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ORIGINAL ARTICLE

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# Effects of contact with wood on blood pressure and subjective evaluation

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**Abstract** This study examined the effects of contact with wood on the living human body using a physiological index and subjective evaluation. Consecutive blood pressure measurements were used as the physiological index, and sensory evaluation using the semantic differential (SD) method was used for subjective evaluation. Consideration was also given to cases in which materials were cooled and heated as well as kept at room temperature, to eliminate the effects of heat flux due to differences in thermal conductivity between wood and other materials. It was found that contact with wood produced coarse/natural sensations, with no associated increase in systolic blood pressure. Contact with cold wood created subjectively dangerous/uncomfortable but still coarse/natural sensations, also with no associated increase in blood pressure; therefore, there was no correspondence between subjective evaluation and physiological responses. Contact with aluminum kept at room temperature and cold acrylic plastic created flat/artificial and dangerous/uncomfortable sensations, with an associated significant increase in blood pressure; thus, there was a close correlation between subjective evaluation and physiological responses. It was therefore concluded that contact with wood, unlike artificial materials such as aluminum, induces no physiological stress even when kept at room temperature or cooled.

**Key words** Wood · Contact · Blood pressure · SD method · Temperature

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## Introduction

People have ample opportunity to directly touch with their hands various materials such as interior wall and floor materials in living spaces, furniture, furnishings, and daily goods. For this reason, very important factors when selecting finish materials for these products include sensory properties, such as the sensations people have on coming into contact with the products, as well as physical properties such as strength and endurance.

There have been a large number of studies on the effects of contact with wood on human senses that aimed to quantify contact sensations. Takeda and Okajima[1] evaluated tactile properties of building finishing materials using a three-dimensional (3D) system of orthogonal coordinates corresponding to thermal sensation, hardness sensation, and roughness sensation to classify these materials into seven groups using cluster analysis. They concluded that their method of evaluation is valid because these groups correspond closely to the appropriate usage of the materials identified from a questionnaire sent to construction professionals.[1] Okajima et al.[2] classified material contact sensations into three groups (thermal, hardness, and roughness), and in particular tried to quantify thermal sensation using the amount of heat transfer as an index. They showed that there was a strong correlation between a psychological quantity representing thermal sensation calculated by paired comparison and the amount of heat transfer measured by a heat transfer measuring instrument. This work also demonstrated that contact thermal sensations can be quantified with the amount of heat transfer.[2] Based on a series of studies, Okajima and Takeda[3,4] also proposed psychophysio dynamics and a method to estimate a psychological quantity representing the sense of touch using three physical quantities as indices: the amount of heat transfer, indentation rigidity, and coefficient of kinetic friction, which correspond to the three basic tactile sensations of thermal sensation, hardness sensation, and roughness sensation, respectively.[5] Wu et al.[6] measured a psychological quantity when contact was made with materials with a surface temperature of 10° to 45°C at a room temperature of 20°C. They showed that thermal sensation, dryness sensation, and comfort sensation vary with surface temperature while hardness sensation and roughness sensation are constant regardless of temperature.[6] There are some reports[7–10] stating that contact thermal sensation can be quantified using the amount of heat flux between a material and the palm and thermal conductivity as indices; thus, the amount of heat transfer is considered to be an important factor that controls contact sensations. However, these studies were designed to use physical quantities of materials as indices to quantify psychological quantities of human sensations, and were therefore limited to examination of psychological and physical quantities.

In evaluating the state of a human being when coming into contact with a material, it is necessary to consider psychological quantities using subjective evaluation and understand the state of an individual from the viewpoint of physiological responses. Very few studies have examined sensations people have on contact with materials including their physiological responses. Otsuka et al.[11] observed white coat hypertension with portable blood pressure manometers and found about a 20% elevation in systolic blood pressure. It is thought that blood pressure change is an index that reflects the state of a human being, but the degree is different depending on the sensory modality. Morikawa et al.[12] measured blood pressure and pulse rate consecutively when people came into contact with wood to clarify the relationship between the sensations experienced on such contact and physiological responses. They showed that silk and sawed surfaces of hinoki (*Chamaecyparis obtusa*) and sugi (*Cryptomeria japonica*) have little influence on blood pressure and pulse rate while stainless steel or a plastic bag filled with cold water have a significant influence.[12] The amount of heat transfer between materials and the palm of the hand is likely to have a great physiological impact on people when coming into contact with these materials. Psychological and physiological evaluation of human subjects under different amounts of heat transfer will help to clarify the characteristics of contact sensations.

The objective of this study was to clarify the effects of contact with materials such as wood on the living body. Blood pressure was consecutively measured as a physiological index using the Finapres method, which allows easy measurement at the fingertip and is convenient for subjects.[13] Sensory evaluation using the semantic differential (SD) method[14] was also conducted to clarify changes in impression created at the time of contact. In addition, the experiment was performed with materials maintained both at room temperature and other temperatures to eliminate the effects of heat flux due to differences in thermal conductivity between wood and other materials.

## Materials and methods

Part of a laboratory was partitioned off with a curtain to create an enclosure with an area of 22 m² (3.6 × 6.1 m) and a ceiling height of 2.67 m, as shown in Fig. 1. An armchair was put at the center of the enclosure and the curtain was positioned close to the right side of the armchair with an opening through which an arm could be extended, thereby hiding the materials from the subject's visual field. A table that was almost level with the armchair was placed in front of the curtain opening and materials were presented on the table. When a material was presented, the subject was signaled to touch the material with the entire palm of the right hand.

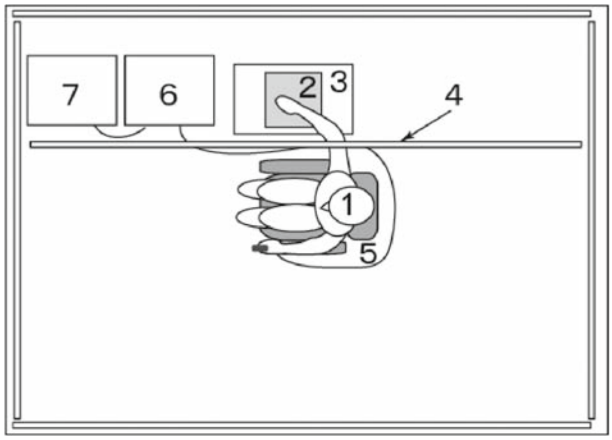


**Fig. 1.** Laboratory overview. *1*, Subject; *2*, specimen (300 × 300 mm); *3*, table for height regulation; *4*, curtain (the section through which an arm could be extended was parted); *5*, armchair (armrests 200 mm above seating surface); *6*, noninvasive continuous sphygmomanometer (Finapres, Ohmeda model 2300); *7*, computer for data storage

The materials presented were sugi (*Cryptomeria japonica*), hinoki (*Chamaecyparis obtusa*), oak (*Quercus crispula*), urethane-coated oak, acrylic plastic, and aluminum (Table 1). All materials were kept at room temperature (20°C). To eliminate the effects of heat flux on contact due to differences in thermal conductivity between those materials, some materials were kept both at room temperature and at different temperatures. Specifically, oak and acrylic plastic samples were cooled in a refrigerator to a temperature of 5°C while aluminum samples were heated on a hot plate to a temperature of 30°C. The materials presented were all cut into samples of 300 × 300 mm, and the contact surfaces of wood materials were processed with a planer. Wood specimens were 15 mm thick while the other materials were 5 mm thick. The order of presentation of the materials was randomized. The indoor environment of the laboratory was maintained at 20° to 25°C, 50% to 60% relative humidity (RH), and 10 to 50 lx.

The subjects of this study were 13 healthy male university students. They were given sufficient information about the objective and procedure of the experiment. The subject was required to sit in a chair, and then a sensor for physiological measurements was attached to the subject. Blood pressure and pulse rate were measured consecutively every 1 s at the second finger of the left hand using a noninvasive continuous sphygmomanometer (Finapres, Ohmeda model 2300). After the subject had remained at rest for more than 20 s in the sitting position with his eyes closed, he was pre-

**Table 1.** Details of test specimens

| Specimens | $h$ (mm) | $\rho$ | MC[a] (%) | Temperature (°C) | $q_{10}$[b] (W/m$^2$) | Condition |
|---|---|---|---|---|---|---|
| Sugi | 15 | 0.40 | 10 | 20 | 95 | Planed finish |
| Hinoki | 15 | 0.49 | 10 | 20 | 107 | Planed finish |
| Oak | 15 | 0.64 | 8 | 20 | 127 | Planed finish |
| | | | | 20 | 122 | Urethane coating |
| | | | | 5 | 180 | Planed finish |
| Acrylic plastic | 5 | 1.18 | – | 20 | 208 | – |
| | | | | 5 | 404 | – |
| Aluminum | 5 | 2.70 | – | 20 | 340 | – |
| | | | | 30 | 119 | – |

$h$, Thickness; $\rho$, specific gravity; MC, moisture content (%), $q_{10}$, heat flux
[a] From high-frequency moisture meter
[b] Reading on the heat-flow meter 10 min after contact between the hotplate (30°C) and a specimen

sented with a material as a stimulant and told to touch the surface of the material for 60 s. The data obtained during the period when verbal instructions were given at the presentation of the stimulation and the period (3 s) of movement of the right arm were removed from the analysis of consecutively measured blood pressure. In addition, systolic blood pressure and diastolic pressure showed a similar tendency, and systolic blood pressure was selected for analysis. Sensory evaluation was performed promptly after the subject came into contact with the material for 60 s. The SD method was used for sensory evaluation. A total of 18 adjectives were used for the sensory evaluation: clear, safe, vague, sticky, brittle, heavy, comfortable, slick, masculine, velvety, sedate, flat, flimsy, artificial, old, warm, prickly, and painful. All the words were written in Japanese on the evaluation form. Evaluation was based on a 7-point scale from −3 to +3.

Wilcoxon signed rank tests were conducted using data from no contact with materials as the control to test the significance of the sensory evaluation. The test of significant difference in changes over time in systolic blood pressure was performed using the paired $t$-test based on the average values for 10 s before stimulation. To avoid type I error, the following was considered. The rate at which significant differences between $N$ data out of the 60 data samplings and 100 would be erroneously detected (the rate that $N$ significant differences would be detected despite the fact of there being no significant differences) can be calculated by using binomial distribution,

$${}_{60}C_N(0.05)^N(0.95)^{(60-N)}$$

when the significance level is 0.05 ("C" expresses a combination). The calculated rate becomes less than 0.05 when $N$ is equal to or larger than 6. Therefore, it was considered that if there were more than 6 significant differences out of 60 data samplings during the stimulation, the change in the physiological index as a whole was significant.

## Results and discussion

Principal component analysis (varimax rotation) on the sensory evaluation using the SD method was conducted. Rotation converged in 6 iterations and 4 factors were extracted with eigenvalues of 1 or greater. With factor loadings of 0.65 or higher, "prickly–not prickly" (0.73), "slick–not slick" (0.71), "flat–not flat" (0.70), and "artificial–natural" (0.65) were extracted for the first principal component, which was named the "sense of coarseness and nature." "Painful–painless" (0.82), "dangerous–safe" (0.81), "uncomfortable–comfortable" (0.74), and "masculine–feminine" (0.69) were extracted for the second principal component, which was named the "sense of safety and comfort." "Not sticky–sticky" (0.77), and "not velvety–velvety" (0.75) were extracted for the third principal component, which was named the "sense of stickiness." "Not flimsy–flimsy" (0.69), and other paired adjectives were extracted for the fourth principal component, which was named the "sense of thickness."

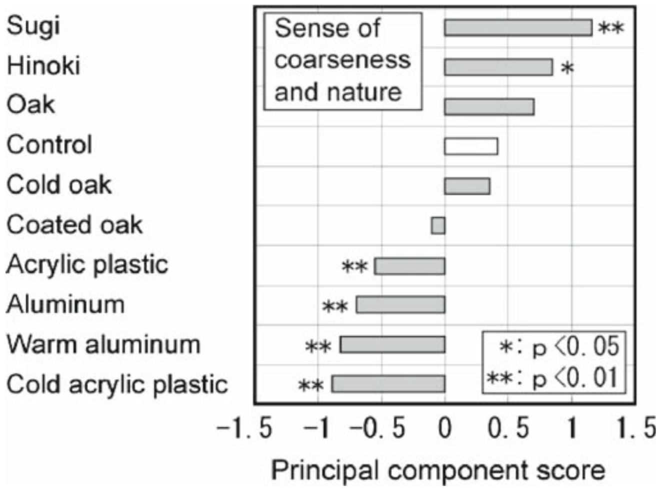


**Fig. 2.** Principal component scores of coarseness/nature for each material. Data given as mean ± standard deviation. Significance according to Wilcoxon's signed rank test

Figure 2 shows principal component scores for the first principal component on contact with the materials. It became clear that when contact was made with sugi and hinoki as wood, the principal component score for the first principal component, the "sense of coarseness and nature" was significantly high and that the stimulation produced a sensation that was prickly, not slick, not flat, and natural. When contact was made with aluminum and acrylic plastic

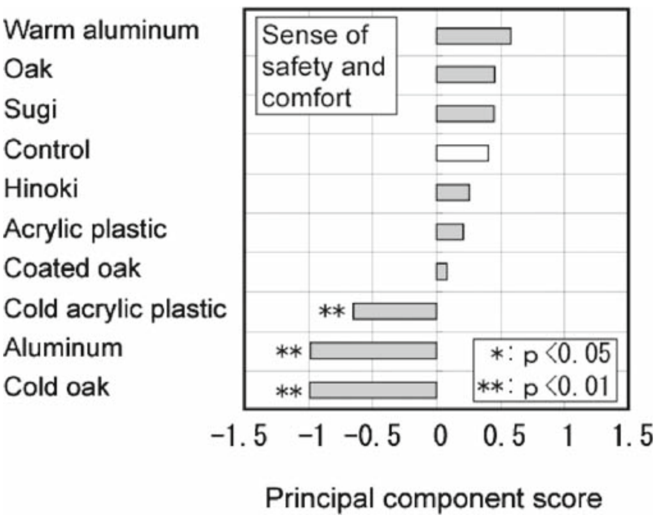


**Fig. 3.** Principal component scores of safety/comfort for each material. Data given as mean ± standard deviation. Significance according to Wilcoxon's signed rank test

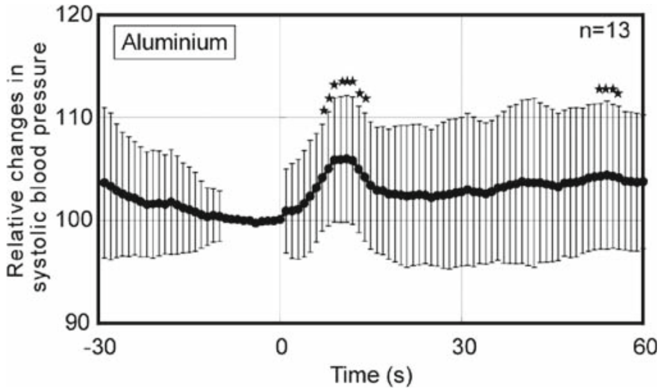


**Fig. 4.** Changes in systolic blood pressure after touching an aluminum board, expressed as relative change when the average values for 10s before simulation were assumed to be 100. Data given as mean ± standard deviation. *Stars*, $P < 0.05$ (paired *t*-test)

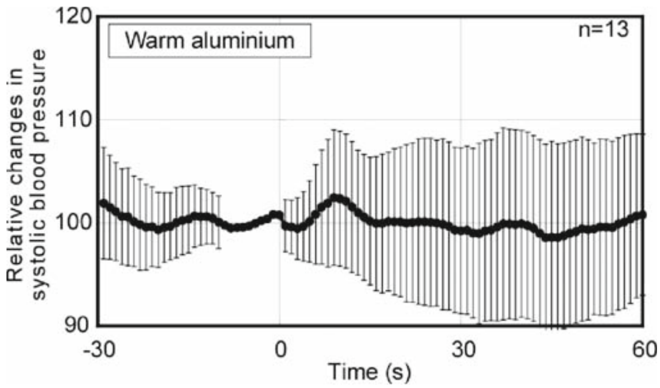


**Fig. 5.** Changes in systolic blood pressure after touching a warm aluminum board, expressed as relative change when the average values for 10s before simulation were assumed to be 100. Data given as mean ± standard deviation

rather than wood, the principal component score for the "sense of coarseness and nature" was significantly low and the stimulation produced a sensation that was not prickly, slick, flat, and artificial. Contact with aluminum heated to 30°C (which is close to skin temperature) produced a slick and artificial sensation as was the case with aluminum kept at room temperature. Contact with acrylic plastic cooled to 5°C produced the slickest and most artificial sensation. Contact with oak wood cooled to 5°C left a coarse and natural impression as was the case with oak kept at room temperature. These data showed that contact with wood materials induces a coarse and natural sensation, while contact with aluminum induces a slick and artificial sensation, regardless of material temperature.

Figure 3 shows principal component scores for the second principal component on contact with the materials. It became evident that when contact was made with aluminum, the principal component score for the "sense of safety and comfort" was significantly low and that the stimulation felt painful, dangerous, and uncomfortable. When contact was made with warm aluminum, the principal component score for the "sense of safety and comfort" was the highest, and, unlike aluminum kept at room temperature, the stimulation produced a sensation of safety and comfort on a par with oak and sugi. In contrast, when contact was made with cold oak, the principal component score for the "sense of safety and comfort" was the lowest, and, unlike oak kept at room temperature, the stimulation produced a sensation of danger and discomfort. These data showed that the "sense of safety and comfort" depends on the temperature of materials, and contact with materials kept at low temperatures induces a sensation of danger and discomfort.

Figure 4 shows changes over time in systolic blood pressure before and after contact with aluminum. Blood pressure increased significantly 7–14s and 53–56s after the contact stimulation. Contact made with aluminum that produced a subjectively flat/artificial and dangerous/uncomfortable sensation raised systolic blood pressure, showing physiologically increased sympathetic nerve activity, namely a state of stress.

Figure 5 shows changes over time in systolic blood pressure before and after contact with aluminum heated to 30°C. Contact made with aluminum heated to 30°C that produced a subjectively safe and comfortable sensation did not raise systolic blood pressure.

Contact made with aluminum kept at room temperature raised blood pressure significantly, while contact made with warm aluminum heated to 30°C did not raise blood pressure. This shows that physiological response to contact with aluminum depends on the temperature of the metal. In addition, the subjective evaluation of the sense of safety and comfort matched the results obtained for physiological responses.

Figure 6 shows changes over time in systolic blood pressure before and after contact with sugi. Blood pressure had a tendency to rise transiently immediately after contact, while afterward it had a tendency to slightly decrease, with no significant difference.

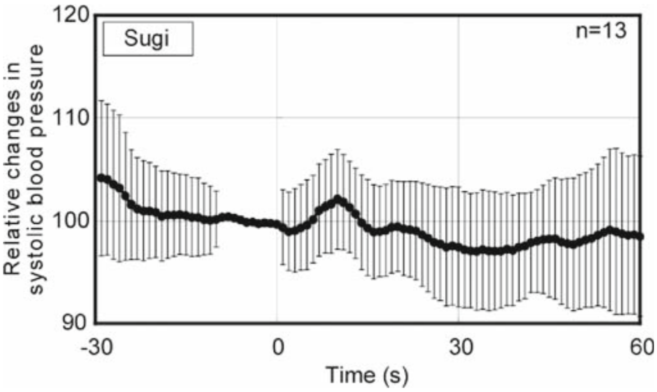


**Fig. 6.** Changes in systolic blood pressure after touching a sugi board, expressed as relative changes when the average values for 10 s before simulation were assumed to be 100. Data given as mean ± standard deviation

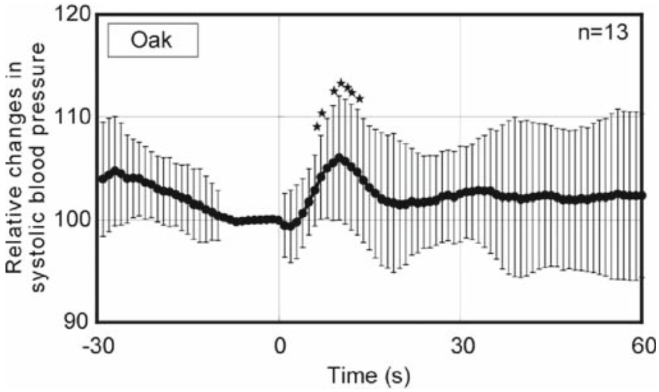


**Fig. 8.** Changes in systolic blood pressure after touching an oak board, expressed as relative changes when the average values for 10 s before simulation were assumed to be 100. Data given as mean ± standard deviation. *Stars*, $P < 0.05$ (paired *t*-test)

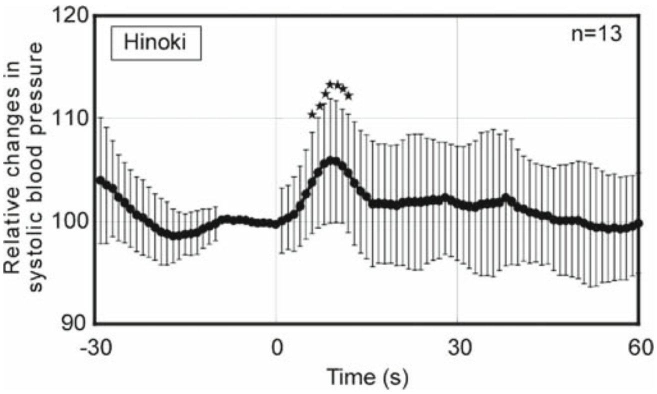


**Fig. 7.** Changes in systolic blood pressure after touching a hinoki board, expressed as relative changes when the average values for 10 s before simulation were assumed to be 100. Data given as mean ± standard deviation. *Stars*, $P < 0.05$ (paired *t*-test)

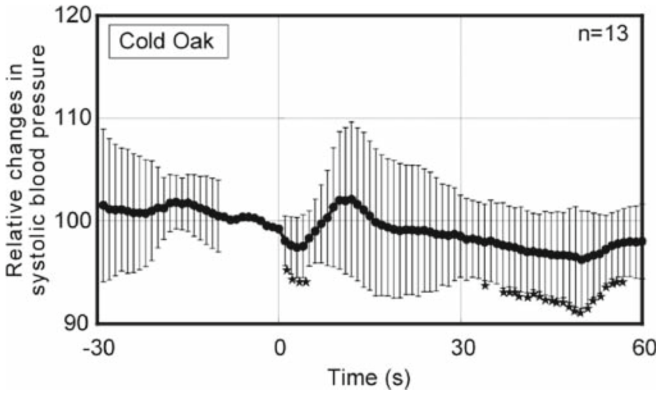


**Fig. 9.** Changes in systolic blood pressure after touching a cold oak board, expressed as relative changes when the average values for 10 s before simulation were assumed to be 100. Data given as mean ± standard deviation. *Stars*, $P < 0.05$ (paired *t*-test)

Figure 7 shows changes over time in systolic blood pressure before and after contact with hinoki. Blood pressure rose transiently 6–12 s after contact, with no significant difference afterward.

Figure 8 shows changes over time in systolic blood pressure before and after contact with oak. Blood pressure rose transiently 7–13 s after contact, with no significant difference afterward as with hinoki. Contact with wood kept at room temperature that produced a subjectively coarse/natural sensation caused no significant change in blood pressure except for a transient increase in blood pressure just after contact.

Figure 9 shows changes over time in systolic blood pressure before and after contact with oak cooled to 5°C. Blood pressure decreased significantly 1–4 s, 34 s, and 37–57 s after contact. Contact with oak kept at room temperature caused no significant change in blood pressure except for a transient increase in blood pressure just after contact, and contact with cold oak cooled to 5°C caused no increase in blood pressure; if anything, a slight decrease was observed. Although contact with cold oak produced a subjective sensation of danger and discomfort, the sympathetic nerve dominance caused no stressful state, with no correspondence between subjective evaluation and physiological responses. This result may be reflected in the fact that oak, even when cooled, produced a coarse and natural sensation according to the subjective evaluation. However, it does not explain why systolic blood pressure decreased in the case of cold oak significantly even though it does not decrease in the case of oak at room temperature.

Figure 10 shows changes over time in systolic blood pressure before and after contact with acrylic plastic. Blood pressure rose significantly 8–13 s and 20–32 s after contact. In contrast, Fig. 11 shows changes over time in systolic blood pressure before and after contact with acrylic plastic cooled to 5°C. Blood pressure rose significantly 6–15 s and 21–60 s after contact. Contact with acrylic plastic kept at room temperature caused a significant increase in blood pressure, while contact with acrylic plastic cooled to 5°C caused an even more remarkable rise, prolonging the time during which blood pressure was significantly high. In the subjective evaluation, contact with acrylic plastic kept at room temperature was rated only as a flat/artificial sensation, while contact with cold acrylic plastic produced a flat/artifi-

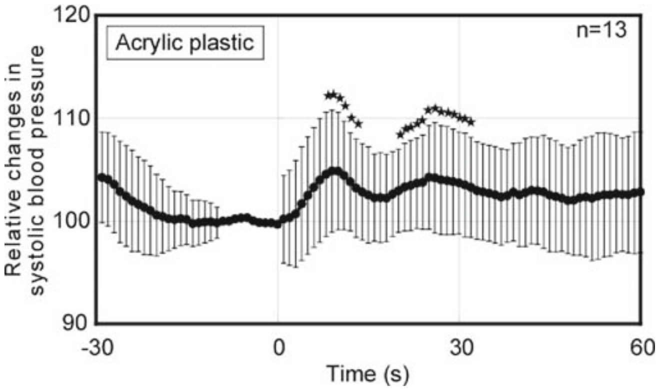


**Fig. 10.** Changes in systolic blood pressure after touching an acrylic plastic board, expressed as relative changes when the average values for 10s before simulation were assumed to be 100. Data given as mean ± standard deviation. *Stars*, $P < 0.05$ (paired *t*-test)

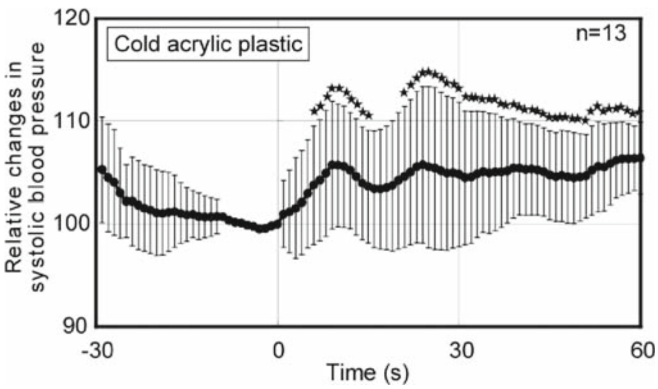


**Fig. 11.** Changes in systolic blood pressure after touching a cold acrylic plastic board, expressed as relative changes when the average values for 10s before simulation were assumed to be 100. Data given as mean ± standard deviation. *Stars*, $P < 0.05$ (paired *t*-test)

cial and dangerous/uncomfortable sensation and increased blood pressure significantly. In other words, subjective evaluation is well matched with physiological responses when contact is made with artificial materials, while subjective evaluation does not match physiological responses when contact is made with wood. Although contact with cold wood produces a subjective sensation of danger and discomfort, it induces no physiological state of stress, showing the advantage of natural materials.

Figure 12 shows changes over time in systolic blood pressure before and after contact with coated oak. Contact with coated oak had a tendency to increase systolic blood pressure. In addition, coated oak produced a less coarse, natural, safe, and comfortable sensation than uncoated oak on subjective evaluation, showing that urethane coating reduces the inherent superiority of wood whether measured subjectively or physiologically.

The above results for cold oak, cold acrylic plastic and coated oak suggest that human bodies are designed to respond positively to natural materials.

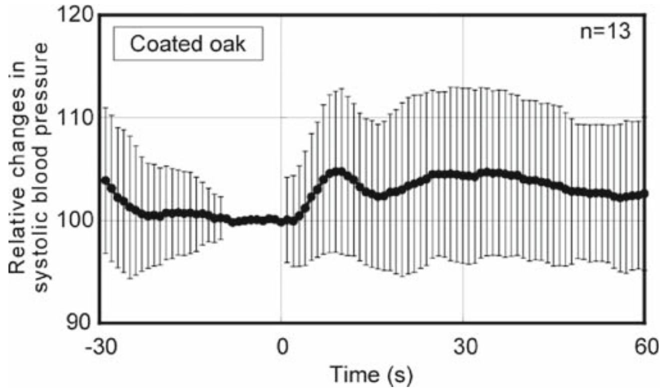


**Fig. 12.** Changes in systolic blood pressure after touching a urethane-coated oak board, expressed as relative changes when the average values for 10s before simulation were assumed to be 100. Data given as mean ± standard deviation

## Conclusions

The main points revealed by this study are:

1. Contact with wood produces a safe/comfortable and coarse/natural sensation and creates no physiological state of stress.
2. Contact with cold wood produces a subjectively dangerous/uncomfortable sensation, but it also produces a coarse/natural sensation and induces no physiological state of stress; in other words, subjective evaluation does not match physiological responses.
3. Contact with aluminum kept at room temperature or cold acrylic plastic produces flat/artificial and dangerous/uncomfortable sensations and increases systolic blood pressure, showing that subjective evaluation closely matched the physiological responses.

It can be concluded that contact with wood, unlike artificial materials such as aluminum, causes no physiological state of stress even if kept at room temperature or cooled.

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