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Positive physiological effects of touching sugi (*Cryptomeria japonica*) with the sole of the feet

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Abstract

In Japanese households, it is customary to walk barefoot on wood floors. This study sought to clarify the physiological effects produced via tactile application of sugi (*Cryptomeria japonica*) to the sole of the feet, using the brain and autonomic nervous activities as indicators. Twenty-seven female university students (mean age, 21.9 ± 1.9 years) participated in this study. Oxy-hemoglobin (oxy-Hb) concentrations in the prefrontal cortex were determined using near-infrared time-resolved spectroscopy. High frequency (HF), denoted parasympathetic nervous activity, and low frequency (LF)/HF indicated sympathetic nervous activity; both were measured using heart rate variability. The wooden material was unpainted sugi wood with two different finishes uzukuri brushing or sanding. A similarly sized marble plate served as a control. The sole of the feet of each participant touched each material for 90 s. The results found that the uzukuri wood significantly decreased oxy-Hb concentration in the left prefrontal cortex compared with touching the marble. Furthermore, compared to before contact, the uzukuri wood showed significantly decreased oxy-Hb concentrations in the right prefrontal cortex, increased *ln*(HF), and decreased the *ln*(LF/HF) ratio. Moreover, the contact with sanded wood significantly decreased oxy-Hb concentrations in the right prefrontal cortex compared with before contact. Thus, it is concluded that tactile application of sugi to the sole of the feet induced physiological relaxation.

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

Modern society today is stressful [1, 2]; thus, there is a growing interest in the relaxation effects of nature-derived stimuli [3, 4]. Wood is a typical nature-derived material that has long been used in houses and furniture in Japan. In recent years, attention has been focused on the effects of wood on human physiological responses, and scientific data have been accumulated primarily by Japanese research teams [5]. In 1992 Miyazaki et al. [6] first reported that Taiwan cypress oil lowered systolic blood pressure. Subsequent to this study, there have been multiple reports regarding olfactory stimulation [7–10]. Conversely, very few reports regarding tactile stimuli were investigated. In response to this, recent research has begun to focus on the effects of tactile stimulation from wood by using the prefrontal cortex and autonomic nerve activity as indexes [11–14]. The physiological effects of palm contact with wood have been investigated for sugi (Japanese cedar, *Cryptomeria japonica*) [11], hinoki (Japanese cypress, *Chamaecyparis obtusa*) [12], and white oak (*Quercus alba*) [13, 14]. Touching with the palm of the hand in the sitting position for 90 s reduced prefrontal cortex activity, increased parasympathetic nervous activity, and decreased the heart rate compared to other types of building materials [11–13] and coated wooden

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materials [14]; thus indicating a state of physiological relaxation for the participants.

Wood is often used as a flooring material. It is necessary to clarify the influence of foot contact with wood, because it is customary to walk barefoot indoors in Japan. In addition, the "uzukuri finish (brushing finish)" is one of the traditional surface finishing methods in Japan. "Uzukuri finish" is a finishing method for coniferous materials such as sugi or hinoki. This finishing method involves scraping off the soft earlywood part with a brush and leaving an embossed hard latewood part exposed [15]. This processing makes the wood-grain standout and emphasizes the feel specific to this wood. We investigated the effects of sole of the feet contact with the uzukuri finished hinoki wood on brain activity and autonomic nervous activity in the previous study [16]. As a result, contact with uzukuri finish hinoki for 90 s decreased the prefrontal cortex activity, increased parasympathetic nervous activity, and decreased sympathetic nervous activity compared to the marble, control, which is a common building material.

Sugi is the most representative wood in Japan, and there is a growing interest in the relaxing effect of this wood. According to the Ministry of Agriculture, Forestry, and Fisheries "Wood Supply and Demand Report [17], sugi wood accounts for approximately 60% (11,848,000 m^3) of the total of 20,660,000 m^3 wood used in 2016. In a previous study on sugi, Sakuragawa et al. [18] examined the effect on blood pressure. As a result, 13 male college students who made palm contact with the sugi showed a decrease in blood pressure except for a temporary change immediately following contact. However, no study has evaluated yet the physiological effects of touching uzukuri finish sugi wood with the sole of the feet.

This study aimed to clarify the physiological effects of tactile stimulation with sugi to the sole of the feet. To evaluate physiological responses, we measured prefrontal cortex activity in terms of oxy-hemoglobin (oxy-Hb) concentrations in the left and right prefrontal cortices using near-infrared time-resolved spectroscopy (TRS), and sympathetic and parasympathetic nervous activities assessed in terms of heart rate variability (HRV) and the heart rate.

Materials and methods

Participants

Considering that we want to continue the previous studies [11–14, 16], a total of 27 female Japanese university students (mean age: 21.9 ± 1.9 years) were included in the current study. None of the participants reported any physiological or psychiatric disorders in their personal histories, and all were non-smokers. Further, none of the participants were menstruating on the day of the experiment. All participants provided written informed consent to participate after being informed about the study's aims and procedures. This study was conducted in accordance with the Declaration of Helsinki and 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 34). This study is registered in the University Hospital Medical Information Network of Japan (Unique ID issued by UMIN: UMIN000032808).
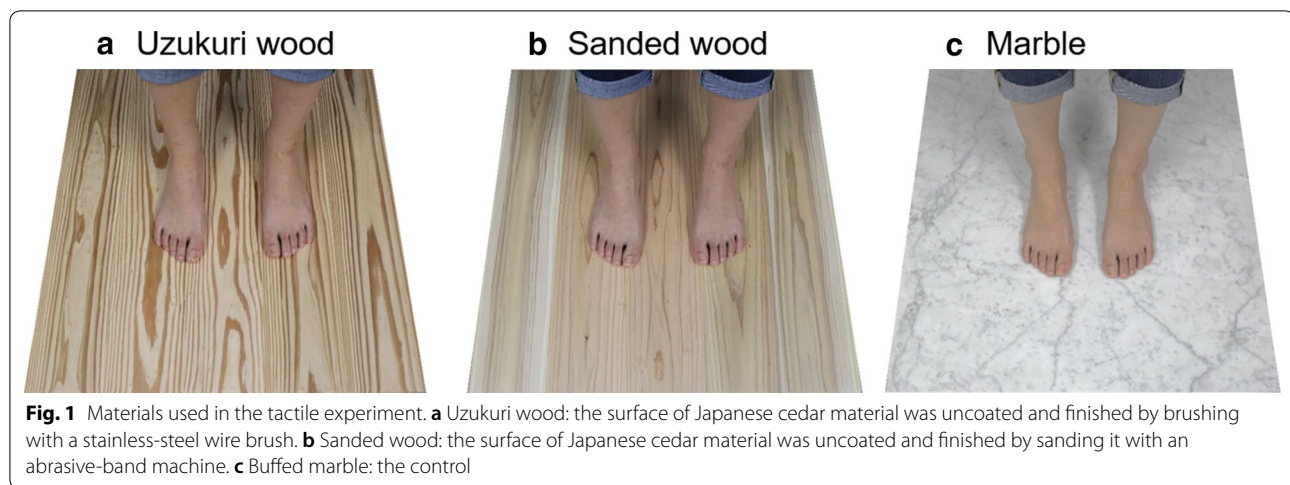
Tactile stimulation

Sugi (Japanese cedar, *Cryptomeria japonica*) wood grown in the Miyazaki Prefecture, Japan, was used as the base material for this experiment. Five wooden laminae without vertical joints (600 × 120 × 20 mm) were bonded together along their width using a water-based polymer isocyanate adhesive. A second bonding was made using sugi plywood (600 × 600 × 24 mm) to prevent bending; the total thickness of the resultant finished product was 44 mm. The surface was uncoated and finished via either (1) brushing using a stainless-steel wire brush (hereafter referred to as "uzukuri wood" Fig. 1a), or (2) sanding using an abrasive-band machine (hereafter referred to as "sanded wood" Fig. 1b). A marble slab (600 × 600 × 20 mm) was used as the control material, because its properties are substantially different from those of wood. Moreover, marble was used as a comparative sample in previous studies [11–13, 16]. In this study, it was placed on a piece of cedar plywood of the same size as that of the plywood bonded to sugi. The surface was processed by buffing (Fig. 1c). This buffed marble sample is hereafter referred to as "marble". All materials were stored at room temperature. The physical properties of the materials are listed in Table 1.

Study protocol

Physiological effects were measured in a chamber with an artificial climate which has a soundproof function maintained at 24 °C, 50% relative humidity, and 230-lux illumination.

Figure 2 depicts the experimental setup, whereas Fig. 3 depicts the experimental protocol. Sensors for the physiological measurements were attached to each participant's forehead and chest. After receiving information about the overall measurement flow, the participants initially trialed the test procedure by placing their feet on a practice material (plastic board) utilizing the same procedure to be followed for the actual measurements. The participants rested with their eyes closed for 60 s (Fig. 2a). By raising the sample using a scissor lift (Fig. 2b), the participants passively touched the samples

Fig. 1 Materials used in the tactile experiment. **a** Uzukuri wood: the surface of Japanese cedar material was uncoated and finished by brushing with a stainless-steel wire brush. **b** Sanded wood: the surface of Japanese cedar material was uncoated and finished by sanding it with an abrasive-band machine. **c** Buffed marble: the control

Table 1 Details of the samples

Material[a]	h (mm)	λ [W/(m K)][b]	Ra (μm)[c]	Rz (μm)[c]
Uzukuri wood	20 (+SP 24)	0.106	52.38	234.91
Sanded wood	20 (+SP 24)	0.120	3.65	35.46
Marble	20 (+SP 24)	1.947	0.16	3.22

The evaluation length was 50 mm. The cut-off value was 8 mm. The central portion of the samples was measured five times with 50-mm spacing, and the average value was calculated
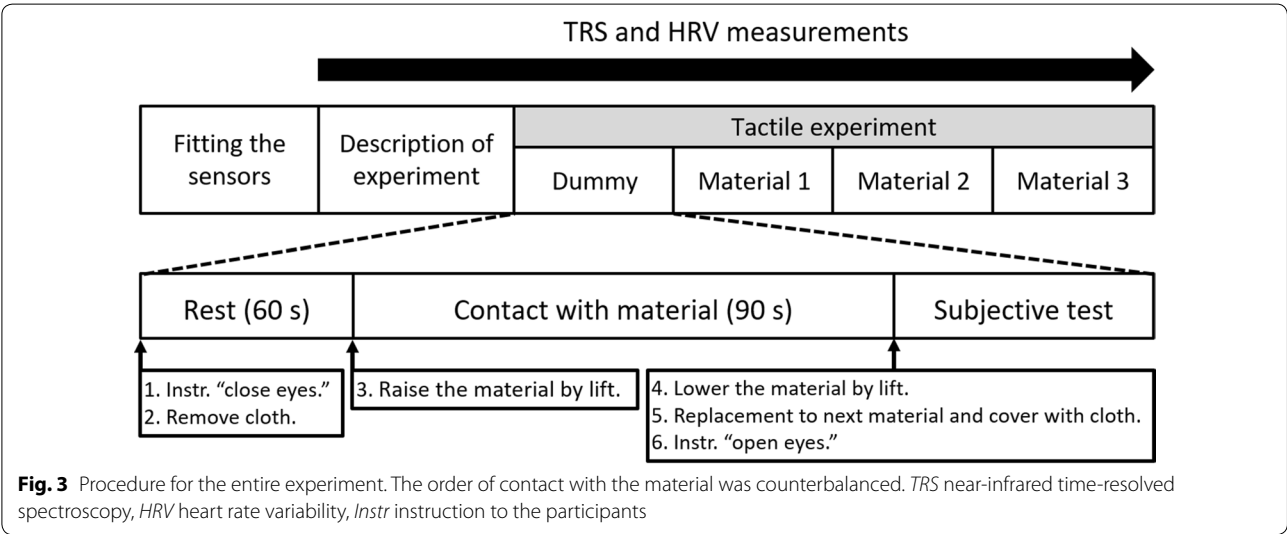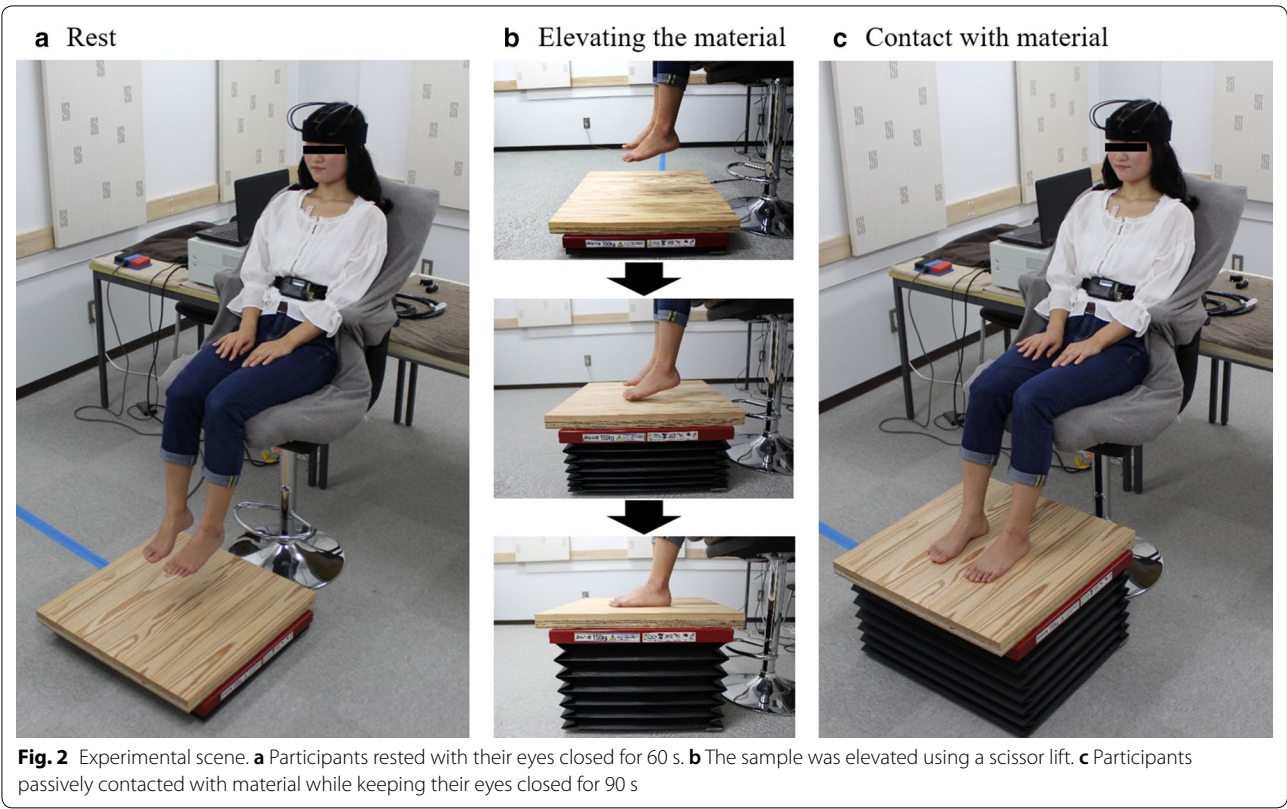
h Thickness of the material, *λ* thermal conductivity, *Ra* arithmetic average roughness, *Rz* maximum height roughness, *SP* structural plywood

[a] The samples were cut out from the center part of the material to a size of 300 × 300 mm, and their physical properties were assessed. Note that the wood samples were used with the cedar plywood attached. [b] A heat flow meter (HFM 436 Lambda; NETZSCH, Selb, Germany), tuned according to ASTM C518-10 [19] and ISO8310 [20], was used. The direction of heat flow was vertically downward. The temperatures of the high- and low-temperature heat plates were 35 ℃ and 15 ℃, respectively. The thermal conductivity at an average material temperature of 25 ℃ was calculated. [c] To determine the roughness of the material, a contact surface roughness profilometer (SE3500; Kosaka Laboratory Ltd., Tokyo, Japan) with a diamond stylus was used

with their sole of the feet while keeping their eyes closed for 90 s (Fig. 2c). The contact was ended by lowering the sample with the scissor lift (Fig. 2a). The researcher then set up another sample for the next measurement, covered the sample with a cloth so that the subjects could not see the sample, and then told the participants to open their eyes. Next, the subjective evaluation tests of the participants were performed. Stimulation with the subsequent materials was performed after a rest period of approximately 5–7 min. The materials were presented in a counterbalance to eliminate any order effects, such as adaptation and fatigue, caused by the sequence of tactile stimulation.

Near-infrared time-resolved spectroscopy (TRS)

Near-infrared time-resolved spectroscopy (TRS), which is one of the methods of near-infrared spectroscopy (NIRS), was used as an index for the prefrontal cortex activity. The prefrontal cortex is a part of the brain that is responsible for higher-order judgments, such as problem-solving and decision-making. It has been reported that NIRS signals were highly correlated with functional magnetic resonance imaging measurements by a previous study using simultaneous NIRS (placing NIRS probes over the frontal brain region including the prefrontal region) and functional magnetic resonance imaging during a battery of cognitive tasks [21]. Thus, NIRS enables the detection of brain activity in the prefrontal cortex region. Sensors were mounted on the participant's forehead, and the oxy-Hb concentrations in the prefrontal cortex were measured using the TRS-20 system (Hamamatsu Photonics K.K., Shizuoka, Japan). Changes in blood flow (rCBF) associated with the local nerve activity in the brain were correlated with changes in the oxy-Hb and total Hb concentrations in the near-infrared spectroscopy measurements [22–24]. Changes to the oxy-Hb concentration measured by TRS reflected the prefrontal activity via a sensor attached to the forehead [25–27]. It has been reported that oxy-Hb concentrations in the prefrontal cortex are reduced by pleasant emotions and increased by unpleasant emotions [28]. The oxy-Hb concentrations in the left and right prefrontal cortices were measured for 30 s before (pre-measurement) and during the 90-s duration in which the participants' sole of the feet touched the materials (post-measurement). All data were transformed by linear interpolation to every 1 s because their sampling intervals were approximately 1.07–1.19 s. In addition, post-measurement values (at every second) were calculated as the differences between the

Fig. 2 Experimental scene. **a** Participants rested with their eyes closed for 60 s. **b** The sample was elevated using a scissor lift. **c** Participants passively contacted with material while keeping their eyes closed for 90 s

Fig. 3 Procedure for the entire experiment. The order of contact with the material was counterbalanced. *TRS* near-infrared time-resolved spectroscopy, *HRV* heart rate variability, *Instr* instruction to the participants

pre-measurement values (mean 30 s). In addition, the total hemoglobin (total Hb) and deoxygenated hemoglobin (deoxy-Hb) concentrations were measured and calculated as described for the oxy-Hb concentration.

Heart rate variability (HRV) and heart rate

HRV and heart rate were employed as indicators of autonomic nervous activity. HRV was analyzed for the periods between consecutive R waves (R–R intervals, RRI), as measured by a portable electrocardiograph (Activtracer AC-301A; GMS, Tokyo, Japan) [29, 30]. This device uses a 3-lead electrocardiogram (Lead II) to

perform necessary measurements. High frequency (HF; 0.15–0.40 Hz) and low frequency (LF; 0.04–0.15 Hz) power level components of HRV were calculated using the maximum entropy method (MemCalc/Win; GMS, Tokyo, Japan) [31, 32]. The HF power indicated parasympathetic nervous activity, whereas the LF/HF power ratio indicated sympathetic nervous activity [29, 33]. The natural logarithmic values for HF, *ln*(HF) power and the LE/HF, *ln*(LF/HF) power ratios were employed to normalize the HRV parameters across participants [34]. The mean HRV and heart rate were calculated for 90 s during which the participants' soles were in contact with each material. Average values for the pre- and post-measurement values for *ln*(HF) and *ln*(LF/HF) were calculated.

The HRV power spectra were also used to estimate the participant's respiratory frequency [35]. Respiratory changes influenced the HRV data, with heart rate generally increasing during inspiration and decreasing during expiration [36, 37]; thus, the respiratory rate could be estimated from the dominant frequency of the HF component, found by detecting the maximal power of the HF component. To detect the peak frequency of the HF component, the model order for the spectral analysis was chosen from 8 to 11; however, the ninth order was used in principle. Since respiratory changes affect HRV data, respiratory frequencies were statistically compared between the mean values over the 90-s contact period for each material and pre- and post-measurement by paired t-tests.

Psychological measurements

The modified semantic differential (SD) method [38] and the short version of the Profile of Mood States Second Edition (POMS2) [39–42] were used to evaluate the psychological effects produced by the tactile stimulation from the materials. In the modified SD methods, seven pairs of adjectives from 13 scales of adjectives were assessed "comfortable–uncomfortable"; "relaxed–awakening"; "natural–artificial"; "warm–cold"; "uneven–flat"; "dry–moist"; and "soft–hard". POMS2 questionnaire was used to evaluate the mood states from the scores for Tension–Anxiety (T-A), Depression–Dejection (D-D), Anger–Hostility (A-H), Fatigue–Inertia (F-I), Confusion–Bewilderment (C-B), Vigor–Activity (VA), and Friendliness (F). The total mood disturbance (TMD) score was calculated using this formula: [(T-A)+(D-D)+(A-H)+(F-I)+(C-B)−(V-A)]. The TMD score reflects the general mood state, whereby a higher score denotes negative feelings of the participant and vice versa. The POMS2 is a well-established means sure of psychological distress derived from factor analysis that has been shown to possess high levels of reliability and

validity. In order to reduce the burden on the participants, a shortened Japanese version of POMS2 with 35 questions was used for this study.

Statistical analysis

The Statistical Package for the Social Sciences software (v21.0; IBM Corp., Armonk, NY, USA) was used for all of the statistical analyses. In all cases, $p < 0.05$ was considered statistically significant.

Paired t-tests were applied to analyze (1) differences in the physiological indices between the three materials (uzukuri wood vs. marble, sanded wood vs. marble, uzukuri wood vs. sanded wood) and (2) comparison before and after contact (pre- vs. post-measurement) for each material. Wilcoxon signed-rank tests were applied to analyze differences in the psychological indices between the three materials.

Holm correction was applied thrice to adjust the family-wise error rate in the comparison between stimuli [43]. The test statistics were calculated for all comparisons, and *P*-values were obtained. Hypotheses were arranged in descending order based upon *P*-values. Since the total number of tests was three, the minimum *P* value was compared with the significance level $\alpha = 0.05/3$. If the result of the aforementioned test was significant, then the second smallest *P*-value was compared with $\alpha = 0.05/2$. In the same manner, proceeding in descending order based on the *P*-values, reduced the denominator by one, for each test. If a non-significant comparison is found, then the test is terminated at that point. For subsequent hypotheses, even if there was a *P*-value lower than the significance level at that step, we will hold all of the conclusions, and conclude that there was no difference found.

Results
Physiological effects
TRS

Figure 4 shows the time-dependent changes in the oxy-Hb concentration per second in the right and left prefrontal cortex during contact with the uzukuri wood, sanded wood, and marble materials. The oxy-Hb concentrations in the left prefrontal cortex showed a transient decrease immediately following contact with all three of the materials. The oxy-Hb concentrations during contact with the uzukuri wood were lower than the concentrations before tactile stimulation and generally took 81 s to return to this state (Fig. 4a, line of brown). The oxy-Hb concentrations during contact with the sanded wood returned to the pre-measurement value at 5 s, but decreased again at 18 s. Following this, it returned to the pre-measurement value at 52 s and then continued to rise
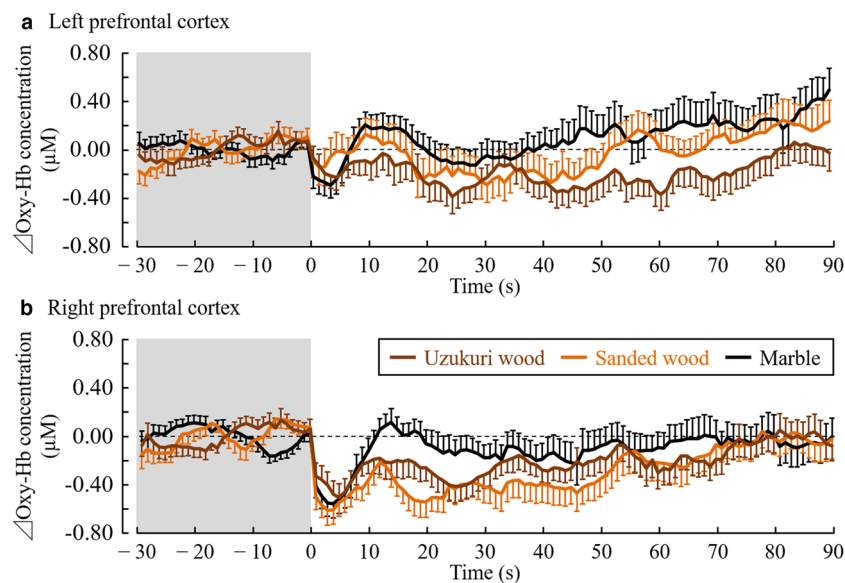
Fig. 4 Changes in the left and right prefrontal cortex activities during sole of the feet contact with the materials for every second over a 90-s period. **a** Oxy-Hb concentrations in the left prefrontal cortex. **b** Oxy-Hb concentrations in the right prefrontal cortex. $n = 27$, mean $\pm$ standard error (SE)

(Fig. 4a, line of orange). The oxy-Hb concentrations during contact with the marble returned to the pre-measurement value at 7 s, but decreased again at 22 s. Then, it returned to the pre-measurement value at 37 s and then continued to rise (Fig. 4a, line of black). The oxy-Hb concentrations in the right prefrontal cortex showed a transient decrease immediately after contact for all three materials. A similar trend occurs in the left prefrontal cortex (Fig. 4b). The oxy-Hb concentrations during contact with the uzukuri and the sanded wood materials both produced a lower value than that prior to contact measurement and then returned to the pre-measurement value at 78 s and 77 s, respectively (Fig. 4b, line of brown and orange). The oxy-Hb concentrations during contact with the marble returned to the pre-measurement value at 11 s, but decreased again at 20 s. Then, it returned to the pre-measurement value at 52 s and continued at similar values to before the contact (Fig. 4b, line of black).

The overall mean for the oxy-Hb concentrations (calculated as the measurement after the stimulus minus the measurement before the stimulus) in the left and right prefrontal cortices during contact with the sole of the feet for each subject at 90 s are shown in Fig. 5a, b, respectively. The oxy-Hb concentrations in the left prefrontal cortex were -0.19 ± 0.10, -0.03 ± 0.11, and 0.09 ± 0.12 μM during contact with uzukuri wood, sanded wood, and marble, respectively. The oxy-Hb concentrations were significantly lower while touching uzukuri wood compared with the control (Fig. 5a,

$p < 0.05$). However, no significant difference was observed in the comparison before and after contact with each of the three materials. Incidentally, the mean baseline oxy-Hb concentrations during the 30 s before contact did not significantly differ between each of the three materials (43.64 ± 0.90 μM for uzukuri wood, 44.48 ± 0.91 μM for the sanded wood, 44.65 ± 0.98 μM for marble; $p > 0.05$). The oxy-Hb concentrations in the right prefrontal cortex were -0.21 ± 0.09, -0.29 ± 0.09, and -0.11 ± 0.10 μM during contact with the uzukuri wood, sanded wood, and marble, respectively. The oxy-Hb concentrations were significantly lower while in contact with the uzukuri and sanded material compared with prior to contact (Fig. 5b, $p < 0.05$). However, no significant difference was observed in the comparison before and after contact with marble. There were no significant differences found for oxy-Hb between the three materials. Incidentally, the mean baseline oxy-Hb concentrations during the 30 s prior to contact did not significantly differ between each of the three materials (43.26 ± 1.03 μM for uzukuri wood, 43.05 ± 1.07 μM for sanded wood, 42.91 ± 1.10 μM for marble; $p > 0.05$).

HRV

The ln(HF) values were 6.04 ± 0.14 lnms^2 during contact with the uzukuri wood, 5.98 ± 0.14 lnms^2 during contact with the sanded wood, and 5.93 ± 0.16 lnms^2 during contact with the marble. The ln(LF/HF) was -0.45 ± 0.16 during contact with the uzukuri wood, -0.20 ± 0.18
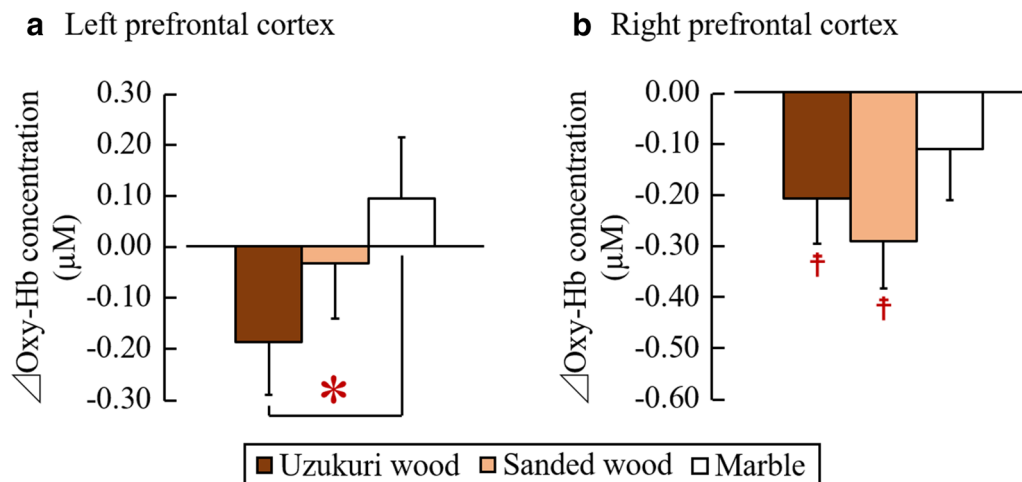
Fig. 5 Overall mean for the left and right prefrontal cortex activities during sole of the feet contact with the materials. **a** Oxy-Hb concentrations in the left prefrontal cortex. $n = 27$, mean ± SE, * $p < 0.05$ (brushed wood vs. marble) as determined using a paired t-test with Holm correction. **b** Oxy-Hb concentrations in the right prefrontal cortex. $n = 27$, mean ± SE, † $p < 0.05$ (pre-measurement vs. post-measurement value) as determined using a paired t-test

during contact with the sanded wood, and -0.22 ± 0.19 during contact with the marble.

Because there was a significant difference found in the breathing frequency between the uzukuri wood and the marble ($p = 0.014$), no comparison was made between these materials in HRV. Conversely, there were no significant differences found in the breathing frequency before and after the contact, so the statistical analysis in HRV was performed. ln(HF) was significantly increased

by tactile stimulation with the uzukuri wood compared with the pre-measurement value (5.83 ± 0.16 lnms² for pre-measurement value, 6.04 ± 0.14 lnms² for post-measurement value; Fig. 6a, $p < 0.05$). There were no significant differences found in the sanded wood (5.87 ± 0.17 lnms² for pre-measurement, 5.98 ± 0.14 lnms² for post-measurement) and marble (5.95 ± 0.19 lnms² for pre-measurement, 5.93 ± 0.16 lnms² for post-measurement) between, before, and after contact. Incidentally, the
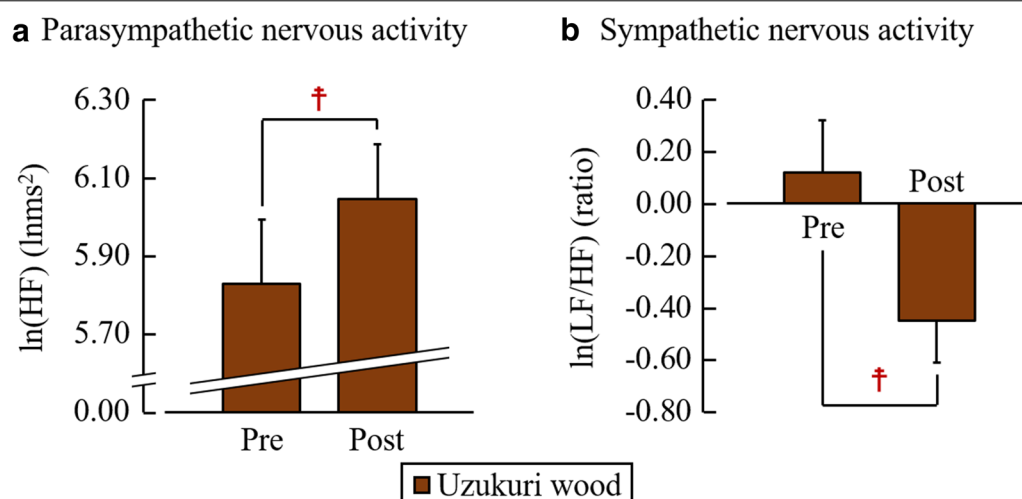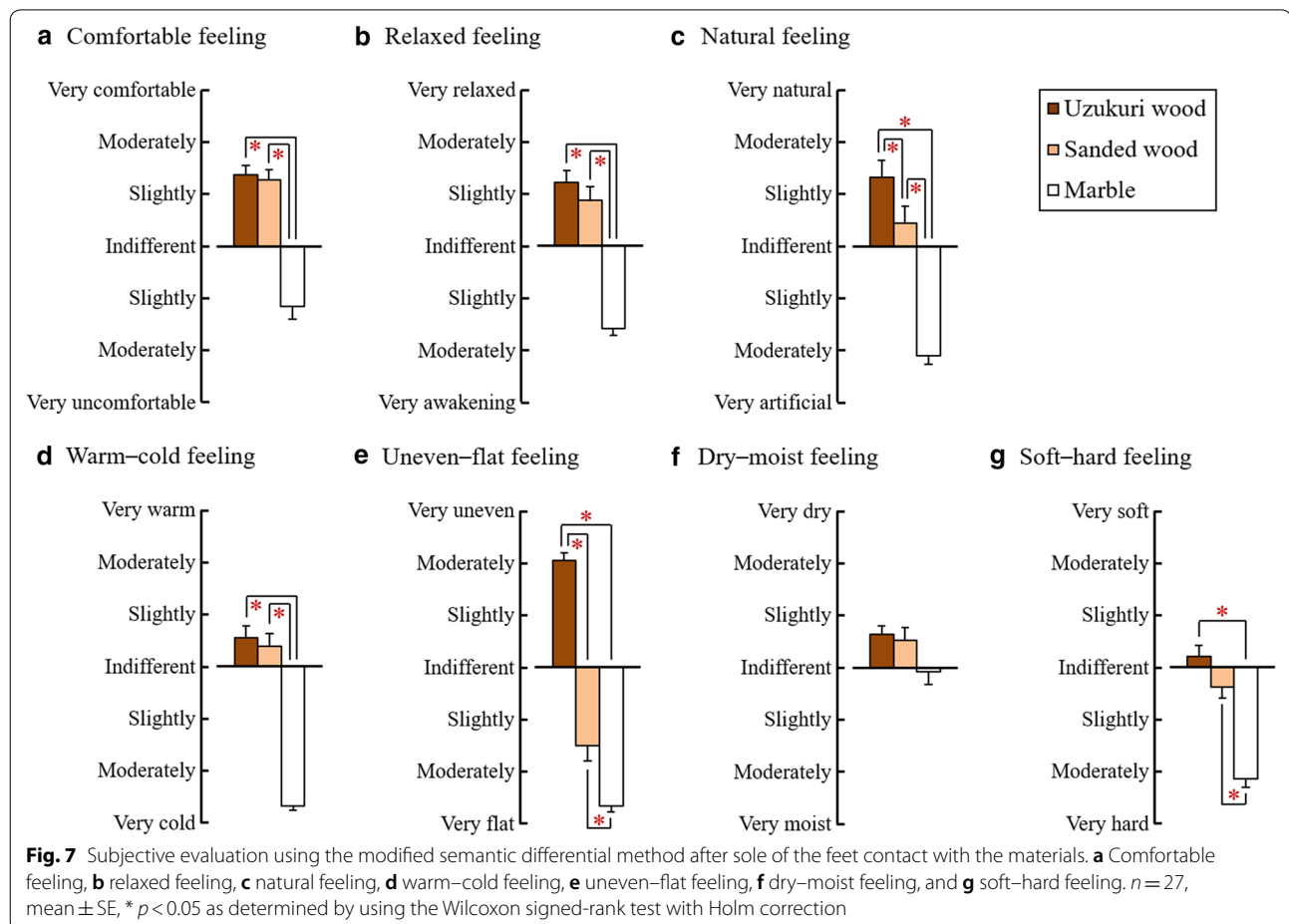

Fig. 6 Pre- and post-measurement values of contact with uzukuri wood via the soles of the feet of parasympathetic and sympathetic nervous activities. **a** The natural logarithm of the high frequency (HF) power component of the heart rate variability. $n = 27$, mean ± SE, † $p < 0.05$ (pre-measurement vs. post-measurement value) as determined using a paired t-test. **b** The natural logarithm of the low frequency/high frequency (LF/HF) of heart rate variability. $n = 27$, mean ± SE, † $p < 0.05$ (pre-measurement vs. post-measurement value) as determined using a paired t-test

mean baseline *ln*(HF) during the 30 s before contact did not significantly differ between each of the three materials ($p > 0.05$). *ln*(LF/HF) was significantly decreased by touching the uzukuri wood compared with the pre-measurement value (0.12 ± 0.20 for pre-measurement, -0.45 ± 0.16 for post-measurement; Fig. 6b, $p < 0.05$). There were no significant differences found in the sanded wood (-0.08 ± 0.22 for pre-measurement, -0.20 ± 0.18 for post-measurement) and marble (-0.43 ± 0.25 for pre-measurement, -0.22 ± 0.19 for post-measurement) between, before, and after contact. Incidentally, the mean baseline *ln*(LF/HF) during the 30 s before contact did not significantly differ between the three materials ($p > 0.05$).

Psychological effects

The results of subjective evaluation by the modified SD method are depicted in Fig. 7. With regard to "comfortable" feeling, the participants subjectively reported feeling "slightly to moderately comfortable" after touching the uzukuri and sanded wood and "slightly to moderately uncomfortable" after touching the marble. Therefore, contact with sugi wood was believed to induce

significantly more comfort than contact with marble (Fig. 7a, $p < 0.05$). With regard to "relaxed" feeling, the participants subjectively reported feeling "slightly to moderately relaxed" while touching the uzukuri wood, "indifferent to slightly relaxed" while touching the sanded wood, and "slight to moderately awakened" while touching the marble. Thus, sugi wood appears to have induced significantly more relaxation than marble (Fig. 7b, $p < 0.05$). With regard to "natural" feeling, uzukuri wood was perceived as "slightly to moderately natural", sanded wood was perceived as "indifferent to slightly natural", and significantly more natural than marble, which was perceived as "moderately to very artificial" (Fig. 7c, $p < 0.05$). Also, there was a significant difference in the natural feeling between the uzukuri and the sanded wood (Fig. 7c, $p < 0.05$). With regard to "warm–cold" feeling, the participants reported feeling "indifferent to slightly warm" after contact with uzukuri or sanded wood and "moderately to very cold" after touching the marble. Thus, sugi wood was perceived as significantly warmer than marble (Fig. 7d, $p < 0.05$). With regard to the "uneven–flat" feeling, uzukuri wood

Fig. 7 Subjective evaluation using the modified semantic differential method after sole of the feet contact with the materials. **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. $n = 27$, mean ± SE, * $p < 0.05$ as determined by using the Wilcoxon signed-rank test with Holm correction

was perceived as approximately "moderately uneven" and significantly more uneven than sanded wood or marble (Fig. 7e, $p < 0.05$). In addition, there was a significant difference in the "uneven–flat" feeling between sanded wood and marble (Fig. 7e, $p < 0.05$). With regard to "soft–hard" feeling, uzukuri wood and sanded wood were perceived as "slightly soft to slightly hard", and significantly different from marble, which was perceived as "moderately to very hard" (Fig. 7g, $p < 0.05$). For the "dry–moist" feeling, no significant differences were observed (Fig. 7f).

The POMS2 scores for the negative subscales A-H, C-B, D-D, and T-A were significantly lower, and the positive subscales V-A and F were significantly higher after touching the uzukuri or sanded wood rather than touching the marble (Fig. 8, $p < 0.05$). F-I was significantly lower after touching the uzukuri wood than after touching the marble (Fig. 8, $p < 0.05$). TMD was significantly lower after touching the uzukuri or sanded wood than after touching the marble, and lower after touching the uzukuri wood than touching the sanded wood (Fig. 8, $p < 0.05$).

Discussion

The overall mean values significantly indicated that touching uzukuri wood significantly decreased the oxy-Hb concentration in the left prefrontal cortex compared with marble (control). Furthermore, compared with the oxy-Hb concentrations before contact, contact with uzukuri wood showed significantly decreased oxy-Hb in the right prefrontal cortex, increased ln(HF), and decreased the ln(LF/HF) ratio. Moreover, contact with the sanded wood significantly decreased oxy-Hb concentrations in the right prefrontal cortex compared to before contact. The impression evaluation using the SD method and the mood evaluation via a shortened version of POMS2 found a significant difference between the sugi with uzukuri and the sanded finish or marble that exhibited a positive correlation with the physiological responses.

The effects of prefrontal activity revealed that the oxy-Hb concentrations of the left and right prefrontal cortices were significantly decreased while touching uzukuri and the sanded wood with the sole of the feet. In a previous study, we reported that the oxy-Hb and total Hb concentrations of the prefrontal cortex were significantly decreased while touching the hinoki with the soles of the feet [16]. Hoshi et al. [28] demonstrated that pleasant feelings decreased oxy-Hb concentrations, and unpleasant feelings increased these levels in the prefrontal cortex during a screen image study. Therefore, we considered that significant decreases in oxy-Hb during sole of the feet contact with uzukuri and the sanded wood in this study reflected the physiological relaxation effects of sugi wood.

The effects to autonomic nervous activity, ln(HF), which is an index of parasympathetic nerve activity, significantly increased, and ln(LF/HF), which is an index of sympathetic nerve activity, significantly decreased with tactile stimulation to the sole of the feet using uzukuri wood. Previous reports utilizing the uzukuri finish, have reported that similar effects can be obtained by palm contact with sugi [11], and sole and palm contact with hinoki [12, 16]. The current study found that physiological relaxation effects could be obtained by sole of the feet contact with uzukuri sugi wood.

In this study, we used sugi, which is a typical softwood in Japan, with two types of finish: uzukuri finish and sanded finish. Uzukuri finish is one of the traditional
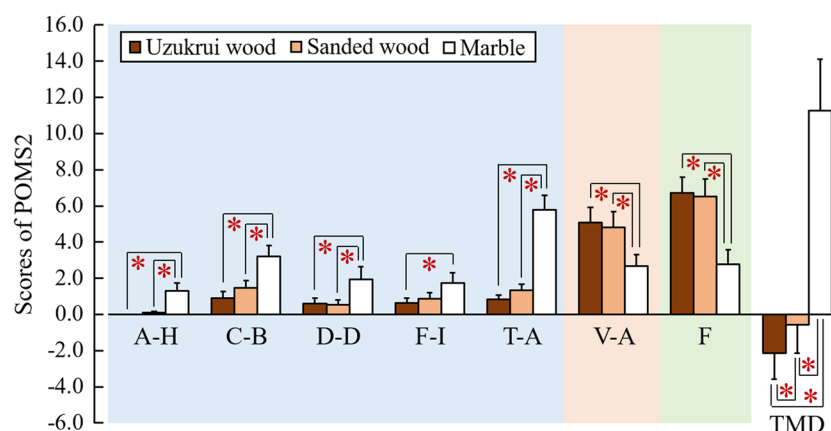
Fig. 8 Subjective feelings using the Profile of Mood States Second Edition after sole of the feet contact with the materials. $n = 27$, mean $\pm$ SE, * $p < 0.05$ as determined by using the Wilcoxon signed-rank test with Holm correction. *A-H* anger–hostility, *C-B* confusion–bewilderment, *D-D* depression–dejection, *F-I* fatigue–inertia, *T-A* tension–anxiety, *V-A* vigor–activity, *F* friendless, *TMD* total mood disturbance

surface finishing methods in Japan and has been used in previous studies that have confirmed the induction of physiological relaxation effects. The sanded finish is a more typical surface finishing method where the wood typically used for desks, furniture, and floors is sanded to a smooth finish. However, sanded finish wood had not yet been studied for the physiological effects of contact with the soles of the feet prior to this study. The physiological indices showed no significant differences between the uzukuri and sanded finish. While, the subjective evaluation, found significant differences in the subjective "natural" and "uneven-flat" feelings via the SD method and TMD scores by POMS2. Therefore, these results showed that the uzukuri finish was more natural and uneven and improved a negative mood state compared to the sanded finish.

In this study, the physical properties and the subjective evaluation of the specimen assessed revealed good correspondence. The thermal conductivity values of each specimen had a good agreement with the subjective evaluation of "warm–cold" using the modified SD method; the surface roughness values of each specimen were consistent with the subjective evaluation of "uneven–flat". However, the relationship between physical properties and physiological responses is an important issue that should be assessed in the future.

Miyazaki has advocated a "back to nature" theory [44, 45]. In this theory, he claims that human physiological functions are adapted to a natural environment because human evolution began from a subset of primates who lived in a natural environment until evolving into our current form approximately 6–7 million years ago [46]. Less than 0.01% of the course of human existence has been in an urban environment, which started with the beginning of urbanization in the Industrial Revolution. From this viewpoint, the highly urbanized and artificial environments that we currently inhabit are the root cause of the "stress state" of modern people. Therefore, we enter a comparatively relaxed state when exposed to the natural environment or to nature-derived stimulation, which may increase our sense of being closer to our original natural state [3, 44, 47]. Wood is a common natural material, which we are in contact with daily, and it is used for manufacturing. When used as a flooring material, the main part of the human body that touches the wood is the soles of the feet, and the results of this current study suggest that contact with wood could be effective in relieving stress in the modern society. The novel features of this study are that it evaluated the physiological effects of tactile stimulation on the sole of the feet, for which there is limited data. This study focused on sugi wood, which is the most famous wood in Japan and has not been evaluated in previous studies. Furthermore,

the simultaneous measurement of the prefrontal cortex activity and sympathetic/parasympathetic nervous activity enabled us to examine the possible relaxation effects imparted by touching this wooden material.

Recently, there has been increased interest in the application of natural therapies for people exposed to high-stress conditions on a daily basis, and researchers have begun to accumulate data on this subject [48, 49]. In the future, the physiological relaxation effects of wood imparted to humans will need to be examined for people under daily stress who have experienced injury or illnesses, such as spinal cord injury, elderly rehabilitation patients, and depression patients.

Limitations of this study

Firstly, this study used uncoated sugi wood; therefore, future studies should determine the physiological effects of touching sugi by utilizing various types of coatings because most wooden objects used in everyday life are coated. Secondly, this study measured the physiological effects of touching wood with only the soles of the feet. It will be necessary to clarify the physiological effect of more active forms of contact, such as stroking the surface of the wood with the foot or hand. Finally, the study population comprised only of young, healthy women in their 20s. To generalize these findings, further studies based on a larger, more varied sample population are required. For example, evaluating differences in the effects between young males and females in their 20s as well as between various age groups.

Conclusions

This study found that tactile stimulation to the sole of the feet induced by touching sugi with the uzukuri finish resulted in calmer left prefrontal cortex activity as compared with contact with marble. Furthermore, tactile stimulation induced by touching sugi with the uzukuri finish resulted in higher parasympathetic nervous activity and lower sympathetic nervous activity as compared with contact with before contact. Also, tactile stimulation induced by touching sugi of sanded finish resulted in calmer right prefrontal cortex as compared with contact with before contact. These findings indicated that tactile stimulation of the soles of the feet with sugi (the uzukuri and sanded wood finish) could effectively induce physiological relaxation effects.

Confusion–bewilderment; V-A: Vigor–activity; F: Friendliness; TMD: Total mood disturbance.

Authors' contributions

YM contributed to the study conceptualization. HI and YM contributed to study design. HI 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. All authors approved the final vision of the manuscript. Each author also agreed to be accountable for all aspects of the work. All authors read and approved the final manuscript.

Availability of data and materials

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

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and 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 34). This study is registered in the University Hospital Medical Information Network of Japan (Unique ID issued by UMIN: UMIN000032808).

Competing interests

The authors declare that they have no competing interests.

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