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RAPID COMMUNICATION

Comparison of the effects of olfactory stimulation by air-dried and high-temperature-dried wood chips of hinoki cypress (*Chamaecyparis obtusa*) on prefrontal cortex activity

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Introduction

Recent studies have focused on the physiological relaxing effects of nature-derived stimulation [1–17], and there are several reports on the effects of wood odor on humans [9–11]. Miyazaki et al. [9] reported that inhalation of Taiwan hinoki oil odor decreases systolic blood pressure. In addition, Tsunetsugu et al. [10] found that the odor of Japanese cedar chips decreases systolic blood pressure and prefrontal cortex activity and that inhalation of α-pinene and limonene, which are major components of the wood odor, also decreases systolic blood pressure. Joung et al. [11] reported that inhalation of D-limonene enhances activity of the parasympathetic nervous system and decreases heart rate. Dayawansa et al. [16] found that inhalation of cedrol induces parasympathetic nerve activity and reduces sympathetic nerve activity. Furthermore, Bensafi et al. [17] reported a negative relationship between the subject's heart rate and a subjective evaluation of feeling comfortable with olfactory stimulation using six essential oil components such as pyridine, L-menthol, and 1,8-cineole.

On the other hand, wood should be dried to prevent deformation or shrinkage before use. In recent years, the share and use of kiln-dried lumber that is subjected to high-temperature drying has increased [18]. Alteration of wood components, however, and a loss of low-boiling-point components after high-temperature drying have been reported [19]; thus, the original odor of wood may change.

There are no data on the differences in olfactory effects on human physiology that result from the different wood-drying methods. Ohira et al. [19] assessed olfactory stimulation with Japanese cedar (*Cryptomeria japonica* D. Don) dried in different ways, but there was only a subjective feeling of sedation among the subjects.

Accordingly, the aim of the present study was to compare the physiological effects of olfactory stimulation by air-dried and high-temperature-dried wood chips of hinoki cypress (*Chamaecyparis obtusa*) using near-infrared time-resolved spectroscopy (TRS) on left and right prefrontal cortex activity.

Materials and methods

Physiological measurements were performed in a chamber with an artificial climate maintained at 25 °C with 50 % relative humidity and 10 lux illumination. Nineteen female university students (age range 22.5 ± 1.6 years) participated in the experiment. Written informed consent was provided by all study participants. The study was performed in accordance with the regulations of the Ethics Committee of the Center for Environment, Health and Field Sciences, Chiba University, Japan.

Part of this study has been presented at the 67th Meeting of Japan Society of Physiological Anthropology, Tokyo, November 2012.

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Hinoki cypress (*Chamaecyparis obtusa*), heart wood grown in Kumamoto Prefecture, Japan, was used. Air drying was conducted for 45 months. High-temperature drying was carried out using a steam heating drying equipment (Olympia Kogyo Co., Ltd., MHB-30). The schedules of the high-temperature drying are shown in Table 1.

Each wood sample treated with one of two different drying processes was prepared in the form of wood chip. The wood chips used in the experiment were stored in a vacuum pack at room temperature; the vacuum pack was then opened on the morning of the experimental day. The sample (80 g) was placed into a 24-L odor bag (polyethylene terephthalate film heat seal bag; NS-KOKEN Co., Ltd. Kyoto, Japan) and presented to each subject with a device that rested on the subject's chest approximately 10 cm under the nose (Fig. 1). The flow rate of air saturated with volatile compounds of each sample was set at 3.0 L/min. Preliminary investigations determined the subjective sensitivity to odor as slight or weak sensation. The odor was administered for 90 s, while the subjects sat with their eyes closed. The two stimuli were randomly presented to the subject.

Physiological effects were determined by measuring oxyhemoglobin (oxy-Hb) concentrations in the prefrontal cortex using TRS (TRS-20 system, Hamamatsu Photonics K.K.; [20–22]). The oxy-Hb concentrations in the left and right prefrontal cortex were measured at 1 Hz for 10 s before (premeasurement condition) odor administration as well as during the 90 s of odor administration (postmeasurement condition). Postmeasurement values (every second) were compared with the premeasurement value (mean 10 s), and differences were determined. Furthermore, we calculated a mean value per 90 s using differences in oxy-Hb concentrations. Data were transformed by linear interpolation as the 1 Hz sampling rate was only approximate.

In addition to the physiological measurements, the subjects underwent a semantic differential (SD) rating test. The modified SD method is based on the subjective evaluation of the emotional impact of the odors [23]. The SD rating test was performed after odor administration and used three pairs of adjectives assessed on 13 scales including "comfortable–uncomfortable," "relaxed–awakening," and "natural–artificial."

Statistical Package for Social Sciences software (v20.0, IBM Corp., Armonk, NY, USA) was used for all statistical analyses. A paired *t* test was used to compare physiological responses. Wilcoxon signed-rank test was applied to analyze differences in psychological indices. Statistical differences were considered significant at $P < 0.05$.

Table 1 High-temperature drying schedule

Time (h)	Dry bulb temperature (°C)	Wet bulb temperature (°C)
0–6	90	90
6–18	90	90
18–42	120	95
42–82	110	90
82–112	105	85
112–120	50	45

Results and discussion

Figure 2 shows the changes in the time-dependent oxy-Hb concentration per second in the prefrontal cortex during olfactory stimulation by air-dried or high-temperature-dried wood chips of hinoki cypress. The oxy-Hb concentration in the left and right frontal cortex during the inhalation of the volatile components of air-dried wood chips remained lower than that of high-temperature-dried wood chips, and it gradually decreased from the baseline level. On the other hand, the oxy-Hb concentration in the left and right frontal cortex remained unchanged during the inhalation of volatile components of high-temperature-dried wood chips.

Fig. 1 Olfactory stimulation procedure and device used to administer the odors

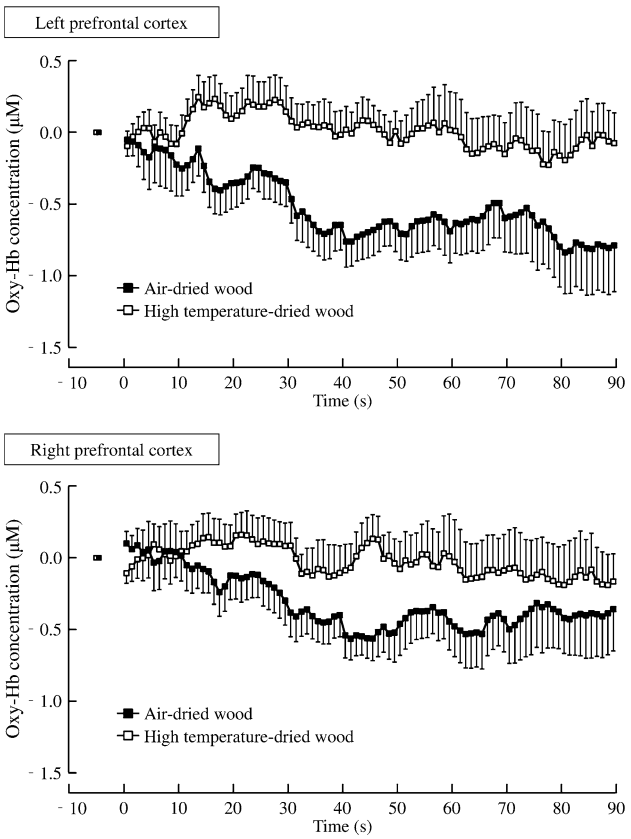

Fig. 2 Time-dependent oxy-Hb concentration changes (per second) in the prefrontal cortex during olfactory stimulation by air-dried or high-temperature-dried hinoki cypress wood chips. The oxy-Hb concentration shown is the difference between the pre- and postmeasurement conditions. *Data* are expressed as mean ± SE; $n = 19$

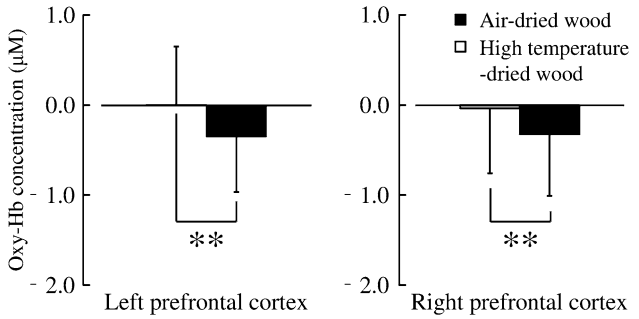

Fig. 3 Comparison of mean oxy-Hb concentrations in the prefrontal cortex after 90 s of olfactory stimulation by air-dried or high-temperature-dried hinoki cypress wood chips. The oxy-Hb concentration shown is the difference between the pre- and postmeasurement conditions. *Data* are expressed as mean ± SE; $n = 19$; $^{**}P < 0.01$, paired t test

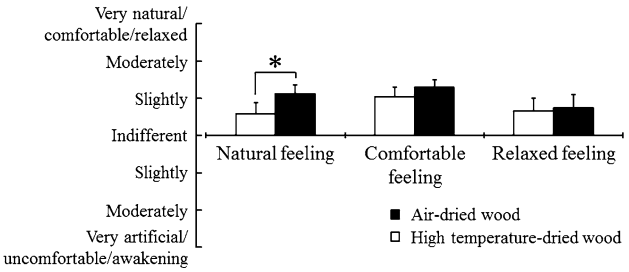

Fig. 4 The subjective feeling measured by the modified semantic differential method after olfactory stimulation by air-dried or high-temperature-dried hinoki cypress wood chips. *Data* are expressed as mean ± SE; $n = 19$; $^{*}P < 0.05$ by Wilcoxon signed-rank test

The comparison of the mean oxy-Hb concentration in the prefrontal cortex after 90 s of olfactory stimulation between air-dried and high-temperature-dried wood chips of hinoki cypress is shown in Fig. 3. At 90 s, the mean oxy-Hb concentration in the left prefrontal cortex was 0.01 μM after exposure to high-temperature-dried wood chips and −0.35 μM after exposure to air-dried wood chips ($P < 0.01$; Fig. 3, left). Olfactory stimulation by air-dried wood chips significantly reduced the oxy-Hb concentration in the left prefrontal cortex compared with high-temperature-dried wood chips. Similarly, in the right prefrontal cortex, the mean oxy-Hb concentration at 90 s was −0.03 μM after exposure to high-temperature-dried wood chips and −0.32 μM after exposure to air-dried wood chips; the difference between them was significant ($P < 0.01$; Fig. 3, right). There were no differences in deoxygenated hemoglobin concentrations.

Subjective reports of feeling "natural" were determined using the modified SD method and are shown in Fig. 4. The reports of feeling "natural" ranged from "slightly natural" to "moderately natural" with air-dried wood chips but from "indifferent" to "slightly natural" with high-temperature-dried wood chips ($P < 0.05$; Fig. 4). Air-dried wood chips were, therefore, perceived as being significantly more natural than high-temperature-dried wood chips. There were no differences in the feelings of comfort or relaxation between olfactory stimulations by air-dried or high-temperature-dried wood chips.

Tsunetsugu et al. [10] reported that the odor of Japanese cedar chips reduces total Hb concentrations in the prefrontal cortex. Other nature-derived olfactory stimuli [12–14] also reduce prefrontal cortex activity. Our present findings of air-dried wood chips are consistent with those of previous studies [10, 12–14].

In a previous study, it was reported that inhalation of α-pinene and limonene, major components of the wood odor, decreases systolic blood pressure [10], whereas inhalation of D-limonene enhances activity of the parasympathetic nervous system and decreases the heart rate [11]. With respect to the volatile components of wood from two different drying processes, Ohira et al. [19] investigated the components and subjective effects of air-dried and high-temperature-dried Japanese cedar wood. Consequently, acetic acid was detected from high-temperature-dried wood, which is generally recognized as an uncomfortable

smell, along with a decrease in the soothing feeling. In the present study, the difference in volatile compounds between the wood chips using different drying methods probably determined the difference in prefrontal cortex activity. However, the relationship remains unclear.

We found that olfactory stimulation by air-dried wood chips significantly reduced oxy-Hb concentrations in the prefrontal cortex, whereas with high-temperature-dried wood chips, they remained unchanged. It was clarified that the prefrontal cortex activity by olfactory stimulation of wood varied depending on the different drying methods.

In future, a multifaceted examination of the physiological effects of wood odor after the wood being subjected to different wood-drying methods, which involves several indicators such as autonomic nervous activity and endocrine parameters, is warranted. Clarification of the relationship between subjective evaluation and physiological response is an important issue in this research field. One should make every effort to address this issue in the future.

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