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Physiological effects of touching sugi (*Cryptomeria japonica*) with the palm of the hand

Harumi Ikei[1,2†], Chorong Song[2†] and Yoshifumi Miyazaki[2*]

Abstract

Wood is used as an interior material in Japan, and it is empirically known that contact with wood induces relaxation in humans. However, evidential data regarding these physiological effects are lacking. In this study, we examined the physiological effects of tactile stimulation based on measurements of brain and autonomic nervous activities by using the wood of sugi (*Cryptomeria japonica*). Twenty-one female university students (mean age, 22.0 ± 2.0 years) participated in the study. Oxyhemoglobin (oxy-Hb) concentrations in the prefrontal cortex were determined using near-infrared time-resolved spectroscopy. High frequency (HF), denoting parasympathetic nervous activity, and the ratio of low frequency (LF)/(LF + HF), indicating sympathetic nervous activity, were measured using heart rate variability. HF (0.15–0.40 Hz) and LF (0.04–0.15 Hz) components were calculated by the maximum entropy method. The wood material surfaces were finished by: (1) brushing with a stainless steel wire brush and (2) sanding with a belt sander. A marble plate served as a comparator. The palm of each participant's right hand touched each material for 90 s. Touching brushed or sanded sugi significantly decreased oxy-Hb concentrations in the left and right prefrontal cortices, increased ln(HF), and decreased the ln(LF/(LF + HF)) ratio compared with touching marble. Thus, our findings indicate that compared with touching marble, touching sugi with the palm induces physiological relaxation, as indicated by calmer prefrontal cortex activity, higher parasympathetic nervous activity, and lower sympathetic nervous activity.

Keywords: Japanese cedar, Tactile, Prefrontal cortex activity, Autonomic nervous activity, Near-infrared spectroscopy, Heart rate variability, Semantic differential method, Profile of mood states, Physiological relaxation, Habitability

Introduction

The interest in the relaxation effects of nature-derived stimuli in humans has increased in recent years [1] because of increased societal stress [2, 3]. Wood is a typical nature-derived material that has long been used in houses and furniture in Japan. Touching wood with the hands and feet is empirically known to induce relaxation in people. However, scientific evidence concerning the physiological relaxation effects of touching wood are limited [4].

We previously reported the physiological effects of touching wood with the palm of the hand using oxyhemoglobin (oxy-Hb) concentrations of the left and right prefrontal cortices measured via near-infrared time-resolved spectroscopy (TRS) as indicators of prefrontal cortex activity, and sympathetic and parasympathetic nervous activities that were assessed using heart rate variability (HRV) as indicators of autonomic nervous activity [5–7]. By using hinoki (Japanese cypress, *Chamaecyparis obtusa*) [5] and white oak (*Quercus alba*) [6, 7] plates as wood samples, we observed that touching uncoated wood with the palms of the hands, as compared with other materials [5, 6] or coated wood [7], reduced prefrontal cortex activity, increased parasympathetic nervous activity, and decreased the heart rate, thus indicating a state of physiological relaxation in the participants. In

*Correspondence: ymiyazaki@faculty.chiba-u.jp
†Harumi Ikei and Chorong Song are the co-first authors who contributed equally to this work
[2] Center for Environment, Health and Field Sciences, Chiba University, 6-2-1 Kashiwa-no-ha, Kashiwa, Chiba 277-0882, Japan
Full list of author information is available at the end of the article

addition, we have also demonstrated the physiological effects of touching hinoki with the soles of the feet [8].

Sugi (Japanese cedar, *Cryptomeria japonica*) is a coniferous tree in Japan that has been widely used as a furniture and building material. As sugi is commonly encountered in daily life in Japan, interest has grown in its possible physiological effects. Sakuragawa et al. [9] examined the influence of sugi on blood pressure. However, no report has clarified the physiological effects of touching sugi with the palms on brain and autonomic nervous activities.

Therefore, this study aimed to clarify the physiological effects of touching sugi (*C. japonica*) with the palm of the hand by assessing prefrontal cortex activity with TRS and evaluating changes in HRV and heart rate.

Materials and methods

The experiment was conducted in a chamber with an artificial climate maintained at 24 °C and 50% relative humidity. In total, 21 Japanese female university students (mean age, 22.0 ± 2.0 years) participated. During the study period, we excluded smokers, people currently receiving treatment for diseases, and menstruating women. This study was conducted in compliance with the Ethical Guidelines for Medical and Health Research Involving Human Subjects of Japan under the Declaration of Helsinki. The protocol was approved by the Ethics Committee of the Center for Environment, Health and Field Sciences, Chiba University, Japan (Project Identification Code Number: 32), and was registered in the University Hospital Medical Information Network of Japan (Unique ID issued by UMIN: UMIN000029089). All participants gave written informed consent in accordance with the Declaration of Helsinki.

Sugi grown in Chiba Prefecture, Japan, was used. Four laminae without vertical joints (300 × 75 × 15 mm) were bonded together along their widths. To prevent bending, a second bonding was made using plywood (300 × 300 × 28 mm). The total thickness of the resulting product was 43 mm. The surface was uncoated and finished via: (1) brushing using a stainless steel wire brush (hereafter referred to as "brushed sugi"); or (2) sanding using an abrasive-band machine (hereafter referred to as "sanded sugi"). In our previous studies [5–7], we showed that physiological relaxation effects could be acquired by contact between the palm of the right hand and hinoki or white oak wood with an uneven surface due to a brushed finish compared with contact with building materials such as stainless steel, tiles, or wood with a thick coating. However, the wood typically used for desks, furniture, and floors is usually sanded to a smooth finish. In this study, therefore, we used sugi, which is a typical softwood in Japan, with two types of finish: the brushed finish used in previous studies that confirmed the induction of physiological relaxation effects and a more typical sanded finish that has not yet been studied for its physiological effects. Marble (300 × 300 × 15 mm) was used as a comparator material because it is a building material that has properties substantially different from wood. The marble was bonded to plywood of the same size as that bonded to sugi. All materials were maintained at room temperature. The thermal conductivity and arithmetic average roughness results of the various sample types were as follows: brushed sugi, 0.121 W/(mK) and 101.56 µm, respectively; sanded sugi 0.102 W/(mK) and 6.03 µm, respectively; and marble 0.151 W/(mK) and 0.66 µm, respectively. The conditions for the physical measurement followed those as previously described [5]. Figure 1 presents the procedure of the entire experiment. The materials were presented in a counterbalanced order to eliminate any effects due to the order.

TRS was employed to assess prefrontal cortex activity. Changes of the oxy-Hb concentrations in the left and right prefrontal cortices as measured using TRS (TRS-20, Hamamatsu Photonics K.K., Shizuoka, Japan) reflect prefrontal activity [10–12]. In addition, post-measurement values were calculated in reference to pre-measurement values.

HRV was employed to assess autonomic nervous activity. R–R intervals were measured using a portable electrocardiograph (Activtracer AC-301A, GMS, Tokyo, Japan) [13, 14]. The power levels of the high-frequency (HF, 0.15–0.40 Hz) and low-frequency (LF, 0.04–0.15 Hz) components of HRV were calculated using the maximum entropy method (MemCalc/Win, GMS, Tokyo, Japan) [15, 16]. The HF component reflects parasympathetic nervous activity, and the LF/(LF + HF) ratio reflects sympathetic nervous activity [17]. To normalize HRV parameters across participants, natural logarithmic-transformed values were used in the analysis [18]. The HRV power spectra were also used to estimate the participant's respiratory frequency [19]. Respiratory changes influence HRV data, with heart rate generally increasing during inspiration and decreasing during expiration [20, 21]; thus, the respiratory rate can be estimated from the dominant frequency of the HF component, found by detecting the maximal power of the HF component. Participants with at least one case where the respiratory frequency could not be estimated because the power spectrum did not show a clear peak in the HF band (0.15–0.40 Hz) were excluded from HRV analysis. As a result, 3 participants were excluded from analysis and mean respiratory frequency of the remaining 18 participants was not significantly different between the conditions.

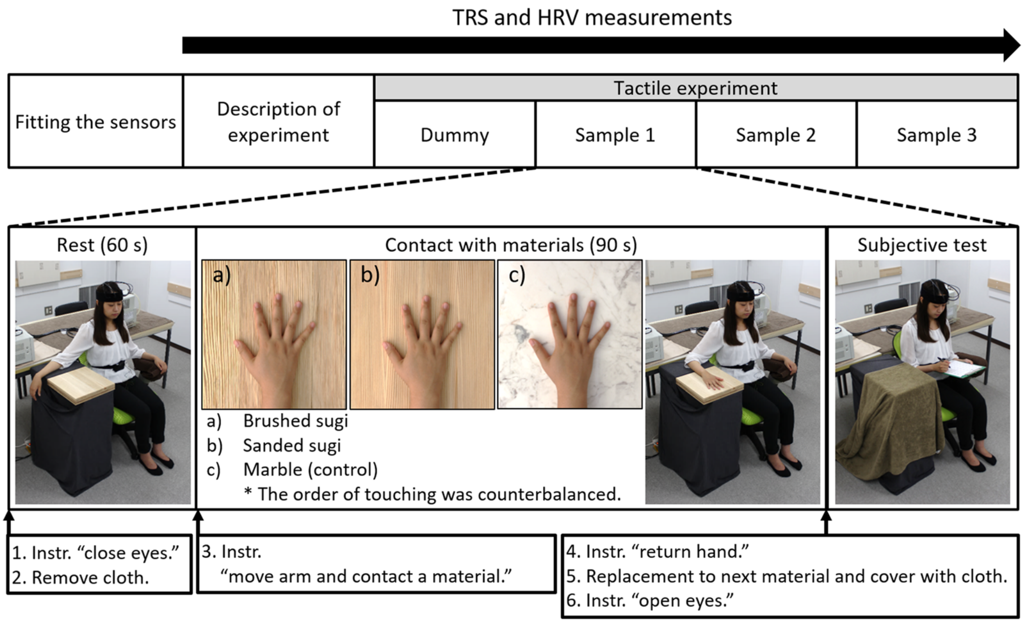

Fig. 1 Experimental procedure. *TRS* near-infrared time-resolved spectroscopy, *HRV* heart rate variability, *Instr.* instruction to the participants

The modified semantic differential (SD) method [22] and the short version of the Profile of Mood States Second Edition (POMS 2) [23–25] were used to evaluate the psychological effects of touching the materials. In modified SD methods, seven pairs of adjectives were assessed: "comfortable–uncomfortable"; "relaxed–awakening"; "natural–artificial"; "warm–cold"; "uneven–flat"; "dry–moist"; and "soft–hard".

Statistical Package for Social Sciences software (v21.0, IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Paired t tests with Holm correction [26] were used to compare physiological responses, and Wilcoxon signed-rank tests with Holm correction were applied to analyze the differences in psychological indices. In all analyses, $p < 0.05$ indicated statistical significance. One-sided tests were used for both comparisons because our hypothesis was that humans would be more relaxed after touching the wood than after touching the other material (marble).

Results

The average changes in oxy-Hb concentrations (calculated as the measurement after the stimulus minus the measurement before the stimulus) in the left and right prefrontal cortices are shown in Fig. 2a, b, respectively. The oxy-Hb concentrations in the left prefrontal cortex were -0.05 ± 0.11, -0.02 ± 0.11, and 0.27 ± 0.09 μM during contact with brushed sugi, sanded sugi, and marble, respectively, with significant differences noted between both sugi types and marble [brushed sugi vs. marble: $t(20) = -2.371$, $p = 0.005$; sanded sugi vs. marble: $t(20) = -2.114$, $p = 0.012$; Fig. 2a]. Similarly, the oxy-Hb concentrations in the right prefrontal cortex were -0.00 ± 0.10, 0.04 ± 0.09, and 0.25 ± 0.07 μM for contact with brushed sugi, sanded sugi, and marble, respectively, with contact with both sugi types linked to significantly lower concentrations vs. marble [brushed sugi vs. marble: $t(20) = -2.225$, $p = 0.012$; sanded sugi vs. marble: $t(20) = -1.902$, $p = 0.027$; Fig. 2b].

The average ln(HF) and ln(LF/(LF + HF)) during contact with the examined materials are shown in Fig. 3a, b, respectively. The ln(HF) values were 6.17 ± 0.14 lnms^2 during contact with brushed sugi and 6.19 ± 0.16 lnms^2 during contact with sanded sugi, both of which were significantly higher than the value during contact with marble (6.01 ± 0.14 lnms^2, brushed sugi vs. marble: $t(17) = 2.257$, $p = 0.019$; sanded sugi vs. marble: $t(17) = 1.839$, $p = 0.042$; Fig. 3a). The ln(LF/(LF + HF)) ratio value were -1.30 ± 0.12 for contact with brushed sugi and -1.27 ± 0.08 for contact with sanded sugi, both of which were significantly decreased as compared with -1.01 ± 0.09 for contact with marble [brushed sugi vs. marble: $t(17) = -2.198$, $p = 0.021$; sanded sugi vs. marble: $t(17) = -2.293$, $p = 0.017$; Fig. 3b].

In modified SD methods, touching sanded sugi was associated with significantly more comfort than touching brushed sugi and marble (sanded sugi vs. marble: $p = 0.002$; Fig. 4a). Meanwhile, both brushed and sanded sugi were linked to significantly more relaxation than marble (brushed sugi vs. marble: $p < 0.001$; sanded sugi

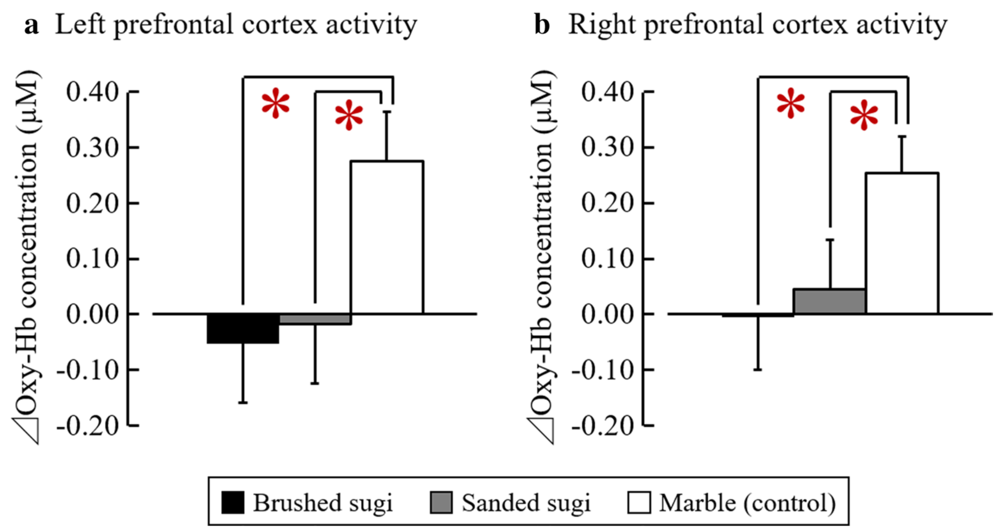

Fig. 2 Response of brain activity indices during contact of materials via the palm of the right hand. **a** Overall mean oxy-hemoglobin (oxy-Hb) concentration in the left prefrontal cortex. **b** Overall mean oxy-Hb concentration in the right prefrontal cortex. $N = 21$, mean ± standard error, $^{*}p < 0.05$ as determined using a paired t test (one-side) with Holm correction

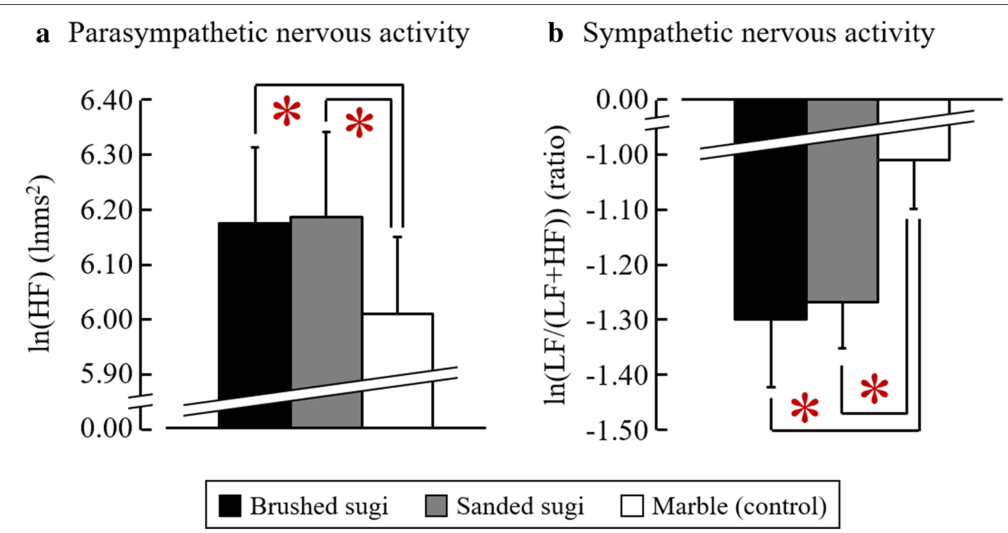

Fig. 3 Response of autonomic nervous activity indices during contact of materials via the palm of the right hand. **a** Overall mean of the natural logarithm of the HF component of HRV. **b** Overall mean of the natural logarithm of the LF/(LF + HF) of HRV. $N = 18$, mean ± standard error, $^{*}p < 0.05$ as determined using a paired t test (one-side) with Holm correction

vs. marble: $p < 0.001$; Fig. 4b). Brushed and sanded sugi were perceived to have a significantly more natural feel than marble (brushed sugi vs. marble: $p < 0.001$; sanded sugi vs. marble: $p < 0.001$; Fig. 4c). Both types of sugi were perceived as being significantly warmer than marble (brushed sugi vs. marble: $p < 0.001$; sanded sugi vs. marble: $p < 0.001$; Fig. 4d). According to the data, brushed and sanded sugi had a significantly more uneven feel than marble (brushed sugi vs. marble: $p < 0.001$; sanded sugi vs. marble: $p < 0.001$; Fig. 4e). Both types of sugi were considered significantly softer in feel than marble (brushed sugi vs. marble: $p < 0.001$; sanded sugi vs. marble: $p < 0.001$; Fig. 4g).

The POMS 2 score for the negative subscale “tension–anxiety” was significantly lower after touching brushed or sanded sugi than it was after touching marble (brushed sugi vs. marble: $p = 0.002$; sanded sugi vs. marble: $p = 0.001$; Fig. 5). The “Total Mood Disturbance” was

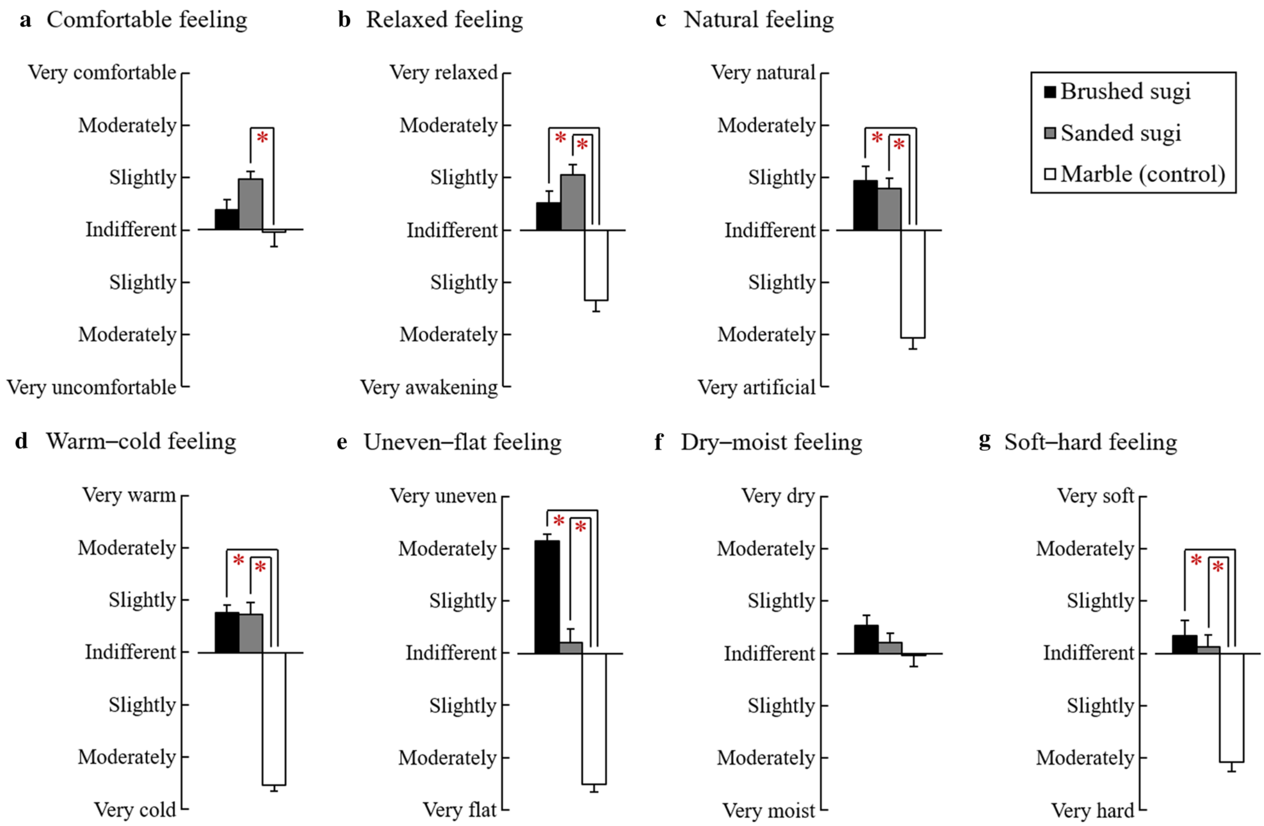

Fig. 4 Subjective evaluation using the modified semantic differential method after contact of materials via the palm of the right hand. **a** Comfortable feeling, **b** relaxed feeling, **c** natural feeling, **d** warm–cold feeling, **e** uneven–flat feeling, **f** dry–moist feeling, and **g** soft–hard feeling. $N=21$, mean ± standard error, *$p<0.05$ as determined by using the Wilcoxon signed-rank test (one-side) with Holm correction

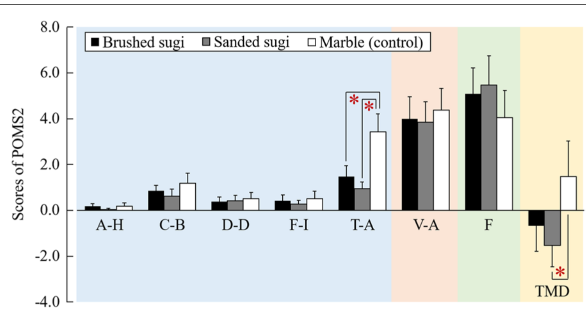

Fig. 5 Subjective feelings using the Profile of Mood States Second Edition after contact of materials via the palm of the right hand. $N=21$, mean ± standard error, *$p<0.05$ as determined by using the Wilcoxon signed-rank test (one-side) with Holm correction. *A–H* anger–hostility, *C–B* confusion–bewilderment, *D–D* depression–dejection, *F–I* fatigue–inertia, *T–A* tension–anxiety, *V–A* vigor–activity, *F* friendless, *TMD* Total Mood Disturbance

significantly lower after touching sanded sugi than it was after touching marble (sanded sugi vs. marble: $p=0.018$; Fig. 5). For the other subscales, no significant differences were observed.

Discussion

The results illustrated that relative to contact with marble, contact with brushed and sanded sugi was linked to significantly decreased prefrontal cortex activity, increased parasympathetic nervous activity, and decreased sympathetic nervous activity. In addition, the psychological responses to contact with marble and contact with brushed and sanded sugi were consistent with the physiological responses.

Previous studies on the effects on the prefrontal cortex and HRV of touching wood with the palm made use of hinoki (*C. obtusa*) [5] and white oak (*Q. alba*) [6]. In both reports, the wood sample was uncoated and brushed, and comparisons were made with marble. The results indicated that tactile stimulation with hinoki and white oak significantly decreased the oxy-Hb concentration in the left prefrontal cortex and increased ln(HF) relative to the effects of marble [5, 6]. As compared with the findings for marble, the average differential (post-measurement minus pre-measurement) of the oxy-Hb concentration in the left prefrontal cortex during contact with hinoki and white oak was reduced by 0.21 and 0.19 μM, respectively. Meanwhile, brushed and sanded sugi were found to have markedly stronger effects (brushed sugi: 0.32 μM, sanded sugi: 0.29 μM) than those comparative effects observed in previous studies. George et al. [27] reported that experiencing happy emotions results in a significant decrease in the right prefrontal cortex activity. Similarly, Hoshi et al. [28] demonstrated in a screen image study that pleasant feelings result in decreased oxy-Hb levels in the prefrontal cortex. The present study showed that compared to contact with marble, contact with sugi resulted in significantly lower oxy-Hb concentrations in the left and right prefrontal cortices, higher parasympathetic nervous activity, and lower sympathetic nervous activity. Collectively, these findings indicate that tactile stimulation of the palm of the right hand with sugi wood induces physiological relaxation effects.

However, the study had certain limitations, and future studies that address these limitations are needed. First, we examined the effect of touching sugi with the palm of the hand. Future research should examine the effect of sugi on physiological responses when contacted by the sole of the foot, as sugi is often used as a flooring material. Second, the physiological effects of wood were only examined via contact using the palm. It will be necessary to clarify the impact on these physiological responses of more active forms of contact. Third, the physiological relaxation effects resulting from tactile stimulation by sugi wood were assessed by comparison with marble as a control and not by a direct comparison of the physiological states before and after touching the sugi materials. Such comparisons are needed in future studies to allow a comprehensive analysis of the physiological response to contact with sugi wood. Fourth, marble was used for the comparison in this study. In future studies, a material more similar to wood, such as a sheet flooring material, could be used as a comparator. Final, although this study used uncoated sugi, it will be necessary to determine the effect on physiological responses of touching sugi with various coatings, because much of the wood used in everyday life is coated.

Conclusions

In conclusion, these findings indicate that compared with touching marble, tactile stimulation induced by touching sugi-based materials resulted in calmer prefrontal cortex activity, higher parasympathetic nervous activity, and lower sympathetic nervous activity, and it could be concluded that touching sugi-based materials induced physiological relaxation.

Abbreviations

HF: high frequency; LF: low frequency; oxy-Hb: oxyhemoglobin; TRS: near-infrared time-resolved spectroscopy; HRV: heart rate variability; SD: semantic differential; POMS 2: Profile of Mood States Second Edition.

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Authors' contributions

YM contributed to the study conceptualization. HI, CS, and YM contributed to study design. HI and CS performed data collection. HI performed statistical analysis and interpretation under the supervision of YM. HI wrote the first draft of the manuscript. YM substantially contributed to the interpretation of the data and provided important manuscript revisions. Each author also agreed to be 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 on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Author details

[1] Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan. [2] Center for Environment, Health and Field Sciences, Chiba University, 6-2-1 Kashiwa-no-ha, Kashiwa, Chiba 277-0882, Japan.

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