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Effects of Inhalation of Emissions from Cedar Timber on Psychological and Physiological Factors in an Indoor Environment

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Abstract: Components extracted from cedar timber have been reported to have stress-reducing effects in humans. If the positive effects of cedar timber in indoor environments are scientifically proven, an indoor environment that utilizes cedar timber may contribute to the improvement or promotion of well-being in humans. In this study, we evaluated the effects of inhaling emissions of volatile constituents from cedar timber (Cryptomeria japonica) on the psychological and physiological factors in indoor environments. A case-control study with a crossover design was conducted with 10 subjects occupying two rooms that were controlled for interior materials, indoor climate, and room size. Cedrol and β-eudesmol were specifically detected in the case room. However, no significant differences were observed in psychological and physiological factors. There was a significant loss in vigor in the control group from the time before entering the room to the time after leaving the room; however, this loss in vigor was not seen in the case group. Temperature conditions were higher than the indoor environmental standard in Japan but similar in the two groups. Our results showed a minor positive change in vigor among participants exposed to cedar timber for a short term. Inhalation of emissions of volatile constituents from cedar timber may have positive effects in humans; however, further research on their efficacy is needed.

Keywords: cedar; emissions; indoor environment; physiological factor; psychological factor; terpenes

1. Introduction

Improvement in health conditions, symptoms, or comfort has been observed in occupants of rooms constructed using nonlaminated/noncomposite natural wood timber. The visual effects of a wood-finished interior have been reported to affect physiological and psychological factors [1–3]. Saito et al. reported that the average score of negative mood items in the Profile of Mood States (POMS), such as Tension–Anxiety, Depression–Dejection, Anger–Hostility, Fatigue, and Confusion, significantly decreased after 30 min in a wood-finished interior [4]. However, no significant changes in score were observed in a vinyl-finished interior. The participants were subjected to the influences of both visual effects of a wood-finished interior and effects of inhaling emissions of volatile constituents from it. It is possible that participants were influenced by the preconceived notion regarding the comfort of wood. Hence, these psychological factors may be influenced by those mixed effects or may be biased, and each independent effect should be clarified.

Cedar timber controls humidity and contamination in indoor environments [5–7]. In addition, several studies have shown the stimulating or sedating effects of fragrances from extracts of specific wood ingredients [8,9]. Fragrance mixtures of terpenes found in several wood extracts such as limonene or α-pinene demonstrated inhibitory effects on the sympathetic nervous system through the olfactory system, which can decrease the feeling of fatigue [10]. Olfaction has a powerful influence on behavior and physiological functions in humans [11]. Inhalation of cedrol extracted from cedar timber, which is a sesquiterpene, has stress-reducing effects in humans [12]. A study investigating the effects of cedrol on sleep showed that cedrol inhibited the excitatory activity of the sympathetic nervous system, possibly enhancing the participants' ability to fall asleep [13]. Hence, we focused on the emissions from cedar timber, especially terpenes, which are expected to show positive effects in humans. If the positive effects of cedar timber in an indoor environment are scientifically proven, an indoor environment that contributes to health promotion or improvement could be proposed. In addition, this may promote forest conservation and sustainable forest development by encouraging the utilization of natural wood timber. Therefore, studying the effects of wood timber in an indoor environment on human health and well-being is important. Based on these insights, we aimed to evaluate the effects of inhaling emitted volatile constituents from cedar timber on psychological and physiological factors when cedar is used in indoor environments.

2. Materials and Methods

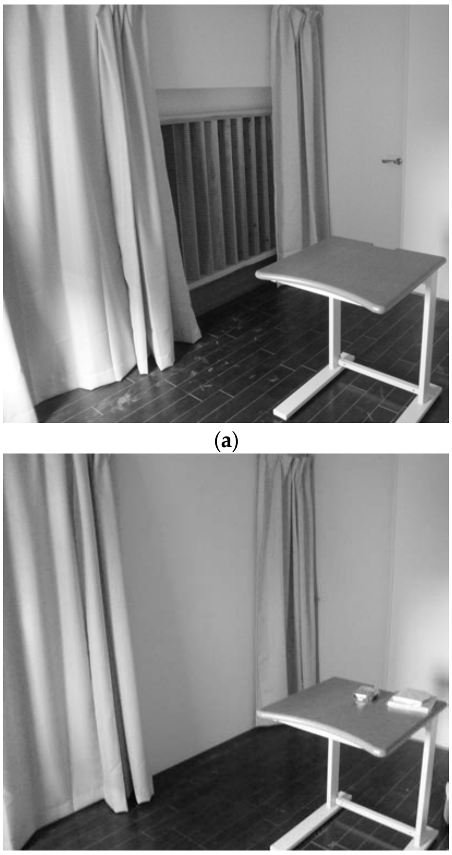
2.1. Subjects, Materials and Experimental Procedure

A case-control study with a crossover design was conducted in 10 healthy male subjects (age, 25–38 years) without symptoms or illnesses. The subjects were divided into two groups and placed in two different rooms (width, 2550 mm; depth, 3550 mm; and height, 2400 mm) that were controlled for interior materials, indoor climate, and room size (Figure 1). The subjects were recruited from healthy general staff of Daiwa House Industry Central Research Laboratory and had no relation to our study. To exclude unhealthy subjects, interviews using a questionnaire on health status, illness under treatment, current medications, and history of illicit drug use were conducted immediately prior to the initiation of the study. Female subjects were excluded from this study because mentality and secretion of saliva, which were the psychological and physiological factors evaluated in this study, are influenced by the menstrual cycle [14–16]. Characteristics of participants are listed in Table 1.

The first round of this study was conducted on 17 June 2009. After a 1-week rest period, the subjects of each group were switched to the other room. Thus, the second round of this study was conducted on 24 June 2009. Conducting the study on the same day of the week was done to create uniformity in routine and work conditions. The experimental design and protocol is shown in Table 2 and Figure 2, respectively. To avoid the visual effects of cedar timbers, a curtain covered the cedar timbers to create a similar view for subjects in each of the two rooms during the experiment.

Cedar timber (Cryptomeria japonica) originating from Kumamoto, a region in the southern part of Japan, was prepared under drying conditions at 60 °C and installed in the case room and covered with a curtain such that it was not visible to the subjects. Boards of cedar timber (width, 100 mm; length, 900 mm; and depth, 30 mm) were prepared, and a ditch was cut on each surface (width, 5 mm; length, 100 mm; and depth, 7 mm) to increase the surface area. A total of 45 boards were positioned slanted against the wall at intervals of 75 mm such that both surfaces of each board were exposed to indoor air. The total installed width and height of the wall was 3375 mm and 900 mm, respectively, and the estimated total surface area of cedar timber was approximately 17.6 m^2 (45 boards $\times$ 0.09 m^2 $\times$ 2 (both surfaces) $\times$ 2.17 (rate of surface area increased by the ditch)). The same types of desks, chairs, floor lights, and spaces to relax were prepared in each room. After entering the room, subjects were instructed to comfortably sit in a chair for the 30-min duration of the experiment. The subjects were not allowed to read or use any electronic devices. Five A4-sized pictures with images of nature, such as flowers, rivers, or forests were printed and put up on the walls in front and to the right of the subject to avoid boredom during the experiment.

The subjects were informed that the purpose of this experiment was to evaluate psychological and physiological factors in two different indoor environments. To avoid misclassification of test data due to subjects' knowledge bias, we did not reveal to the subjects that cedar timber was used in the experimental room. All experiments were conducted as single-blind tests to ensure study reliability and validity. The experimental room was designed in a way that the subjects would not notice the cedar timber. A crossover experimental design was further used to reduce the subject' selection bias.



(**a**)

(**b**)

Figure 1. Overview of experimental rooms. To avoid a potential visual effect of cedar timber, a curtain was closed to create a same view for subjects in the two rooms during the experiment. (**a**) Case room; (**b**) Control room.

Table 1. Characteristics of participants.

Team	Male	Mean Age	SD	Range
A	5	30.0	4.5	27–38
B	5	28.6	3.0	25–33

Abbreviations: SD, standard deviation.

Table 2. Experimental design.

Round	Team A	Team B
First round	Case room	Control room
Second round	Control room	Case room

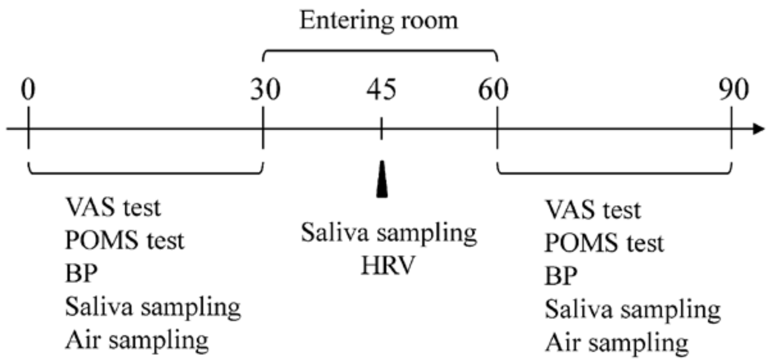


Figure 2. Experimental protocol.

2.2. Experimental Setup and Monitoring Methods

Salivary alpha-amylase (sAA), salivary cortisol, blood pressure (BP), and heart rate variability (HRV) were measured before the subjects entered the assigned rooms and after they left the rooms. Subjects began each round of the experiment at the same time of day and on the same day of the week to avoid any effects of circadian rhythms on the outcome of the experiment [17–20]. Stress levels can be easily and objectively assessed by measuring sAA activity [21,22] and salivary cortisol levels [23]. sAA activity was measured with a CM-2.1 monitoring device produced by NIPRO Corp [24], and salivary cortisol levels were evaluated by a saliva test from SRL, Inc. Saliva used for cortisol measurements was collected by swabbing the mouth of the subject with a cotton roll [25]. After collection, samples were stored up to two days at −80 °C and sent to SRL, Inc. (Tokyo, Japan) for analysis. Both systolic and diastolic BPs were measured using a sphygmomanometer.

HRV is a physiological phenomenon where the time interval between heart beats varies, and it is measured by the variation in the beat-to-beat interval (RR). This variation is caused by the sympathetic and parasympathetic nervous systems, which are the two branches of the autonomic nervous system, as well as humoral factors [26]. The activity of the parasympathetic nervous system is determined by the high frequency (HF) component parameter, whereas that of the sympathetic nervous system is determined by the low-to-high frequency component ratio (LF/HF) parameter. HRV was continuously measured using a RS800CX monitoring device (POLAR Electro., Kempele, Finland) when the subjects were entering the room.

Questionnaires were used to assess the effects of cedar timber on psychological factors. POMS was used to assess psychological factors and the Visual Analogue Scale (VAS) was employed to evaluate the degree of fatigue. POMS is a psychological rating scale used to assess transient, distinct mood states [27]. The long version of POMS comprises of 65 items rated by subjects on a 5-point scale. Six factors were obtained from this test: Tension–Anxiety (T–A), Depression–Dejection (D), Anger-Hostility (A–H), Vigor–Activity (V), Fatigue–Inertia (F), and Confusion–Bewilderment (C). We used the long version, translated and validated in Japanese, to evaluate these psychological traits [28]. The VAS test sheet used to evaluate the degree of fatigue was developed by the Japanese Society of Fatigue Science [29].

Indoor Volatile Organic Compounds (VOCs), terpenes, temperature, relative humidity, and ventilation rate were measured in each room. VOCs were collected by the canister method, and 60 compounds were measured using a Gas Chromatography/Mass Spectrometry (GC/MS, Agilent Technologies, Santa Clara, CA, USA) analyzer. Terpenes were collected in tubes containing

Tenax TA. The tubes were then thermally desorbed and analyzed by GC/MS for detectable levels of 17 terpenes [30]. The ventilation rate, which was roughly estimated by measuring air flow at the door undercut of each experimental room, was approximately 0.1 air change per hour (ACH) in both rooms (calculating air flow without density correction, air flow rate = 0.07 m/s; clearance at door undercut = 0.009 m^2; room volume = 21.726 m^3). Temperature and relative humidity were measured by continuous monitoring on experimental days.

2.3. Data Analysis

The rate of change in VAS scores, sAA activity, cortisol levels, BP values, and POMS scores, measured before entering and after leaving the study rooms, were statistically compared between the case subject group and the control subject group (Mann–Whitney *U* test). In addition, observed values of VAS, sAA, cortisol levels, and POMS, measured before entering and after leaving the assigned study room, were statistically compared within each subject group (Wilcoxon signed-rank test). The HF and LF/HF parameters measured when the subjects were entering the room were statistically compared between the case subject group and the control subject group (Mann–Whitney *U* test). A *p*-value of <0.05 was defined as statistically significant. All data analyses were carried out using SPSS statistics version 18 (IBM, Armonk, NY, USA).

2.4. Ethics

This study was approved by the ethical committee for human research at Kinki University Faculty of Medicine (No. 21-3, 2009).

3. Results

The average temperature in each test room during the first round of the experiment was 30.3 °C (range, 29.5 °C–30.9 °C) in the case room and 29.1 °C (range, 28.5 °C–29.7 °C) in the control room, and that in each test room during the second round of the experiment was 29.0 °C (range, 28.2 °C–29.6 °C) in the case room and 29.0 °C (range, 28.5 °C–29.6 °C) in the control room. The average relative humidity in each test room during the first round was 44.6% (range, 42.0%–47.0%) in the case room and 42.6% (range, 39.0%–45.0%) in the control room, and that in each test room during the second round was 63.1% (range, 59.0%–65.0%) in the case room and 63.1% (range, 58.0%–65.0%) in the control room. Temperatures in both rooms were maintained throughout the experiment at almost the same level. The environmental standard for room temperatures according to Japanese building regulations is between 17 °C and 28 °C [31]. Room temperatures in this study were higher than this standard.

The relative humidity in the case room was similar to that in the control room in both study rounds. However, a difference of approximately 20% relative humidity was observed between the rounds. The rainfall in the morning of the second round is presumed to be the cause of the increased humidity during this round. The environmental standard for relative humidity stated in the Japanese building regulations is 40%–70%. Our measurements were within the standard range. The potential for bias due to the humidity condition in statistical test of comparison between groups could be reduced by a crossover experimental design.

VOCs and terpene levels in the two rooms are shown in Figures 3 and 4, respectively. Total VOC (TVOC) was between 75 and 112 μg/m^3. Numerous VOCs have been detected in an indoor environment, but the health-based air quality guidelines for those VOCs could not be developed. Thus, the Japanese Ministry of Health, Labour and Welfare implemented the TVOC approach as an important indicator to prevent an increase in the indoor air pollution and estimated the temporary target concentration of TVOC to be 400 μg/m^3. This target concentration was derived from the median value calculated based on results from a national field survey of VOCs in Japan [32]. TVOC concentrations in both rooms were sufficiently below the target concentration. As shown in Figure 4, higher mean concentrations of β-eudesmol and cedrol were observed in indoor air in the experimental room compared with those in the control room (6.3 vs. 0.02 μg/m^3 for β-eudesmol and 4.5 vs. 0.08 μg/m^3 for cedrol).

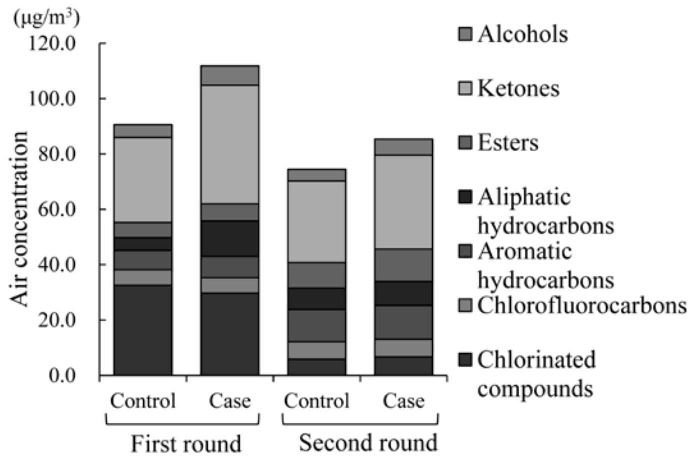


Figure 3. Air concentrations of volatile organic compounds (VOCs).

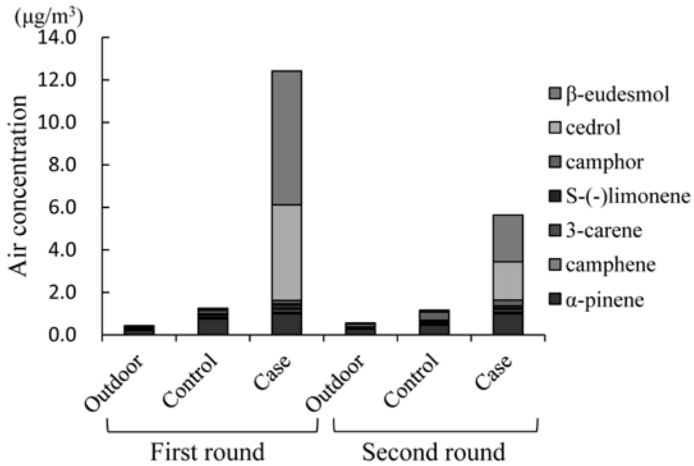


Figure 4. Air concentrations of terpenes.

The results of sAA, salivary cortisol, and VAS evaluation are shown in Figure 5, and BP and HRV are depicted in Figures 6 and 7, respectively. POMS data are shown in Figure 8. As seen in Figures 5–7, no significant differences were observed in sAA activity, cortisol concentration, blood pressure, and HRV between groups. In the questionnaire designed to measure the effects of cedar on psychological factors, no significant differences were found in tension, depression, anger, vigor, fatigue, and confusion between groups. The observed values measured before entering and after leaving the rooms are shown in Table 3. A significant decrease in vigor was measured in the control group from the time before they entered the room to the time they left the room, whereas no decrease was seen in the case group.

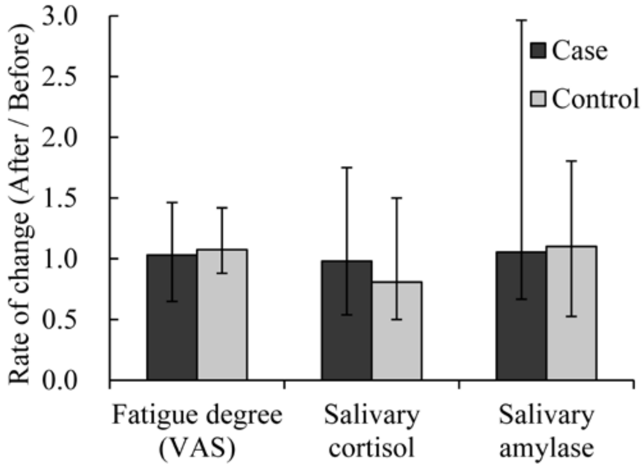


Figure 5. Fatigue degree and secretions in saliva.

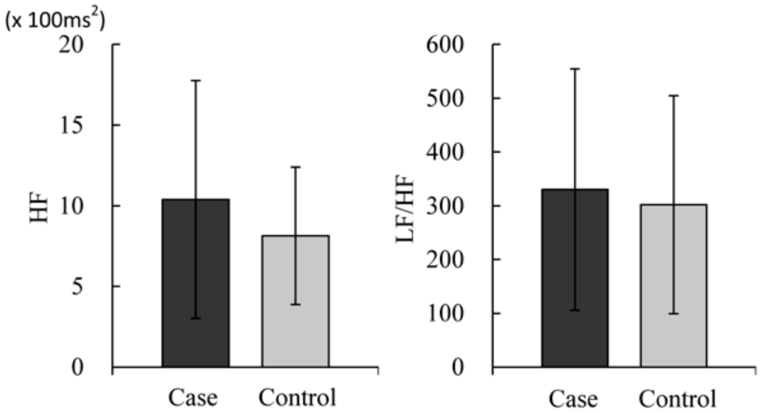


Figure 6. High frequency (HF) component and low-to-high frequency (LF/HF) component ratio.

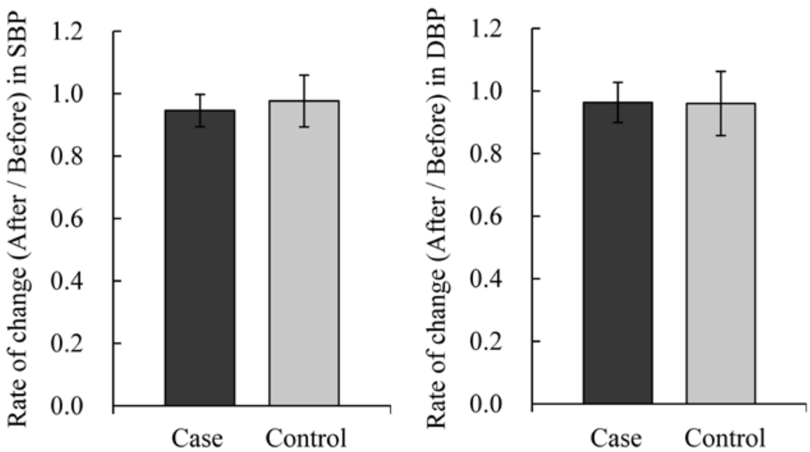


Figure 7. Rate of change in systolic blood pressure (SBP) and diastolic blood pressure (DBP).

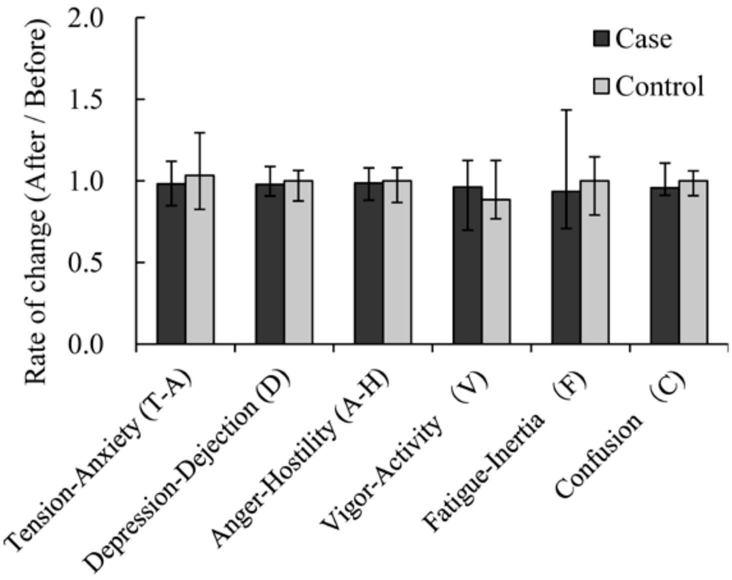


Figure 8. Profile of Mood States.

Table 3. Observed values measured before entering the rooms and after leaving the rooms.

Measure	Subject Group	Maximum Value		Minimum Value		Medium Value		*p* Value
		Before (n = 10)	After (n = 10)	Before (n = 10)	After (n = 10)	Before (n = 10)	After (n = 10)	
VAS score	Case	71.1	70.6	18.6	21.6	39.7	41.2	0.959
	Control	69.1	69.6	24.7	29.9	40.0	45.4	0.093
Salivary cortisol (μg/dL)	Case	0.270	0.280	0.100	0.090	0.155	0.160	0.799
	Control	0.310	0.300	0.140	0.110	0.190	0.160	0.284
sAA activity (KIU/L)	Case	144.0	114.0	15.0	23.0	49.5	52.0	0.878
	Control	158.0	101.0	19.0	22.0	49.0	72.0	0.959
T-A score	Case	59	59	34	34	44.0	42.0	0.260
	Control	63	53	33	36	41.5	44.0	0.552
D score	Case	58	62	40	39	45.0	43.5	0.438
	Control	65	57	39	39	43.5	42.0	0.588
A-H score	Case	54	55	37	37	44.5	43.5	0.621
	Control	53	51	37	37	39.5	40.5	0.606
V score	Case	67	65	35	30	41.5	40.5	0.159
	Control	70	64	35	27	43.5	41.0	0.028 *
F score	Case	52	66	34	34	45.5	42.0	0.440
	Control	62	56	34	34	41.0	40.5	0.889
C score	Case	60	60	37	40	45.0	43.0	0.281
	Control	66	60	33	35	45.0	46.0	0.739

* Significant at $p < 0.05$. Abbreviations: VAS, visual analogue scale; sAA, salivary alpha-amylase; T-A, Tension-Anxiety; D, depression-dejection; A-H, anger-hostility; V, vigor-activity; F; fatigue-inertia; C, confusion-bewilderment.

4. Discussion

We evaluated the effects of emissions of volatile constituents from cedar timber on psychological and physiological factors when it was used in indoor environment. A significant decrease in vigor ($p < 0.05$) and a marginally significant increase ($p < 0.1$) in degree of fatigue determined by VAS was observed in the control group but not in the case group from before entering the room to after leaving the room. The negative effects in the control group may be due to high temperature conditions in the room; however, similar effects were not observed in the case group. When comparing values measured before entering and after leaving the rooms, sAA activity appeared higher whereas cortisol concentrations appeared lower in the control group, but the differences were not statistically significant. The case group appeared to show a decrease in tension, depression, anger, fatigue, and confusion from the time before entering to after leaving the room, but these results were not statistically significant.

The indoor environment of the rooms had relative humidity and VOC levels within the standards set by the Japanese Ministry of Health, Labour and Welfare. Indoor temperatures were higher than the recommended standard, but the difference between the temperatures in the rooms was negligible. Cedrol and β-eudesmol were specifically detected in the case room with installed cedar timber boards. It is important that indoor building materials do not emit hazardous compounds into the indoor environment. The Cedar timber of Kumamoto origin specifically emitted cedrol and β-eudesmol when processed at low-temperature (60 °C) drying conditions by an experienced timber processing specialist. In general, high-temperature drying conditions such as those at 100 °C–130 °C are applied to shorten the total drying time of timber processing. However, several VOCs, including aldehydes (e.g., formaldehyde or acetaldehyde), aromatic hydrocarbons (e.g., toluene), and terpenes (e.g., α-pinene or γ-cadinene), are produced under high-temperature drying conditions [33,34]. Aldehydes and aromatic hydrocarbons are hazardous to human health [32]. However, the low-temperature drying process used in our study ensured that low concentrations of VOC emissions from cedar timber were maintained (Figure 3). In addition, specific terpenes with low volatility, using which health promotion would be expected, were detected in the case room (Figure 4). Future research is needed to optimize indoor air conditions, including the determination of mechanistic details, process conditions, and loading factors of indoor materials. In our study, we set up the indoor environments to have specific differences in levels of terpenoid volatile components resulting from the presence of cedar timber. Our results suggested that the degree of fatigue and POMS test results in this study may be positively affected by the presence of cedar timber. Cedrol and β-eudesmol could be the reason for these changes. Before this study was started, we assumed that cedrol was detected in the case room, but surprisingly, β-eudesmol was also detected in the case room.

Cedrol, which is extracted from cedar wood oil, has sedative effects on the activity of the sympathetic nervous system [35]. Akutsu et al. suggested that cedrol inhibits an increase in dopamine metabolism that is induced by immobilization stress and that the sedative effects of cedrol on behavioral and autonomic activities were, in part, due to the inhibition of dopaminergic neurotransmission and modulation of neural activity in the lateral hypothalamic area [36]. In addition, inhaled cedrol acts on the lower airways and pulmonary system and may have potential therapeutic uses for reducing hypertension [37].

Obara indicated that β-eudesmol promotes biosynthesis of neurotrophic factors such as nerve growth factor [38], whereas Tsuneki et al. suggested that β-eudesmol inhibits angiogenesis and aids in the development of drugs to treat angiogenic diseases [39]. In addition, Kimura suggested that the antiangiogenic effects of β-eudesmol are favorable for the treatment of angiogenic diseases, including diabetic complications and cancer [40]. Although multiple pharmacological effects of β-eudesmol have been reported, the effect of inhaled β-eudesmol has not yet been elucidated.

Cedrol extracted from cedar wood oil was reported to have sedative effects on the activity of the sympathetic nervous system. A study exposed healthy human subjects to vaporized cedrol (14.2 ± 1.7 μg/L, 5.0 L/min) through facemasks for 10 min [35]. sAA activity was significantly lower during inhalation of the fragrance, i.e., in the case group than that in the control group. In addition, the inhaled fragrance induced positive effects on work performance. Another study placed terpenes extracted from wood on cotton. The fragrance was inhaled by the case group through the cotton held under their noses [10]. In these studies, the subjects inhaled large amounts of cedrol in a short time.

Yamamoto et al. reported that sleep time increased and sleep onset latency was shortened in a case group exposed to cedrol compared to those in the corresponding control group [13]. Cedrol was volatized at 1.665 μg/L/h in an indoor environment for 4 h, and the subjects reported that they sensed an odor in the case room. Matsuura et al. also reported a significant improvement in sleep and shortened sleep latency due to exposure to cedrol [41]. A pillowcase was infused with cedrol in these studies, and the subjects inhaled small amounts of cedrol over a long period of time.

Although several prior studies have reported the positive effects of cedrol and β-eudesmol on human well-being, a pharmacological effect for medical treatment by introducing cedar timber into indoor environments cannot be expected based on the results of this study. It is important to adequately achieve low concentrations of hazardous VOC emissions to avoid adverse health effects caused by the concentrations of VOCs emitted from cedar timber installed in indoor environments. In this study, TVOC concentrations in the room where cedar timbers were installed were sufficiently below the maximum concentration of TVOCs recommended in Japan.

On the other hand, it is preferred that the positive effects indicative of promotion or improvement of well-being in humans are caused by cedar timber installed in an indoor environment. In this study, cedrol and β-eudesmol were exclusively detected in the case room with installed cedar timbers. A significant decrease in vigor was found in the control group but not in the case group. In this experiment, room temperatures in both rooms were higher than the recommended indoor environmental standard in Japan. We did not decrease room temperatures because differences between indoor and outdoor temperatures influence blood circulation and thermal sensations [42,43]. We maintained natural conditions as much as possible. Thus, the significant decrease in vigor seen in the control group may have been caused by high temperatures. However, no decrease in vigor was observed in the case group, suggesting that the presence of cedar timber plays a role in maintaining a feeling of well-being in these participants, despite high temperatures. The indoor environment in the case room was created by the addition of cedar timber processed under low-temperature drying conditions. Further research on the indoor environmental effects and processing conditions of cedar timber, including high indoor concentrations of cedrol or β-eudesmol and long-term indoor exposure, is needed to clarify the effects of emissions of volatile constituents from cedar timber on human health.

The present study has some limitations. First, the very small sample size makes the results vulnerable to selection bias. This could be improved by including a larger study population. Second, the time of exposure to emissions from cedar timber in the experimental rooms was only 30 min. Further evaluation of longer exposures would provide valuable information for understanding the positive effects of cedar timber installed in an indoor environment. Third, indoor air concentrations of cedrol and β-eudesmol produced by the cedar timber were only 1.8–4.5 $\mu g/m^3$ and 2.2–6.3 $\mu g/m^3$. Further studies with high indoor concentrations of these terpenes may reveal additional positive effects of cedar exposure to humans.

5. Conclusions

In this study, the effects of emissions of volatilization constituents from cedar timber on psychological and physiological factors in indoor environments were evaluated. Cedrol and β-eudesmol were specifically detected in the case room. However, no significant differences were found in the psychological and physiological factors. There was a significant loss in vigor in the control group from the time before entering the room to the time after leaving the room; however, this loss in vigor was not seen in the case group. Temperature conditions were higher than the indoor environmental standard in Japan but similar in the two groups. Our results showed a minor positive change in vigor among participants exposed to cedar timber for a short term. Cedrol and β-eudesmol exposure has demonstrated positive effects on the activity of the autonomic nervous system and neurotrophic factors in previous studies. The effects of emissions of volatile constituents from cedar timber may be better understood by controlling the degree of exposure, and further research pertaining to this aspect is warranted.

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Conflicts of Interest: The authors declare no conflict of interest.

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