaire on the character of the smell in each room was comprised of nine pairs of adjectives. The eigenvalue was assumed to be  $\geq 1$ . Three repetitions resulted in the end of the rotation, and two explicable factors were extracted. Table 4 provides the extracted factors and factor loadings. The initial eigenvalues showed that factor 1 was 3.58, and factor 2 was 2.01. The



**Table 2** The ANOVA results for the T-scores on the POMS-SF, the scores for factors measuring the impression of the room, character of smell, and the impression of smell for both rooms A and B

Evaluation	Scale	Main effect			Interaction			Pairwise comparison								
		Room A	Room B	DoF (1,81)	$\eta p^2$	$\eta p^2$	p	W Group		L Group		Room A	Room B	$\eta p^2$	p	
						Room A	Room B	Room A	Room B	Room A	Room B					
POMS	T-A	ns		8.612	0.096	0.004	0.007	39 (0.996)	41 (1.119)	0.087	0.007	ns				
	V	ns		17.724	0.18	0.001	1.35	41 (1.326)	37 (1.257)	0.001	0.001	39 (1.592)	43 (1.509)	0.073	0.014	
	F	ns		6.175	0.071	0.015	0.044	38 (1.031)	40 (1.110)	0.057	0.057	ns				
	C	ns		4.174	0.049	0.044	0.046	44 (0.970)	46 (1.174)	0.053	0.053	ns				
	D	ns		2.879	0.046	0.052	0.047	42 (0.903)	44 (1.040)	0.050	0.050	ns				
	A-H	ns		ns				ns				ns				
Impression of the room	LC	ns		24.297	0.322	0.001	0.292	0.41 (0.128)	-0.38 (0.134)	0.001	0.001	-0.29 (0.154)	0.25 (0.160)	0.116	0.020	
	T	0.20 (0.094)	-0.21 (0.103)	18.059	0.231	0.001	0.388	0.46 (0.120)	-0.42 (0.132)	0.001	0.001	ns				
(SD questionnaire results of factor analysis)	I	ns		23.719	0.239	0.001	0.194	0.38 (0.113)	-0.30 (0.131)	0.001	0.001	-0.33 (0.136)	0.21 (0.157)	0.093	0.05	
	S	ns		7.873	0.089	0.006		ns				-0.42 (0.190)	0.14 (0.151)	0.056	0.032	
Character of smell	LCS	0.11 (0.086)	-0.10 (0.109)	2.990	0.308	0.001	0.310	0.45 (0.110)	-0.47 (0.140)	0.001	0.001	-0.24 (0.132)	0.27 (0.168)	0.087	0.007	
	PL	ns		13.389	0.142	0.001	0.082	1.9 (0.111)	0.24 (0.133)	0.009	0.009	0.21 (0.133)	-0.27 (0.159)	0.073	0.014	
Impression of smell	F	ns		23.717	0.226	0.001	0.141	-0.27 (0.133)	0.32 (0.136)	0.001	0.001	0.28 (0.160)	-0.36 (0.613)	0.118	0.010	
	IS	ns		3.118	0.037	0.081		ns				-0.40 (0.212)	0.40 (0.212)	0.041	0.066	

Data are means. Significance by two-way repeated-measures ANOVA. DoF degrees of freedom, LCS level of comfort, T texture, I impression, S smell, LCS level of comfort. (Character of smell), PL pungency level, F feeling, IS smell (impression of smell), ns no significant difference

**Table 3** Extracted factors and factor loadings of semantic difference questionnaire for rooms A and B

Evaluated item	Factor loading				Interpretation
	Factor 1	Factor 2	Factor 3 III	Factor 4	
Comfortable–uncomfortable	0.96	0.04	– 0.13	– 0.02	Level of comfort
Calm–tension	0.91	0.24	– 0.21	– 0.02	
Not tired–tired	– 0.71	0.12	– 0.05	– 0.13	
(feel can do work) Well–not well	0.57	– 0.16	0.32	0.04	
Accessible–inaccessible	0.53	0.00	0.40	– 0.01	
(smell) Refreshed–unrefreshed	0.48	– 0.05	0.23	0.26	
Cold–warm	0.47	0.12	0.24	– 0.22	
(visual) Light–heavy	– 0.19	0.94	0.04	0.06	Texture
(visual) Refreshed–unrefreshed	– 0.06	0.65	0.21	0.07	
Bright–dark	0.23	0.64	– 0.14	0.02	
Soft–hard	0.34	0.46	– 0.01	– 0.04	
(smell) Natural–artificial	0.25	– 0.01	0.58	– 0.07	Impression
(visual) Natural–artificial	0.03	0.36	0.44	– 0.11	
Simple–intricate	– 0.06	0.03	0.44	– 0.09	
Secure–insecure	0.37	0.00	0.37	– 0.10	
(smell) Light–strong	– 0.01	0.00	0.41	– 0.69	Smell
(smell) Light–heavy	0.12	0.15	0.19	0.67	
Eigenvalue	7.71	1.53	1.31	1.02	
Contribution rate (%)	45.36	9.00	7.68	6.02	
Accumulated contribution rate (%)	45.36	54.36	62.04	68.06	

Factor extraction method: maximum likelihood method, rotation method: promax rotation method (eigenvalue adopts 1 or more)

two-factor solution explained 62.10% of the variance. The adjectives comprising factor 1 were related to how the subjects felt when they perceived the smell in the rooms;

**Table 4** Extracted factors and factor loadings of character of smell questionnaire for rooms A and B

Evaluated item	Factor loading		Interpretation
	Factor 1	Factor 2 II	
Refresh	0.87	– 0.03	Level of comfort
Fresh	0.81	0.20	
Soft	0.75	– 0.27	
Calm	0.72	– 0.36	
Perfumed	0.62	0.43	
Sweet	0.48	0.20	
Spicy	0.09	0.70	Pungency level
Bitter	0.06	0.62	
Sour	0.11	0.51	
Eigenvalue	3.58	2.01	
Contribution rate (%)	39.72	22.38	
Accumulated contribution rate (%)	39.72	62.10	

Factor extraction method: maximum likelihood method, rotation method: promax rotation method (eigenvalue adopts 1 or more)

thus, factor 1 was designated the ‘level of comfort.’ The adjectives comprising factor 2 were related to how pungent subjects felt the smell was; we thus designated factor 2 as the ‘pungency level’ (Table 4).

Regarding the questionnaire on the character of the smell, in the case of the factor score of factor 1, a marginal main effect of room was observed. Room A was rated significantly higher than Room B. In addition, the interaction between room and group was reflected by the finding that the W group gave Room A higher scores than they did for Room B, and the L group gave Room B higher scores. Regarding factor 2, a significant interaction between room and group was observed; the W group’s scores for Room A were lower than those they gave Room B, and the opposite was true of the L group (Table 2).

The questionnaire on the impression of the smell had seven pairs of adjectives. The eigenvalue was assumed to be  $\geq 1$ . Three repetitions resulted in the end of the rotation, and two explicable factors were extracted. Table 5 lists the extracted factors and factor loadings. The initial eigenvalues showed that factor 1 was 3.48, and factor 2 was 1.90. The two-factor solution explained 76.76% of the variance. The adjectives comprising factor 1 were related to the subjects’ impressions of the smell; thus, factor 1

**Table 5** Extracted factors and factor loadings of impression of smell questionnaire for rooms A and B

Evaluated item	Factor loading		Interpretation
	Factor 1 I	Factor 2 II	
Comfortable–uncomfortable	0.98	0.06	Impression
Like–dislike	0.91	− 0.01	
Calm–tension	0.90	0.01	
Plain–over powered	0.51	− 0.40	
Fresh–unfresh	0.49	0.16	Smell
Concentrated–diluted	0.00	0.91	
Strong–faint	0.14	0.87	
Eigenvalue	3.48	1.90	
Contribution rate (%)	49.70	27.07	
Accumulated contribution rate (%)	49.70	76.76	

Factor extraction method: maximum likelihood method, rotation method: promax rotation method (Eigenvalue adopts 1 or more)

was designated as ‘impression.’ The adjectives comprising factor 2 were related to how strong the subjects felt the smell was; factor 2 was, therefore, designated as ‘smell’ (Table 5).

Concerning the subjects’ impression of the smell, a comparison of factor 1 showed an interaction between room and group. Room A received lower scores from the W group compared to Room B. Room B received lower scores from the L group compared to Room A. Regarding factor 2, there was a marginal interaction between room and group, The L group’s scores for Room B were higher than those for Room A, but no significant difference was found for the W group (Table 2).

We also observed significant differences in the group of 51 females (Wilcoxon signed ranks test). The female subjects rated Room A more ‘comfortable’ ( $72 \pm 5$  vs.  $63 \pm 6$ ,  $t = 2.593$ ,  $p = 0.012$ ), more ‘calm’ ( $72 \pm 6$  vs.  $63 \pm 6$ ,  $t = 2.772$ ,  $p = 0.008$ ), and more ‘bright’ ( $69 \pm 6$  vs.  $51 \pm 6$ ;  $t = 4.445$ ,  $p = 0.001$ ) than Room B. No significant difference was found in the male group.

### Temperature, humidity, and VOCs

There was no significant between-room difference in the temperature (room A:  $17.6 \pm 0.5$  °C, room B:  $17.5 \pm 0.5$  °C,  $t$  (F) = 0.126 (330),  $p = 0.900$ ) or humidity (room A:  $47.1 \pm 1.6\%$ , room B:  $49.1 \pm 2.9\%$ ,  $t$  (F) = − 1.63 (330),  $p = 0.105$ ).

The concentrations of all sesquiterpenes in Room A were higher than those in Room B (Table 6). In both rooms, the component with the highest level was  $\delta$ -cadinene. The concentrations of  $\delta$ -cadinene,  $\alpha$ -cubebene,  $\beta$ -caryophyllene,  $\alpha$ -humulene,  $\gamma$ -cadinene,

**Table 6** The concentrations ( $\mu\text{g}/\text{m}^3$ ) of the components and contents of VOCs emitted from Room A (planed Japanese cedar lumber) and Room B (printed grain resin sheet overlay boards)

No.	Compound	Room A	Room B	<i>p</i>
1	$\alpha$ -Cubebene	$37.30 \pm 13.39$	$14.54 \pm 2.64$	0.045**
2	$\alpha$ -Copaene	$22.68 \pm 8.00$	$13.13 \pm 2.37$	0.119
3	$\beta$ -Elemene	$14.98 \pm 5.59$	$8.45 \pm 1.67$	0.125
4	$\beta$ -Caryophyllene	$16.61 \pm 5.50$	$5.07 \pm 1.13$	0.024**
5	<i>cis</i> -Thujopsene	$3.44 \pm 1.21$	$3.04 \pm 0.48$	0.622
6	<i>cis</i> -Muuroala-3,5-diene	$2.40 \pm 1.19$	$0.74 \pm 0.06$	0.073
7	$\alpha$ -Humulene	$8.96 \pm 2.89$	$4.06 \pm 0.72$	0.046**
8	$\gamma$ -Cadinene	$6.78 \pm 1.83$	$1.34 \pm 0.64$	0.008***
9	$\gamma$ -Muuroleone	$6.15 \pm 2.15$	$4.93 \pm 0.68$	0.400
10	<i>trans</i> -Muuroala-4(14),5-diene	$24.56 \pm 9.08$	$6.73 \pm 1.86$	0.029**
11	$\alpha$ -Muuroleone	$37.26 \pm 12.54$	$28.22 \pm 6.95$	0.336
12	$\delta$ -Cadinene	$73.65 \pm 25.26$	$28.62 \pm 8.84$	0.043**
13	Calamenene	$26.25 \pm 9.42$	$22.40 \pm 5.71$	0.577

$p < 0.05$  by Student’s *t* test. \*\*\* $p < 0.01$ , \*\* $p < 0.05$

and *trans*-muuroala-4(14),5-diene in Room A were significantly higher than those in Room B.

### Discussion

The results of the present study demonstrated that the subjects’ systolic blood pressure decreased in the room with Japanese cedar boards, their pulse rate decreased in the room with particleboard, and their salivary alpha-amylase activity was repressed in both rooms. The subjects’ subjective evaluation of each room was highly dependent on their preference; each room received more positive evaluation from the subjects who liked it. However, although the subjects’ feelings were also influenced by their preference, the room with Japanese cedar boards did not elicit negative feelings, even from the subjects who disliked it.

Here, all of the subjects showed decreased SBP after their stay in Room A, and this result corresponds with those of previous studies [3, 7, 10]. In contrast, no significant difference in SBP occurred after the subjects stayed in Room B. We, thus, speculate that VOCs from solid natural wood can suppress SBP regardless of the subjects’ subjective preference. On the other hand, although the pulse rate of both the L- and W-preferring groups decreased significantly in Room B (medium effect size,  $\eta p^2 = 0.077 > 0.06$ ), the change was only 1 beat per minute. The effect of the room on this physiological response can, thus, be considered limited.

Since the temperature and humidity were not significantly different between the rooms, we could exclude

their influence. The subjects' SAA values were decreased in both rooms; the SAA can be used to evaluate the sympathetic nervous/adrenal medullary system (SAM system) [19, 20]. Previous studies of woody spaces showed that in subjects performing arithmetic work, the SAA was lower in a room with Japanese cedar than in one without [6]. When subjects performed arithmetic in rooms with different quantities of Japanese cedar board compared to a room without Japanese cedar, the rooms with Japanese cedar suppressed the increase of SAA, but the efficiency of SAA suppression was not linked to the quantity of the Japanese cedar board [6].

Another study reported that when subjects stayed in rooms with different quantities of Japanese cedarwood, i.e., Hiba (*Thujopsis dolabrata*) for 30 min, no significant difference was found in physiological markers between the rooms [21]. Our present analyses revealed that the SAA values of the subjects in both rooms A and B were suppressed. Both of these rooms had wooden interiors, but the ratios of compounds in the rooms were different. It has been suggested that VOCs from wood material can suppress the SAA regardless of the ratio and subjective preference.

Our subjects' POMS-SF results showed no main effect of room in any sub-scale except Anger–Hostility; however, the other five subscales, i.e., Tension–Anxiety, Depression, Fatigue, Vigor, and Confusion were found to interact with room preference. This means that the subjects' mood was relatively affected by their preference for one room over the other. Moreover, the subjects who preferred Room A scored lower on the four subscales other than Vigor when staying in Room A compared to their scores for Room B. This suggests that the (wood-preferring) subjects in the W group felt less Tension–Anxiety, Depression, Fatigue and Confusion in Room A than in Room B. No corresponding significant differences were observed in the (laminated-preferring) L group. On the other hand, for the positive scale Vigor, the W group gave Room A a higher score, whereas the L group gave Room B a higher score. We thus conclude that the positive scale of subjective mood status can be influenced by one's personal preference, but the negative scale of subjective mood status can be relieved by the presence of solid natural wood.

The impression evaluation results show the effects of personal preference on the subjects' assessments. In the case of the 'level of comfort,' 'impression,' and 'smell,' both the L and W groups gave their preferred room a higher score. However, both groups gave Room A a higher score on 'texture.' Previous investigations related to the visual effects of wood material reported that impressions changed depending on the quantity of the wood material [22]. When the number of knots in todomatsu

wood increased, the subjects' positive evaluation of the wood decreased [23]. To the best of our knowledge, however, no prior investigation focused on impressions other than appearance. Our subjects' questionnaire responses regarding the character of the smell in the rooms showed that the scores for 'strength of smell' and 'pungency' depended on the subjects' room preferences. Both the L and W groups evaluated the room they did not prefer as having more 'pungency' and a 'stronger' smell. The reason for the negative evaluation could be ascribed to their feeling that the smell was too strong or that they disliked the smell. The subjects' positive evaluations were associated with comments like 'smells good,' 'decent smell,' and 'relaxing.' The subjects' subjective evaluation was influenced by their personal background and health and the VOC ratio of each compound. A study of child subjects reported that the smell of cypress induced an image of pesticides and received a low evaluation [24].

Our present findings revealed that the Japanese cedar and laminate rooms had the same types of volatile organic compounds. This was also observed in another study [13], and we suspect that the reason for this is that high-temperature dried Japanese cedar wood was used as the structural material of the laminate room. Our present investigation differs from a report that that air-dried, conventionally dried, and high-temperature dried Japanese cedar wood chips emitted different VOCs [25]. Some of the reasons for these differences may be differences in the analytical methods used, including differences in the sorbent tubes used to collect VOCs. In this study, we detected the same terpenes in the two rooms. Furthermore, the peaks of components other than terpenes were so small that it was difficult for us to find a sufficient difference between the VOCs of the rooms. Therefore, the difference between psychological response and subjective assessment may have been caused by different amounts of terpenes.

The concentrations of  $\alpha$ -cubebene,  $\beta$ -caryophyllene, *cis*-muurola-3,5-diene,  $\gamma$ -cadinene, *trans*-muurola-4(14)5-diene, and  $\delta$ -cadinene were higher in Room A.  $\delta$ -cadinene and  $\alpha$ -muurolol, components of the essential oil of *Cananga odorata*, regulate human autonomic nervous system (ANS) activity via the stimulation of parasympathetic nerve system (PSNS) activity [26]. The  $\delta$ -cadinene and  $\alpha$ -muurolol present in Meniki (*Chamaecyparis formosensis*) essential oil might be the factors in the increase of PSNS activity; it is possible that Meniki essential oil could improve ANS activity via an increase in HRV [27].  $\delta$ -cadinene was abundant in our room A and our results, thus, suggest that  $\delta$ -cadinene influenced the physiological response and subjective evaluations.

Differences in the concentrations of VOCs may well have influenced our subjects' subjective evaluations.

Since no single compound was isolated for evaluation, we could not distinguish which compound(s) had the effects, or the mechanisms of the effects. However, for the item 'comfort of smell,' all subjects gave Room A a higher score than Room B, which suggests that all of the subjects found the Japanese cedar room more comfortable compared to the room with artificial materials.

Both rooms had nearly the same appearance to eliminate the influence of visual effects, and none of the subjects mentioned knots or any visual features in their responses to the questionnaires after the experiments.

In addition, when we compared the females and males regardless of the subjects' preferences, differences in the subjective ratings of comfort, calm, and brightness between the rooms were revealed in the group of female subjects, suggesting that females may perceive indoor environments differently from males. The male subjects did not report any difference in the aforementioned three subscales between the Japanese cedar and artificial rooms. Thus, men may be less sensitive to the living environment than women.

## Conclusions

We investigated the effects of two rooms with different types of wood material on subjects' physiological responses and subjective evaluations. In terms of physiological responses, no parameter was influenced by the subjects' personal preference. The subjects' blood systolic pressure decreased significantly in the room with planed Japanese cedar lumber, which seemed to have a stronger influence on the subjects' physiological responses than the room with printed grain resin sheet overlay boards. These findings may have been obtained because the Japanese cedar boards had different concentrations of some types of terpenes compared to the printed grain resin sheet overlay boards. For the subjective evaluation, the subjects' personal preferences showed a clear influence (except for the evaluation of visual texture). The subjects' evaluation of visual quality was not related to their personal preferences. Though the moods of the subjects were influenced by their personal preferences, the room with planed Japanese cedar lumber received a more positive evaluation than the room with printed grain resin sheet overlay boards; thus, negative mood changes could be suppressed more efficiently in the room with planed Japanese cedar lumber.

Our findings verify some of the effects of wood VOCs reported previously in fully controlled experimental settings in realistic circumstances, such as spaces in which people performed casual deskwork. The results indicate that people's physiological responses were not in accordance with their subjective evaluations. Analyses of physiological responses are, thus, important to ensure

the validity of similar assessments. Further research that uses experimentally controlled stressors or attention-depleting tasks in two rooms with different wood materials is necessary to verify possible restorative properties of wood interiors.

## Limitations

Although we prepared the two rooms so that they would have almost the same appearance to eliminate the influence of visual effects, some of the subjects described feeling visual differences between the two rooms. Some subjects may have sensed some difference since the two rooms' doors had different outside surfaces; we also did not test the effect of the room-exposure order. We also did not detect enough of the components other than the terpenes to identify them, and this we did not compare those other components between the two rooms. We, therefore, could not consider the influence of VOCs derived from artificial materials used in Room B, such as glues.

## Abbreviations

ANS: Autonomic nervous system;  $1-\beta$ :  $1-\beta$  error probability of statistical test; GC/MS: Gas chromatography–mass spectrometry; HF: High-frequency; HRV: Heart rate variability; L group: Group preferred Laminate; LF: Low-frequency; LOQ: Limit of quantification; MANOVA: Multivariate analysis of variance; MDF: Medium density fiberboard; POMS: Profile of mood states; PSNS: Parasympathetic nerve system; SAA: Salivary alpha-amylase; SAM: Sympathetic nervous/adrenal medullary; SBP: Systolic blood pressure; SD: Semantic differential; SS: Sum of squares; TDU: Thermal desorption unit; VAS: Visual analog scale; VOCs: Volatile organic compounds; W group: Group preferred Wood;  $\eta p^2$ : Partial eta-squared.

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## Authors' contributions

SMK analyzed and interpreted the data and was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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## Availability of data and materials

The datasets generated during and analyzed in this study are available from the corresponding author on reasonable request.

## Competing interests

The authors declare that they have no competing interests.

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