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NOTE



# Psychological and physiological effects of sole contact with oil-finished wood

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**Abstract**

In Japanese households, it is customary to walk barefoot on wooden floors. Previous reports on the psychological and physiological relaxing effects of feet contact with uncoated solid wood have already been published. However, there are no studies on the effects of feet contact with coated wood, which is commonly used for residential floors. This study aimed to validate the psychological and physiological relaxing effects of sole contact with oil-finished wood. In total, 27 women university students (mean age: 21.9 ± 1.9 years) participated in this study. Psychological indices such as the modified semantic differential method and the Profile of Mood States Second Edition were used. The oxyhemoglobin (oxy-Hb) concentrations in the prefrontal cortex were determined using near-infrared time-resolved spectroscopy. The sympathetic nervous activity and the parasympathetic nervous activity were measured using heart rate variability. The flat plate for tactile stimulation was oil-finished wood, and uncoated wood and marble were used for comparison. The sole of the feet of each participant touched each material for 90 s. Feet contact with oil-finished and uncoated wood had relaxing effects on psychological and physiological responses compared with marble. The relaxing effects of oil-finished wood and uncoated wood were similar. That is, they significantly increased subjective feelings of comfort and relaxation, improved mood states, and decreased oxy-Hb concentration in the left prefrontal cortex compared with marble. However, there were no statistically significant differences in terms of right prefrontal cortex and sympathetic nervous activities between oil-finished wood and marble. Oil-finished wood had a slightly weaker physiological relaxation effect than uncoated wood.

**Keywords** Japanese cedar, Oil finish, Tactile, Semantic differential method, Profile of mood states, Prefrontal cortex activity, Autonomic nervous activity, Near-infrared spectroscopy, Heart rate variability, Relaxation

## Introduction

Wood is a common representative natural material as it has long been used for housing and other construction purposes. Empirically, it has a relaxing effect among humans. Miyazaki advocated the "back to nature theory," which states that our bodies can naturally adapt and that we relax by coming into contact with natural stimuli [1]. For approximately 6–7 million years, our ancestors have started evolving into the modern humans we are today [2]. Over 99.99% of our evolutionary timeline involved living in a natural environment, and our bodies have evolved to cope with the natural environment. In stressful situations currently experienced in urban environments, exposure to nature-derived stimuli such as wood promotes relaxation and brings us physiologically closer to our original state as human beings.

Hand or feet contact with wood promotes a sense of relaxation. However, data on the physiological relaxation effect based on physiological indicators such as brain activity, autonomic nervous activity, and endocrine

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activity are limited [3]. The accumulation of scientific data began with palm [4–7] and feet contact [8, 9] studies. Palm contact with uncoated solid wood, Japanese cedar [4], Japanese cypress [5], and white oak [6, 7] promotes physiological relaxing effects by calming the prefrontal cortex activity, increasing the parasympathetic nervous activity and decreasing the sympathetic nervous activity. The physiological relaxing effects of sole contact with uncoated Japanese cedar [8] and Japanese cypress [9] is similar to those of palm contact. Previous studies have shown that palm and feet contact with uncoated solid wood has physiological relaxing effects on the human body and brain.

However, in wood actually use, various types of coating are often applied to prevent staining and scratching. The effects of contact with coated wooden materials among humans should be validated. In a palm contact experiment, the participants were exposed to different coated wooden materials crafted from white oak [7]. Uncoated solid wood has physiological relaxation effects compared with other varieties of coated wood such as urethane- or glass-finished. However, contact with oil-finished wood increased the parasympathetic nervous activity, which indicates physiological relaxation. Hence, oil-coated wood had a physiological relaxing effect that fell between that of uncoated solid wood and various types of coated wood.

This study aimed to assess the effects of sole contact with oil-finished wood on psychological and physiological responses.

## Results and discussion

In the modified SD method, oil-finished and uncoated wood were rated as slightly comfortable. Hence, contact with oil-finished and uncoated wood were significantly more comfort than contact with marble (oil-finished wood: $p<0.001$, $PS_{dep}=0.857$; uncoated wood: $p<0.001$, $PS_{dep}=0.929$; Fig. 1A). Oil-finished and uncoated wood were rated as slightly relaxed. Thus, contact with oil-finished and uncoated wood were significantly more relaxation than contact with marble (oil-finished wood: $p<0.001$, $PS_{dep}=0.964$; uncoated wood: $p<0.001$, $PS_{dep}=0.964$; Fig. 1B). Oil-finished and uncoated surfaces were rated as slightly natural. Therefore, there was a significant difference between oil-finished and uncoated wood and marble (oil-finished wood: $p<0.001$, $PS_{dep}=0.929$; uncoated wood: $p<0.001$, $PS_{dep}=0.964$, respectively; Fig. 1C). Significant differences were also observed between oil-finished and uncoated wood and marble in terms of warm–cold feeling (oil-finished wood: $p<0.001$, $PS_{dep}=0.893$; uncoated wood: $p<0.001$,

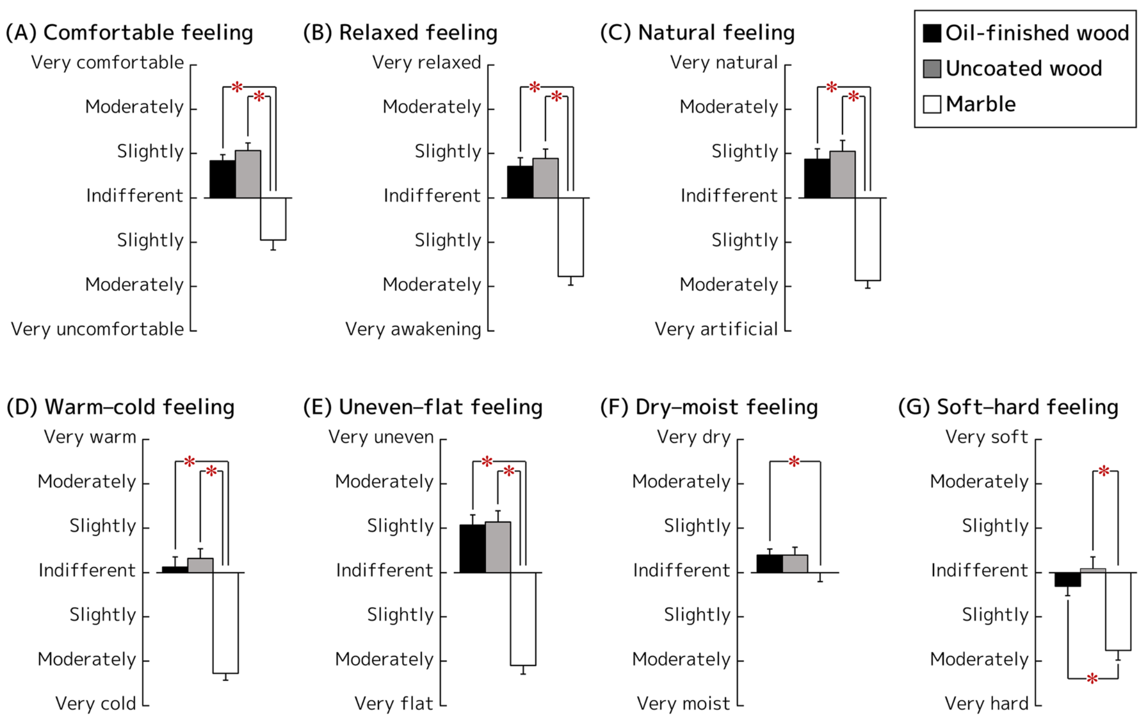


**Fig. 1** Subjective evaluation using the modified semantic differential method after sole contact with oil-finished wood, uncoated wood, and marble. **A** Comfortable feeling, **B** relaxed feeling, **C** natural feeling, **D** warm–cold feeling, **E** uneven–flat feeling, **F** dry–moist feeling, and **G** soft–hard feeling. N = 28, mean ± standard error. *p < 0.05 as determined using the Wilcoxon signed-rank test with Holm correction

$PS_{dep}$ = 0.964; Fig. 1D), uneven–flat feeling (oil-finished wood: $p < 0.001$, $PS_{dep}$ = 0.964; uncoated wood: $p < 0.001$, $PS_{dep}$ = 0.929; Fig. 1E), and soft–hard feeling (oil-finished wood: $p < 0.001$, $PS_{dep}$ = 0.821; uncoated wood: $p < 0.001$, $PS_{dep}$ = 0.857; Fig. 1G). For dry–moist feeling (Fig. 1F), significant differences were found between marble and oil-finished wood only ($p$ = 0.014, $PS_{dep}$ = 0.536). Although there was no significant difference, a similar change was also observed in uncoated wood ($p$ = 0.067, $PS_{dep}$ = 0.536). In terms of contact with uncoated wood, the results of subjective evaluations using the modified SD method were consistent with those of previous studies on feet contact with Japanese cedar [8] and Japanese cypress [9]. Comfortable feeling, relaxed feeling, natural feeling, warm–cold feeling, uneven–flat feeling, and soft–hard feeling were almost identical between oil-finished and uncoated materials.

The POMS2 scores (Fig. 2) for the negative subscales anger–hostility (oil-finished wood: $p$ = 0.007, $PS_{dep}$ = 0.357; uncoated wood: $p$ = 0.006, $PS_{dep}$ = 0.357), tension–anxiety (oil-finished wood: $p < 0.001$, $PS_{dep}$ = 0.893; uncoated wood: $p < 0.001$, $PS_{dep}$ = 0.929), and total mood disturbance (oil-finished wood: $p < 0.001$, $PS_{dep}$ = 0.857; uncoated wood: $p < 0.001$, $PS_{dep}$ = 0.821) were significantly lower after contact with the oil-finished or uncoated wood rather than contact with the marble. The friendliness scale scores of oil-finished food and uncoated wood were significantly higher than those of marble (oil-finished wood: $p < 0.001$, $PS_{dep}$ = 0.571; uncoated wood: $p < 0.001$, $PS_{dep}$ = 0.643). The depression–dejection scale score was significantly lower only with an oil-finished wood ($p$ = 0.002, $PS_{dep}$ = 0.429). However, similar changes were observed in uncoated wood ($p$ = 0.045, $PS_{dep}$ = 0.321). No significant differences were found in confusion–bewilderment (oil-finished wood: $p$ = 0.088, $PS_{dep}$ = 0.500; uncoated wood: $p$ = 0.108, $PS_{dep}$ = 0.429), fatigue–inertia (oil-finished wood: $p$ = 0.229, $PS_{dep}$ = 0.286; uncoated wood: $p$ = 0.239, $PS_{dep}$ = 0.250), and vigor–activity (oil-finished wood: $p$ = 0.027, $PS_{dep}$ = 0.464; uncoated wood: $p$ = 0.222, $PS_{dep}$ = 0.464). The results on contact with uncoated wood were consistent with those of previous studies on feet contact with Japanese cedar [8] and Japanese cypress [9]. The POMS2 results of both uncoated and oil-finished wood were almost identical.

Figure 3 depicts the average Δoxy-Hb concentrations in the left and right prefrontal cortex during 90 s of contact with three materials. In the left prefrontal cortex, the values were −0.58 ± 0.16 μM (mean ± standard error) for oil-finished wood, −0.45 ± 0.14 μM for uncoated wood, and 0.04 ± 0.16 μM for marble. Oil-finished wood and uncoated wood were associated with significantly decreased oxy-Hb concentration compared with marble (oil-finished wood: $t(27) = -2.744$, $p$ = 0.011, $d$ = 0.54; uncoated wood: $t(27) = -2.524$, $p$ = 0.018, $d$ = 0.43; Fig. 3A). In the right prefrontal cortex, the concentrations were −0.33 ± 0.15 μM in oil-finished wood, −0.54 ± 0.13 μM in uncoated wood, and 0.04 ± 0.19 μM in marble. In comparisons between materials, contact with uncoated wood showed a

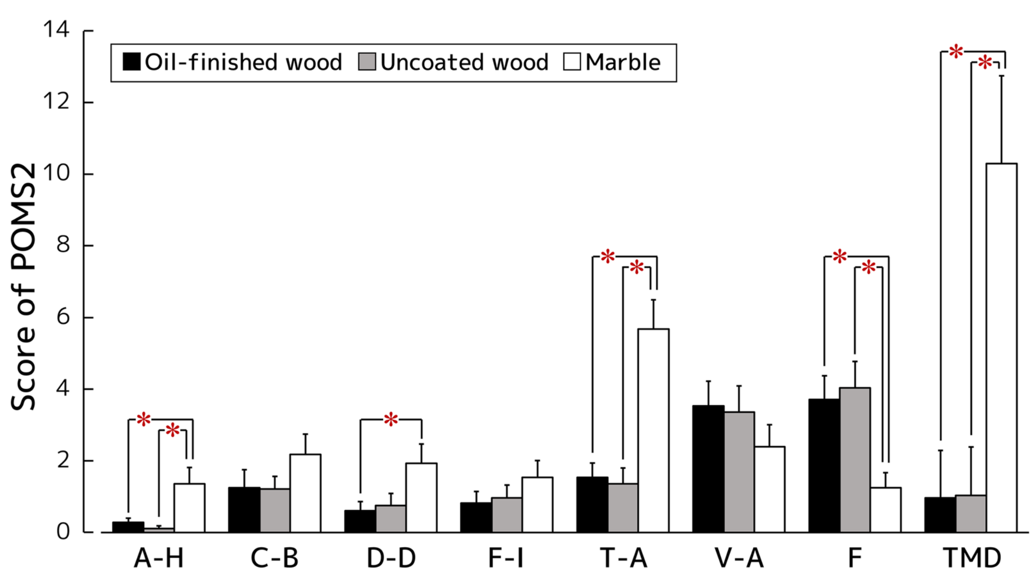


**Fig. 2** Subjective feelings using the Profile of Mood States Second Edition after sole contact with oil-finished wood, uncoated wood, and marble. A–H: anger–hostility, C–B: confusion–bewilderment, D–D: depression–dejection, F–I: fatigue–inertia, T–A: tension–anxiety, V–A: vigor–activity, F: friendliness, TMD: total mood disturbance. N = 28, mean ± standard error. *p < 0.05 as determined using the Wilcoxon signed-rank test with Holm correction

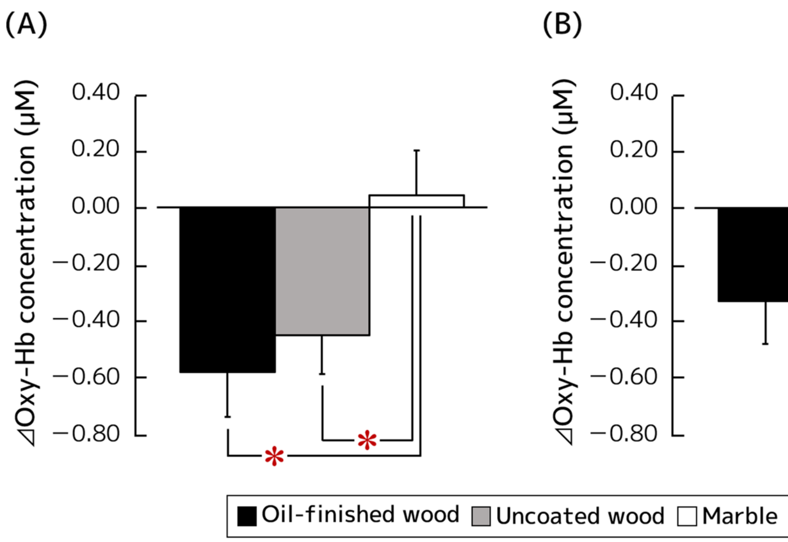


**Fig. 3** Prefrontal cortex activity during sole contact with oil-finished wood, uncoated wood, and marble. **A** The average oxy-hemoglobin (oxy-Hb) concentration in the left prefrontal cortex for 90 s during sole contact. **B** The average value of oxy-Hb concentration in the right prefrontal cortex. N = 28, mean ± standard error. *p < 0.05 as determined using the paired *t*-test with Holm correction

significant decrease compared to contact with marble ($t(27) = -2.792$, $p = 0.010$, $d = 0.44$, Fig. 3B), which is consistent with previous studies on feet contact with Japanese cypress wood [9]. There was no significant difference between oil-finished wood and marble ($t(27) = -1.793$, $p = 0.084$, $d = 0.25$, Fig. 3B). In the left prefrontal cortex activity, contact with oil-finished wood and uncoated wood significantly decreased compared to contact with marble. Only uncoated wood had a significant difference in terms of right prefrontal cortex activity, and oil-finished wood had a similar change. Both oil-finished wood and uncoated wood could relax the prefrontal cortex activity.

No significant difference was observed in terms of respiratory rate; therefore, a statistical analysis of HRV data was performed. Figure 4 shows the average values of sympathetic nervous activity over 90 s. In Δln(LF/HF), which reflects sympathetic nervous activity, oil-finished wood $-0.21 \pm 0.17$, uncoated wood $-0.33 \pm 0.17$ and marble $0.26 \pm 0.20$, with uncoated wood showing a significant decrease compared to marble ($t(27) = -2.663$, $p = 0.013$, $d = 0.50$, Fig. 4). The oil finish wood had similar changes. However, it was not significant ($t(27) = -2.663$, $p = 0.097$, $d = 0.33$, Fig. 4). For contact with uncoated wood, the results were consistent with those of a previous study on feet contact with Japanese cypress wood [9]. In Δln(HF), which reflects parasympathetic nervous activity, there was an increase of $0.31 \pm 0.13$ lnms$^2$ for oil-finished and $0.30 \pm 0.14$ lnms$^2$ for uncoated compared to $-0.14 \pm 0.16$ lnms$^2$ for marble, but the difference was not significant (oil-finished wood: $t(27) = 2.191$, $p = 0.037$, $d = 0.42$; uncoated wood: $t(27) = 2.178$, $p = 0.038$, $d = 0.41$).

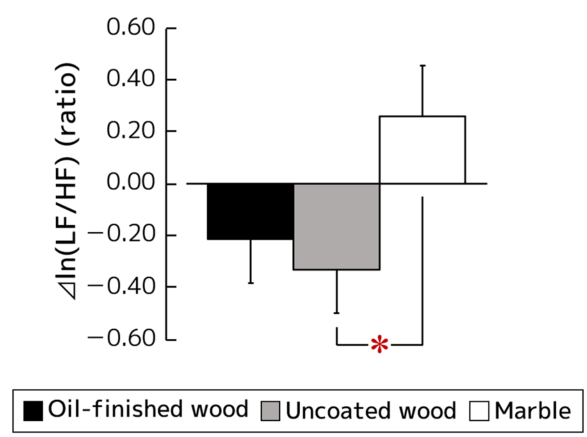


**Fig. 4** Sympathetic nervous activity during sole contact with oil-finished wood, uncoated wood, and marble. The average value of the natural logarithm of the LF/HF of HRV for 90 s of sole contact. N = 28, mean ± standard error. *p < 0.05 as determined using the paired *t*-test with Holm correction

## Conclusions

Sole contact with both oil-finished and uncoated solid wood compared with marble induced psychological and physiological relaxation effects. Oil-finished wood had analogous relaxing effects compared with uncoated wood. In particular, tactile stimulation with oil-finished wood significantly increased the subjective feelings of comfort and relaxation, improved mood states, and decreased oxy-Hb concentrations in the left prefrontal cortex compared with tactile stimulation with marble. The right prefrontal cortex activity and the sympathetic nervous activity significantly differed between contact with uncoated wood and marble. Meanwhile, there were no significant differences between contact with oil-finished wood and marble. Hence, oil-finished wood can have a slightly diminished physiological relaxation effect compared with uncoated wood.

## Materials and methods

Twenty-eight Japanese women (mean age: 21.7 ± 1.3 years) consented to participate in this study, which was conducted by the principles outlined in the Declaration of Helsinki. This study was approved by the Ethics Committee of the Center for Environment, Health and Field Sciences, Chiba University, Japan (Project Identification Code Number 41). This study is registered in the University Hospital Medical Information Network of Japan (Unique ID issued: UMIN000038729).

Japanese cedar (*Cryptomeria japonica*) wood was used as the base material for this experiment. Five wooden laminae without vertical joints (600 mm × 120 mm × 20 mm) were bonded together along their width. Furthermore, a second bonding was performed using plywood (600 mm × 600 mm × 24 mm) to prevent bending. The total thickness of the finished product was 44 mm. The surface was brushed with a stainless-steel wire brush and finished via either (1) plant oil containing perilla oil as the main ingredient applied once as a topcoat using a roll coater (hereafter referred to as "oil-finished wood"), or (2) uncoated solid wood with physiological relaxing effects based on previous studies [4, 8] on palm/sole contact (hereafter referred to as "uncoated wood"). A marble is a common building material. However, its properties differ significantly from those of wood. In this study, it was used for comparison.

**Table 1** Details of the samples

| Material[1] | λ [W/(m K)][2] | *Ra* (μm)[3] | *Rz* (μm)[3] |
|---|---|---|---|
| Oil-finished wood | 0.050 | 11.22 | 63.08 |
| Uncoated wood | 0.076 | 11.58 | 63.93 |
| Marble | 3.384 | 0.14 | 3.02 |

λ: thermal conductivity; *Ra*: arithmetic average roughness; *Rz*: maximum height roughness. [1]Note- that the wood samples were used with attached cedar plywood. [2]A thermal conductivity tester (HC-10 Quick λ; EKO Instruments Co. Ltd., Tokyo, Japan) was used. The central part of the sample that was in contact with the sole of the participant's foot was measured thrice at 50 mm intervals, and the average value was calculated. [3]A contact surface roughness profilometer (Handysurf + 40; Tokyo Seimitsu Co. Ltd., Tokyo, Japan) was used. The mean evaluation length was 12.5 mm. The central portion of the samples was measured five times with 50-mm spacing, and the average value was calculated

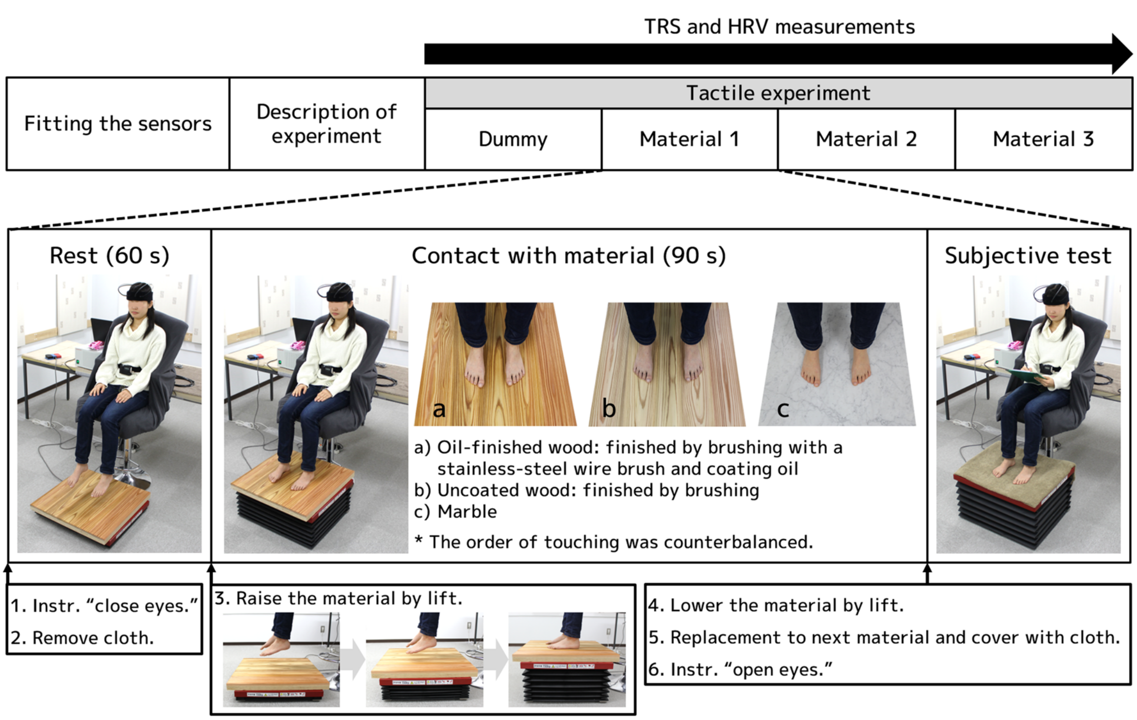


**Fig. 5** Measurement flow. *TRS* near-infrared time-resolved spectroscopy, *HRV* heart rate variability, *Instr.* instruction to the participants

The physical properties of these materials are listed in Table 1.

The within-subject experiment was conducted in a soundproof artificial climate chamber with a room temperature of 24 °C and humidity of 50%. Figure 5 depicts the measurement flow. The participants passively touched the samples with their soles for 90 s after resting for 60 s with their eyes closed. The oil-finished wood, uncoated wood, and marble used as tactile stimuli were acclimated to an environment of 24 °C and 50% humidity in the chamber the day before the experiment. Physiological indicators (Near-infrared time-resolved spectroscopy (TRS [10–12]) and heart rate variability (HRV [13–19])) were continuously measured from the start of rest to the end of stimulation. Subjective evaluations (The modified semantic differential (SD [20]) method and Profile of Mood States Second Edition (POMS 2 [21, 22])) were completed by participants after each sample exposure.

The Statistical Package for the Social Sciences software (v29.0; IBM Corp., Armonk, NY, the USA) was used in all statistical analyses. A p-value of $< 0.05$ was considered statistically significant in all cases. Holm correction was applied thrice to adjust the Familywise error rate in the comparison between stimuli [23]. Cohen's d ($d$) [24] was calculated as the effect size for the physiological indices. Probability of superiority ($PS_{dep}$) [25] was calculated as the effect size for each psychological index.

Other detailed materials and methods are available as Additional file 1.

**Abbreviations**

| | |
|---|---|
| TRS | Near-infrared time-resolved spectroscopy |
| oxy-Hb | Oxyhemoglobin |
| HRV | Heart rate variability |
| HF | High frequency |
| LF | Low frequency |
| SD | Semantic differential |
| POMS 2 | Profile of Mood State Second Edition |
| T–A | Tension–anxiety |
| D–D | Depression–dejection |
| A–H | Anger–hostility |
| F–I | Fatigue–inertia |
| C–B | Confusion–bewilderment |
| V–A | Vigor–activity |
| F | Friendliness |
| TMD | Total mood disturbance |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s10086-024-02134-4.

**Additional file 1.** Detailed materials and methods.

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**Author contributions**

HI and YM contributed to the study conceptualization. HI and YM contributed to establishing the study design. HI and HJ performed data collection. HI conducted statistical analysis and interpretation. HI wrote the first draft of the manuscript. YM substantially contributed to the interpretation of the data and made important manuscript revisions. Each author is accountable for all aspects of the work. All authors read and approved the final manuscript.

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**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## Declarations

**Ethics approval and consent to participate**

This study was conducted in accordance with the Declaration of Helsinki. It adhered to the regulations set by the Ethics Committee of the Center for Environment, Health, and Field Sciences, Chiba University, Japan (Project Identification Code Number 41). This study is registered in the University Hospital Medical Information Network of Japan (Unique ID: UMIN000038729).

**Competing interests**

The authors declare that they have no competing interests.

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## Publisher's Note