Doctoral Dissertation (Shinshu University)

Investigation into the relationship between human feeling and characteristics of wood by using subjective and objective evaluations

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Contents

Chapter 1

Introduction

1.1 Background

1.1.1 Feelings of comfort associated with wood

The feeling of comfort when touching wooden products or staying in a house constructed from wood is a common experience that has been investigated in a number of previous studies [1-3]. Nomura et al. investigated consumer preferences for wooden flooring materials using open-ended questioning, revealing that approximately 60% of participants preferred natural wood over artificial wood. In response to open-ended questioning, participants used words related to human feelings, including warm, kind, calm, friendly and natural [4]. Thus, previous evidence suggests that human beings prefer natural wood, which is associated with an unconscious positive sense of comfort.

Japan is heavily forested, with forest covering 68.5% of the country, providing substantial forestry resources [5]. However, the wood self-sufficiency rate in Japan is relatively low. To address this situation, the Japanese government enacted a law to promote the use of Japanese wood in 2010 [6]. Nevertheless, according to a report by the government Forest Agency, the wood self-sufficiency rate in Japan was 36.1% in 2017. This rate is lower than in many other heavily forested countries, such as Sweden, in which the wood self-sufficiency rate exceeds 100% [7, 8]. The detailed relationships between human emotion and the characteristics of wood are unclear. As suggested by Nakamura [9], a quantitative criterion for evaluating the sense of comfort evoked by wood could potentially be applied to the production of wooden goods, and may be useful for developing approaches for increasing the wood self-sufficiency rate in Japan.

1.1.2 Topics of this study and relevant studies

As mentioned in section 1.1.1, it is important to understand the relationships between human emotional states and the characteristics of wood, including what people perceive and feel when they use wooden products or spend time in wooden structures. Human feelings are typically based on five senses or perceptions: touch, taste, hearing, vision and smell. The relationships between human feelings and the characteristics of wood are likely to be complex, relying on multimodal perception and multisensory integration. For example, a previous study examined participants' impressions of Japanese cedar, assessed via tactile sensation and visual-tactile sensation [10]. In another study, a local Japanese cedar variety (*Yoshino Sugi*) was assessed via tactile, olfactory, and visual sensation [11]. Similarly, Overvliet et al. investigated natural impressions of wood via visual-tactile perception, tactile perception, and visual perception [12].

When encountering wooden products, people typically begin to instinctively handle them and feel their surfaces. Thus, visual observation and touch are important components in purchasing wooden products, and these behaviors are likely to interact through visual-tactile perception, as a form of multisensory integration. Therefore, the current study focused on the relationship between the visual-tactile impressions felt when observing and touching wood, and the characteristics of wood. The study was designed to determine the relative influence of the visual and tactile sensory modalities on visual-tactile perception. Therefore, the experiment described in Chapter 2 explored the relationships between the characteristics of wood and participants' sensations and feelings when subjectively evaluating wood.

Humans obtain a substantial amount of external information via visual perception [13], and many previous studies have investigated the relationships between visual perception and characteristics of wood [14-22]. One previous study reported a correlation between human feeling and the color and glossiness of wood [14]. Another study examined visual impressions of *Hinoki* (*Hinoki cypress*, white cedar) using two factors: “color pattern” and “personal preference” [15]. Moreover, the visual appearance of wood has been found to influence participants’ physical reactions [16-19]. Some of these previous studies have used “digital” images of wood, rather than actual wood [20-22]. Because tactile perception is important for examining this question, “actual” natural wood samples were used as stimuli in the current study. Tactile perception is also a fundamental perceptual modality in humans, and newborn infants typically rely heavily on sensations from the skin to obtain information about the external environment before vision and hearing are well developed [23]. Tactile sensation involves many different receptor organs and sensory modalities, such as heat and pressure [24, 25]. Thus, tactile perception itself is “multisensory”. The experiments described in Chapters 3 and 4 focused on tactile perception. Moreover, while the experiment described in Chapter 2 used a subjective evaluation method, the experiments in Chapters 3 and 4 examined hand movements, which are related to tactile perception, as an objective evaluation method.

Therefore, the current thesis sought to investigate the sense of comfort evoked by natural wood using subjective and objective evaluation methods.

1.2 Outline

The purpose of the current thesis was to investigate the sense of comfort evoked by the characteristics of wood, focusing on the relationship between human feeling (particularly the feeling of comfort) and the characteristics of wood, using a combination of sensory testing as a subjective measure, and hand movement as an objective measure.

In the current study, the sense of comfort was hypothesized to be evoked by the characteristics of wood via a three-layered process, as shown in Figure 1-1. The formation of visual-tactile impressions was investigated in Chapter 2. To reveal the relationships between visual-tactile impressions, visual impressions, and tactile impressions, a hypothetical three-layered model describing the formation of visual-tactile impressions was tested. The first layer involves the material properties of wood, the second layer generates visual and tactile impressions, and the third layer generates visual-tactile impressions. It is hypothesized that each layer is combined in a linear fashion. To verify this hypothetical model, the relationships were examined using sensory tests and measurements of the material properties of wood.

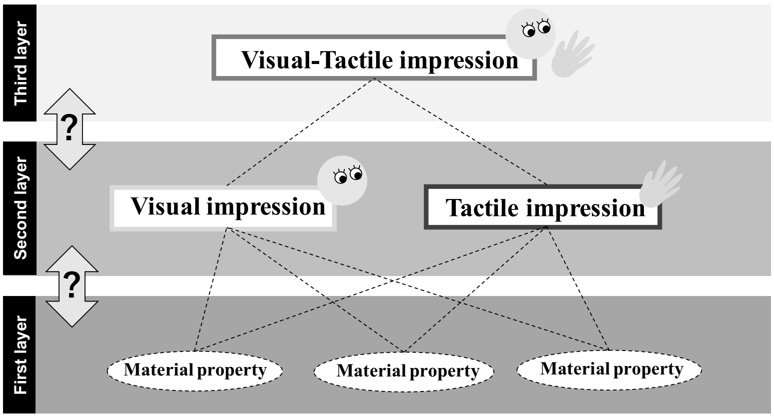


Figure 1-1. Three-layered hypothetical model

Tactile impressions are important when assessing wooden products. The experiment described in Chapter 3 focused on hand movements, which have a direct relationship with tactile impressions, as an objective evaluation method. Hand movements were measured while participants assessed wood with four fundamental terms related to material properties. To measure the characteristics of hand movements when assessing each term, a 3D real-time motion measurement system and a pressure distribution measurement system were used.

Overall, the purpose of this thesis was to investigate the relationships between the sense of comfort and the characteristics of wood. The experiment described in Chapter 4 examined hand movements when assessing the impression of comfort and subjective preferences from the characteristics of wood. Moreover, hand movements were classified while participants evaluated these two emotional terms, based on the hand movements identified in Chapter 3.

Chapter 5 presents a summary of the findings, and possibilities for future research.

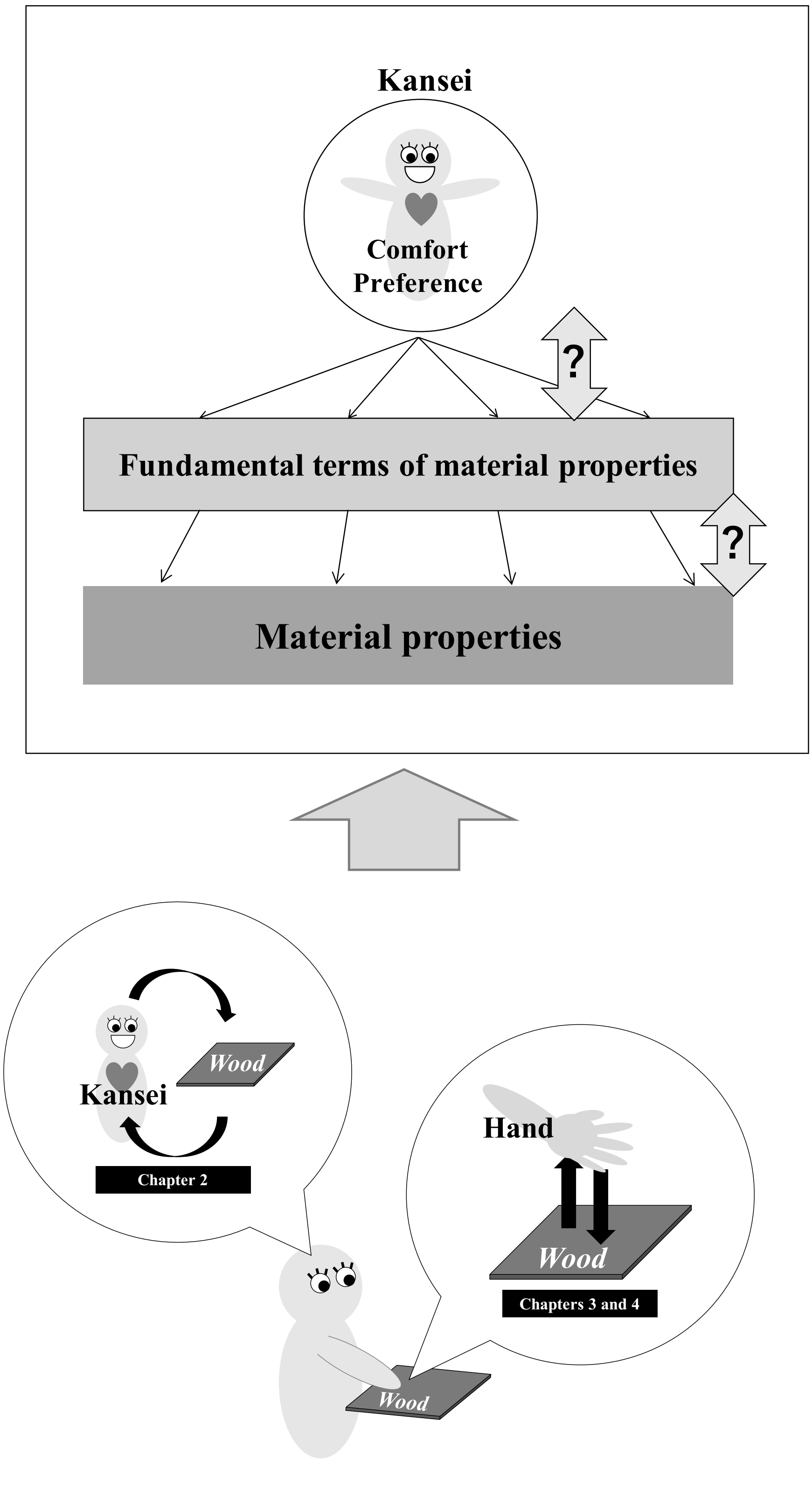


Figure 1-2. Key concepts in this thesis

Chapter 2

Investigation of the relationships between tactile impressions, visual impressions, and visual-tactile impressions when evaluating the characteristics of wood specimens

2.1 Introduction

When encountering wooden products, people often instinctively handle them and feel their surfaces. Thus, observation and touch are important when purchasing wooden products, and these sensory modalities are likely to function together through visual-tactile perception, as a form of multisensory integration. Therefore, the experiments in the current thesis examined the relationship between visual-tactile perception and the characteristics of wood, using the following research questions: what is the relative influence of visual perception and tactile perception on visual-tactile perception, and how are these perceptual modalities influenced by the material properties of wood. In a previous study, Overvliet et al. examined the correlation between visual-tactile perception and tactile and visual perception when assessing participants' natural impressions [12]. However, the influence of the material properties of wood on tactile and visual perception remains unclear. Therefore, the study described in the current Chapter 2 examined the relationships among tactile perception, visual perception, and visual-tactile perception, when evaluating the characteristics of wood, using a sensory evaluation method.

To elucidate the relationship between the sense of comfort associated with characteristics of wood, the formation of impressions must be understood. Thus, the study in Chapter 2 was designed to investigate the formation of visual-tactile impressions in relation to wood. To investigate the relationship between tactile perception, visual perception, and visual-tactile perception, a hypothetical three-layered model is proposed. The first layer involves the material properties of wood, the second layer involves visual and tactile impressions, and the third layer involves the generation of visual-tactile impressions. This model hypothesizes that the first and the second layers are combined in a linear fashion, and the second and the third layers are also linearly combined. To verify this hypothetical model, the relationships among layers were examined using sensory tests and measurements of material properties.

2.2 Purpose

The purpose of this experiment was to investigate the relationships between human feeling and the characteristics of wood via subjective evaluation. Specifically, the formation of visual-tactile impressions was examined. To investigate the relationship between the visual-tactile impression and visual or tactile impressions, a hypothetical three-layered model was proposed. To verify this hypothetical model, the relationships between material properties of wood, visual or tactile impressions and visual-tactile impressions were examined using measurements of material properties and sensory tests.

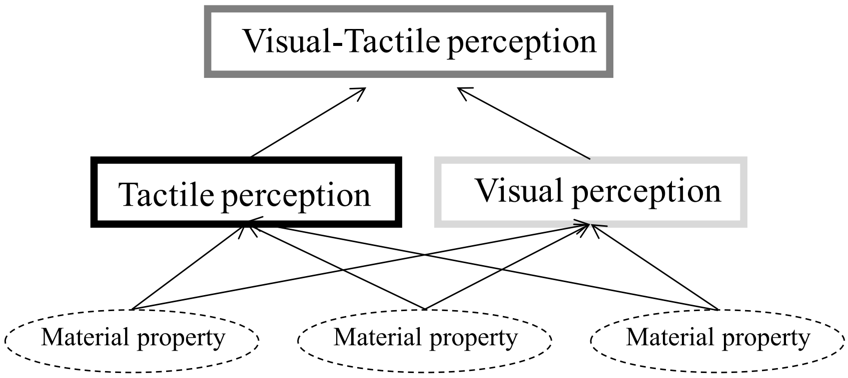


Figure 2-1. Hypothetical three-layered model of the formation of visual-tactile impressions

2.3 Wood specimens

2.3.1 Wood species and coatings

Eight wood specimens were prepared [26, 27], including four wood species and two types of coating.

The four wood species were beech (*Fagus sp*), Japanese cedar (*Cryptomeria japonica*), oak (*Quercus crispula*), and black walnut (*Juglans nigra*). The characteristics of each wood species are described below:

- Beech is a hardwood, and is white and light brown in color. The wood has a dotted pattern rather than a clear grain.
- Japanese cedar is a softwood with a light brown color. It is relatively soft and has a clear straight grain.
- Oak is a hardwood with a light brown color. It has a special silver-gray grain, known as torafu in Japanese, which looks similar to the markings of a tiger (tora).
- Black walnut is a hardwood with a dark brown color.

Before coating, all wood specimens were sanded with sandpaper (abrasive grain size #180 and #240). Oil and urethane coating were then applied.

Oil coating is an impregnation technique in which wood specimens are painted using a brush, retaining the natural texture of the wood. After under-coating (IG-12, Gen gen Corporation, Aichi, Japan), wood specimens were sanded again using sandpaper (#400) and top-coating was applied (IG-17, Gen gen Corporation, Aichi, Japan).

Urethane coating is a film-forming technique using a spray, and is a widely used method in furniture production. After under-coating (base compound: UW-33-P; hardening compound: CB-079; diluent: TU-12-P; Gen gen Corporation, Aichi, Japan; ratio of base compound: hardening compound: diluent = 1 : 1 : 0.75), wood specimens were sanded again with sandpaper (#400). Middle-coating was then undertaken (base compound: US-30-CP; hardening compound: CB-079; diluent: TU-12-P, Gen gen Corporation, Aichi, Japan; ratio of base compound: hardening compound: diluent = 1 : 0.5 : 0.75), and specimens were sanded again with sandpaper (#400). Finally, top-coating was applied (base compound: UF-25-99P; hardening compound: CB-079; diluent: TU-12-P, Gen gen Corporation, Aichi, Japan; ratio of base compound: hardening compound: diluent = 1 : 1 : 0.75).

All specimens were square, with dimensions of 280 mm (longitudinal direction; L) × 280 mm (radial direction; R) × 10 mm (tangential direction; T). These sets were prepared for each wood specimen to avoid the effects of individual differences. The following abbreviations were used for each type of wood: beech (B), Japanese cedar (C), oak (O) and black walnut (W). Each type of coating was abbreviated as follows: oil coating (o) and urethane coating (u). Thus, beech with oil coating was abbreviated to (Bo).

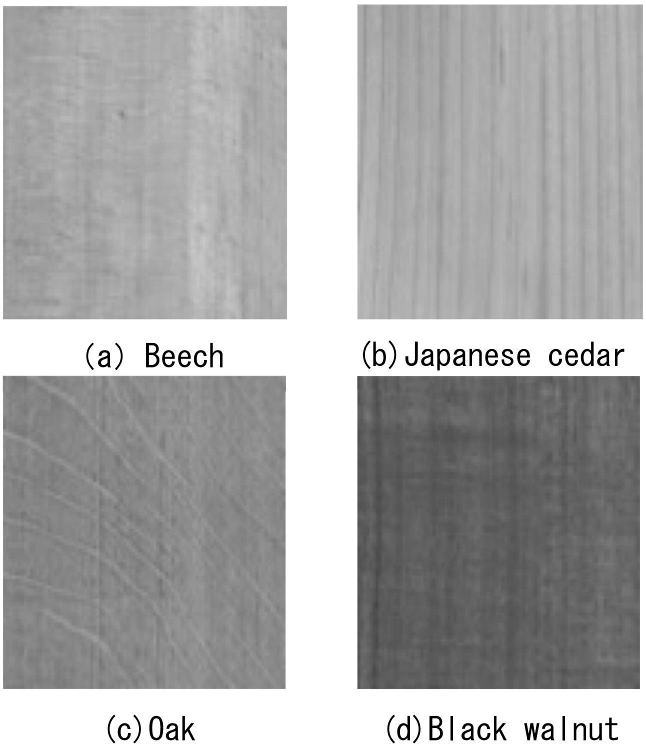


Figure 2-2. Specimens of four species

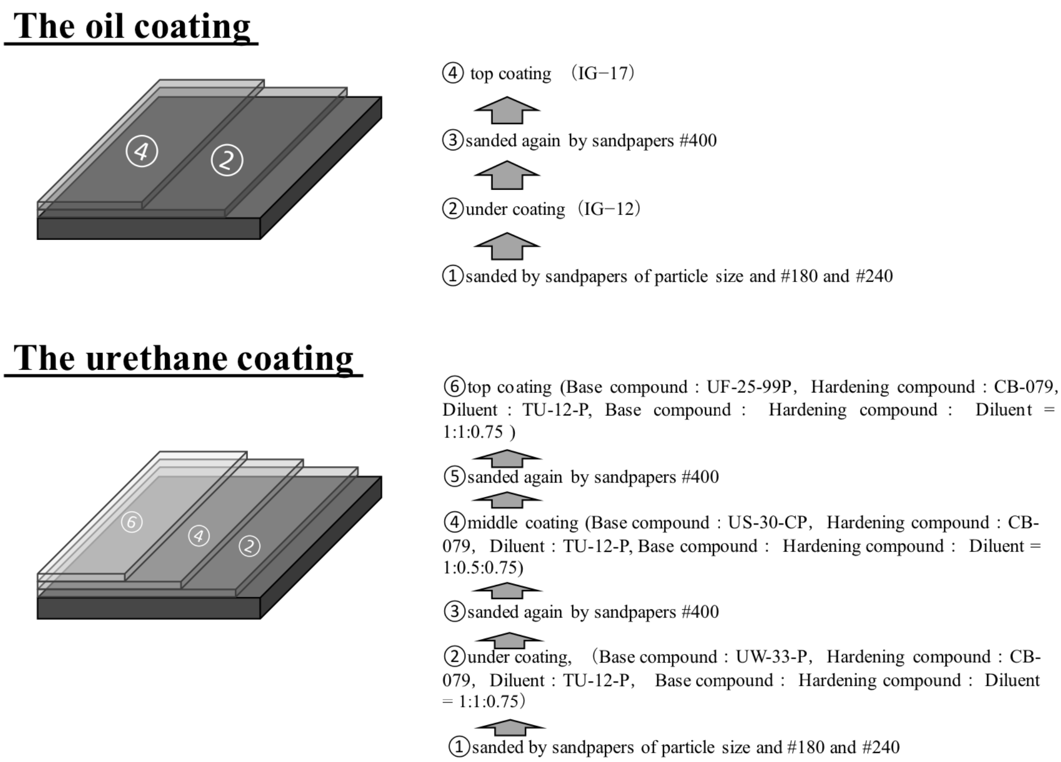


Figure 2-3. Surface treatment with two coating types

2.3.2 Measurement of material properties

Material properties were measured by each method. The measurement environment was 20°C and 50% RH. All test specimens were kept in a room at that measurement environment for more than 24 hours before measurement.

I. Surface hardness

The hardness (Brinell hardness) of the specimens was measured on the Brinell scale using a mechanical tester (AUTOGRAPH AG-IS, SHIMADZU Co., Kyoto, Japan). The protocol followed JIS Z2101:2009 [28], except for the size of specimens. Hardness was measured at 12 different points for each specimen, and the measured values were averaged.

II. Maximum value of heat flux (q-max) as a thermal property

"q-max" (peak heat flux) scores can be used to reflect thermal properties, measured using the Kawabata Evaluation System Thermo Labo IIB (KES F7, Katotech Co., Kyoto, Japan). Immediately after touching an object, heat flux per unit area increased sharply and reached a maximum value, then decreased. Kawabata et al. reported that heat flux reached a maximum value within 0.2 s after touching a cloth. Higher q-max scores are associated with a cooler sensation when touching an object [29].

If the field of wood research, thermal conductivity is commonly used to measure the thermal properties of wood [12, 30]. However, Sakuragawa et al. reported a strong correlation between cool-warm impressions and heat flux [31]. Therefore, the current study focused on heat flux when touching wood, and q-max was employed as the thermal property.

q-max was measured at nine different points for each specimen, and the measured values were averaged.

III. Coefficient of dynamic friction

The coefficient of dynamic friction was measured using a friction measurement system (Tribo Mastor TL201Ts, Trinity Lab Co., Tokyo, Japan). The indenter was constructed from polyurethane resin, and mimics the human fingerprint to represent the human finger [32, 33]. Preliminary tests were conducted, and the following specifications were determined: 1 ms sampling frequency, 10 mm/s velocity, and 40 mm measurement distance. The size of the indenter was 32 mm × 14 mm, and the area of the fingerprint was 15 mm × 10 mm with a depth of 150 μm at 500 μm intervals. Four measurements were conducted for each direction (parallel and perpendicular to the grain) for each specimen, and the measured values were averaged.

IV. Color properties

Color properties (L^*, a^* and b^*) of the specimens were measured with a color-difference meter (Spector Color Meter SE 2000, Nippon Denshoku Industries Co., Ltd., Tokyo, Japan). L^* represents brightness, a^* represents reddish and greenish color properties, and b^* represents yellowish and bluish color properties. Measurements were conducted at nine different points for each specimen, and the measured values were averaged.

V. Density

Density of three sets for each specimen was measured and calculated with a digital weight scale, and the measured values were averaged.

The material properties of eight specimens are shown in Table 2-1.

Table 2-1. Material properties of eight specimens.

Specimens	Hardness (N/mm^2)	q-max ($W/c\ m^2$)	Coefficient of dynamic friction		Color properties			Density ($g/c\ m^3$)
			Parallel to grain	Perpendicular to grain	$L*$	$a*$	$b*$	
Beech -oil coating	15.12	0.14	0.25	0.26	68.02	9.43	30.24	0.66
Beech -urethane coating	14.63	0.15	0.33	0.34	67.20	9.37	29.03	0.67
Japanese cedar -oil coating	10.31	0.11	0.18	0.18	66.70	11.17	31.05	0.37
Japanese cedar - urethane coating	9.62	0.12	0.20	0.23	63.42	12.83	28.72	0.38
Oak -oil coating	23.18	0.14	0.16	0.15	56.24	10.10	28.79	0.77
Oak -urethane coating	21.83	0.14	0.20	0.17	56.87	9.33	27.18	0.72
Black walnut -oil coating	14.07	0.14	0.15	0.17	37.77	8.93	13.83	0.64
Black walnut - urethane coating	15.63	0.14	0.15	0.16	39.51	10.01	15.91	0.64

Note: Beech: *Fagus sp*; Japanese cedar: *Cryptomeria japonica*; oak: *Quercus crispula*; black walnut: *Juglans nigra*. Dimensions of the specimens were 280 mm (L) × 280 mm (R) × 10 mm (T). All test specimens were kept in a room at 20°C and 50% relative humidity (RH) for more than 24 hours before measurement.

2.4 Methods

2.4.1 Procedure

Eight wood specimens, as described in section 2.3.1 above, were prepared for this experiment, and 37 university students (male: 19; female: 18) were recruited as participants. The experiments were carried out over 3 days. On the first day, participants were instructed to touch the wood specimens without looking at them ("tactile perception"). On the second day, participants were instructed to visually observe the wood specimens without touching them ("visual perception"). On the third day, participants observed and touched the wood specimens ("visual-tactile perception"). The experiments were performed in the experimental room maintained at 20°C and 50% RH, and an average luminance of 1,339 ± 551 lx.

On the first day, when performing the tactile perception test, a test specimen was placed in a black box. Participants reached into the box with their hand, and touched the test specimen without looking. Participants sat on a chair and touched the specimen freely with their palm, but were instructed not to scratch or hold it.

When performing the visual perception test on the second day, a test specimen was placed on a black table. Participants sat on a chair and observed the specimen without touching it.

When performing the visual-tactile perception test on the third day, the test specimen was placed on a black table. Participants sat on a chair and observed the specimen while touching it freely with their palm, but were instructed not to scratch or hold it.

After assessing the test specimen for approximately 60 s, participants gave verbal responses in the sensory test, and responded to open-ended questioning. Eight wood specimens were presented in a random order, and the position of each specimen was kept with the grain perpendicular to the participant.

Statistical analyses were performed with an Excel statistical software package (Excel-Toukei 2012; Social Survey Research Information Co., Ltd.). The Kolmogorov-Smirnov test was used to test the normality of the data for four wood species and two types of coating. Because normality was not confirmed, non-parametric methods were applied. The Wilcoxon signed-rank test was performed to analyze differences between coating conditions, and the Friedman test was performed to analyze differences between the four wood species.

To investigate the influence of material properties on impressions of wood specimens, multiple regression analyses were performed. Objective variables were scores for tactile or visual perception, and explanatory valuables were the scores of material properties. However, the study design involved several limitations. Because the experiment examined a large number of material properties, the coefficient of determination was larger than expected. Moreover, there was a possibility of multicollinearity because of strong correlations among material properties. To address these issues, principal component analysis (PCA) was carried out to reduce the data and create new feature quantities to demonstrate comprehensive characteristics of material properties. In addition, a forward selection method was utilized to solve this problem in multiple regression analysis. Using these procedures, the explanatory variable was the principle component score derived from material properties, and the objective variable was the visual or tactile perception score. Thus, these analyses were used to examine the relationships between material properties and visual perception or tactile perception.

Moreover, the relationships between visual-tactile perception, visual perception, and tactile perception were examined. The objective variable was the visual-tactile perception score, and the explanatory variable was the visual and tactile perception score.

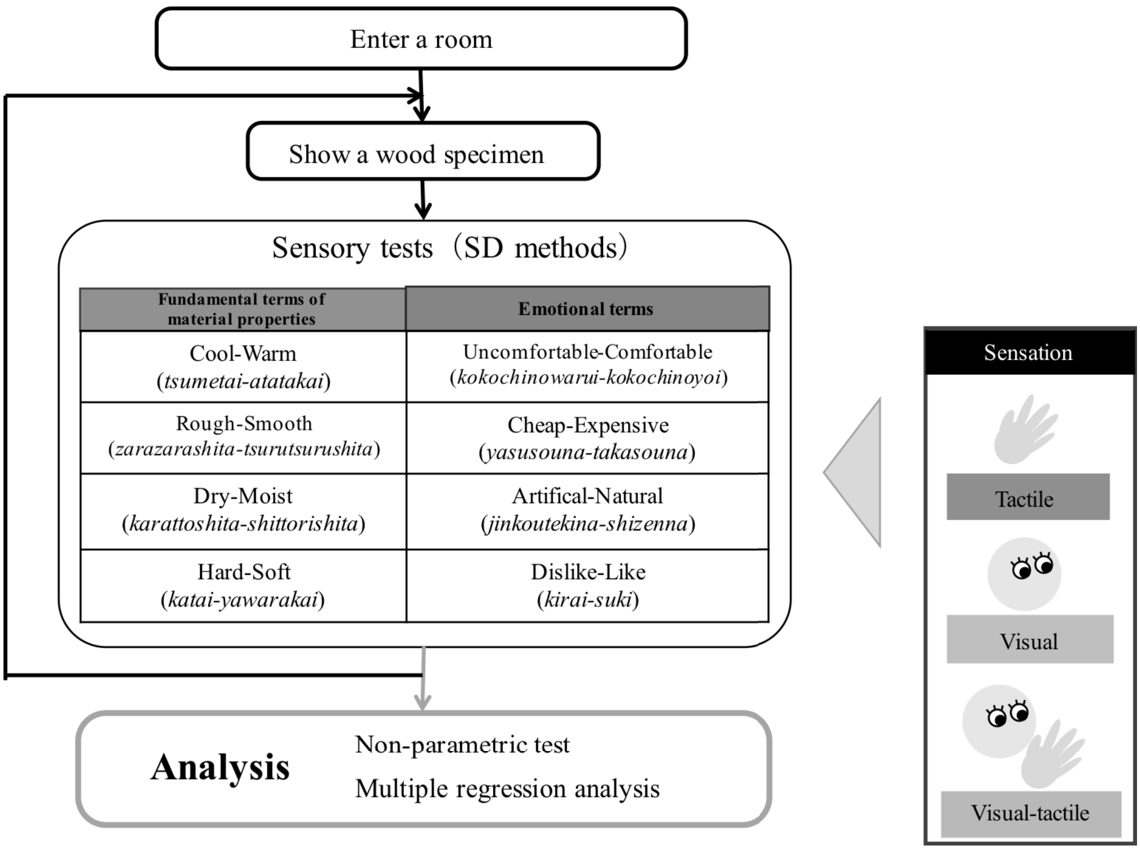


Figure 2-4. Experimental outline

2.4.2 Sensory tests

A semantic differential (SD) method was used as a sensory test, with a 7-grade scale. The evaluation terms were determined in reference to a previous study by Nakamura et al. [9]. "Cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*),", "dry-moist (*karattoshita-shittorishita*)," and "hard-soft (*katai-yawarakai*)" were the four fundamental terms for material properties. The four emotional terms were "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)," "cheap-expensive (*yasusouna-takasouna*)," "artificial-natural (*jinkoutekina-shizenna*)," and "dislike-like (*kirai-suki*)," based on feeling and Kansei (emotional feeling).

2.5 Results and discussion

2.5.1 Results of tactile perception, visual perception, and visual-tactile perception

Figure 2-5 shows the sensory test results for evaluating tactile impressions. Significant differences were found in "cool-warm (*tsumetai-atatakai*)" and "rough-smooth (*zarazarashita-tsurutsurushita*)" for both coating type and wood species, and significant differences were found between coating types for "dry-moist (*karattoshita-shittorishita*)," "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)," "artificial-natural (*jinkoutekina-shizanna*)," and “dislike-like (*kirai-suki*)”. Of the four wood species, only Japanese cedar was associated with the impression of warmth. Urethane coating was associated with smooth and moist impressions, compared with oil coating. Since participants obtained information about the surface by touching without observing specimens, the results indicated that differences between the two coating types affected participants’ assessments.

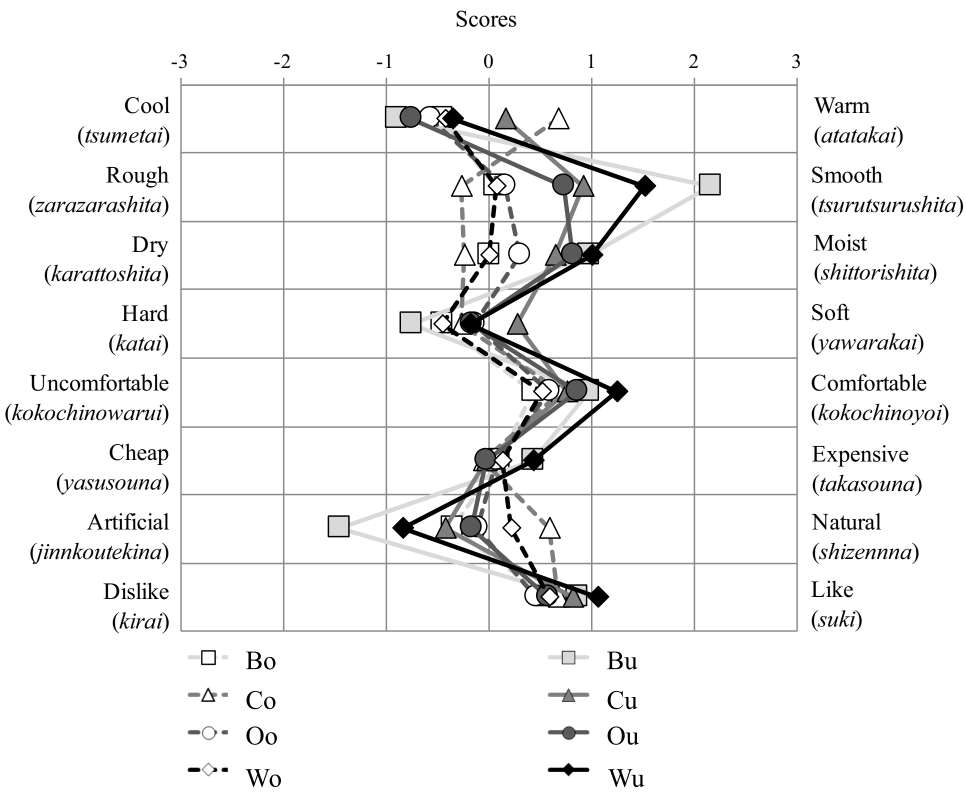


Figure 2-5. SD profiles of tactile impressions of eight specimens

Figure 2-6 shows the sensory test results when evaluating visual impressions. Significant differences were found between wood species, but not coating types, when assessing emotional terms. These were not found in terms related to fundamental material properties. Responses to open-ended questions indicated that participants focused on color and the presence of grain. When assessing oak specimens, participants felt a sense of discomfort, and a negative impression was associated with "torafu," a type of grain specific to oak. Thus, the color and grain of the wood specimens were found to influence participants' visual impressions.

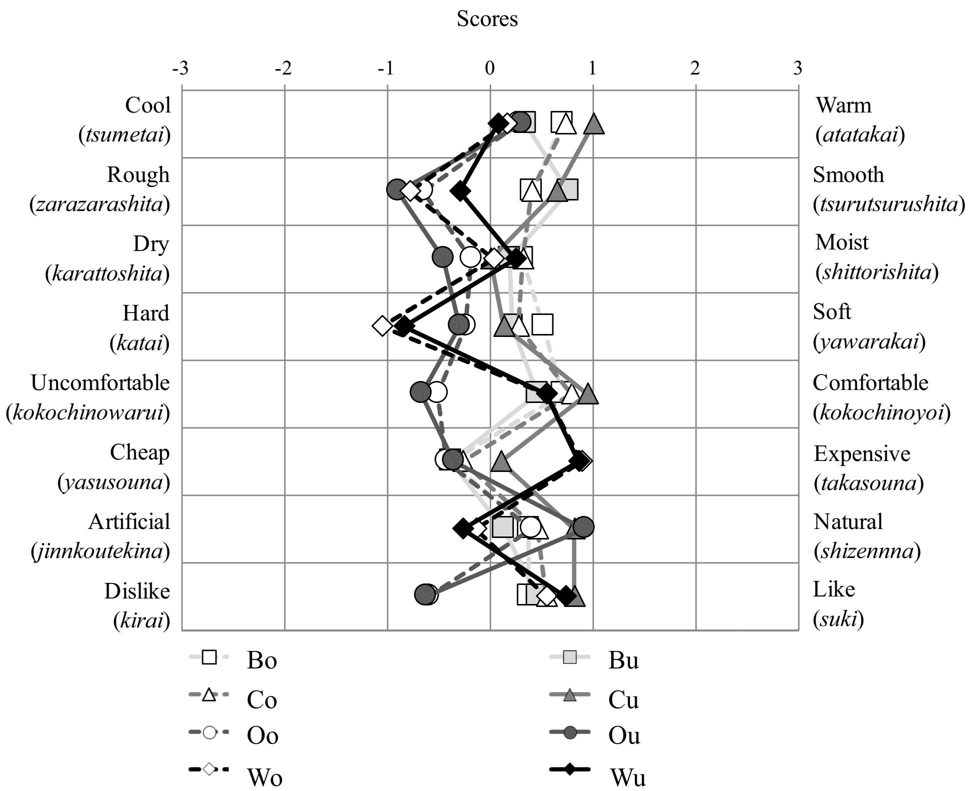


Figure 2-6. SD profiles of visual impression of eight specimens

Figure 2-7 shows the sensory test results when evaluating visual-tactile impressions. Significant differences were found for all terms between wood species, and for all terms except "hard-soft (*katai-yawarakai*)" between coating types. Many significant differences were found compared with tactile or visual impressions, suggesting that participants assessed these impressions by integrating tactile and visual perceptions.

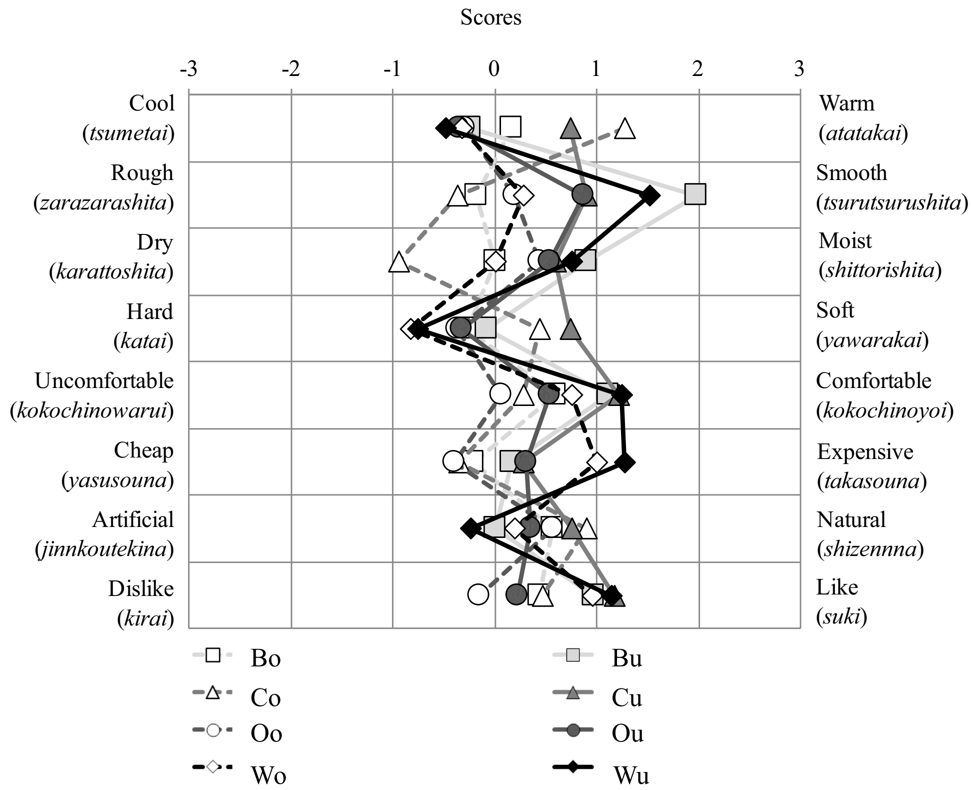


Figure 2-7. SD profiles of visual-tactile impressions of eight specimens

Figures from 2-8 to 2-15 show the sensory test results with three impressions of each specimen. The results revealed a similar tendency between tactile and visual-tactile impressions in the fundamental terms of material property, and between visual impressions and visual-tactile impressions in emotional terms.

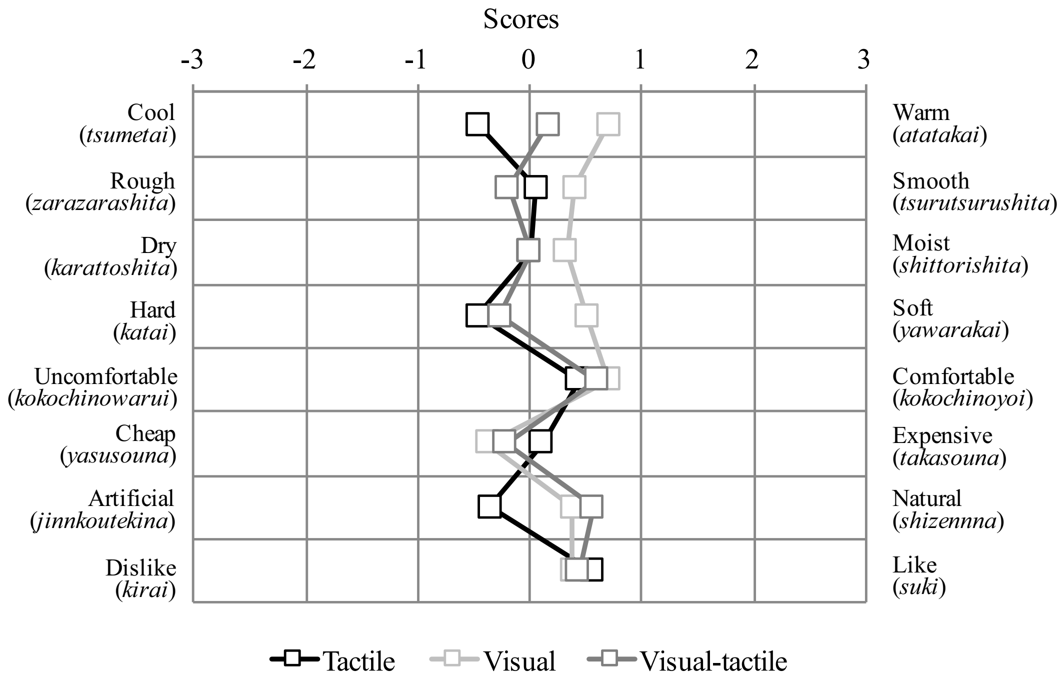


Figure 2-8. SD profiles of three impressions of Beech-oil coating

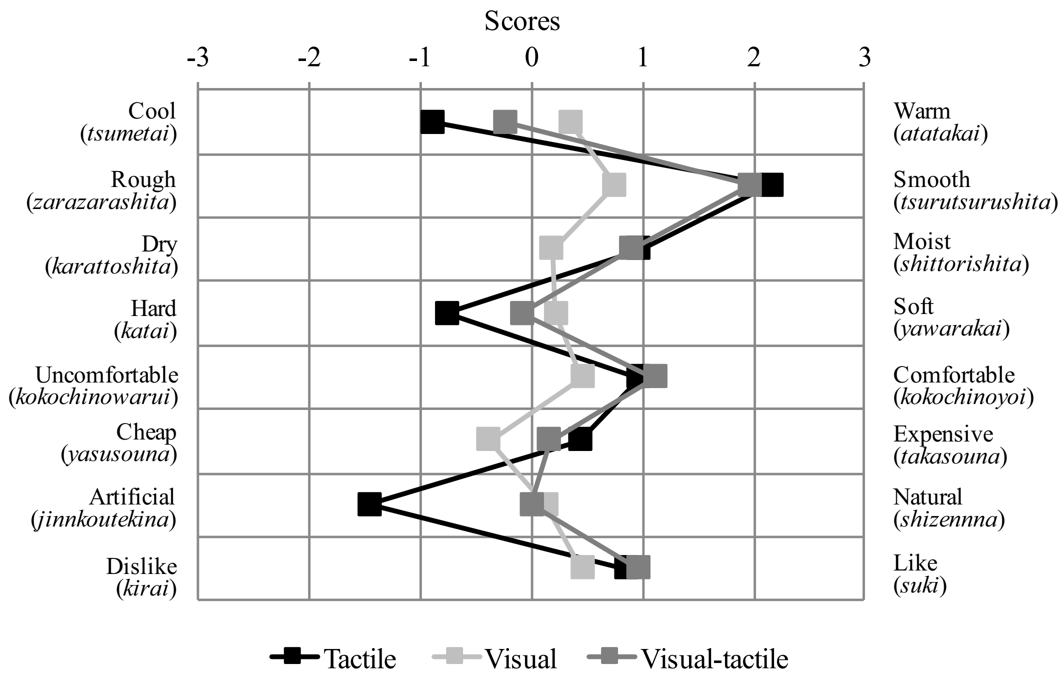


Figure 2-9. SD profiles of three impressions of Beech - urethane coating

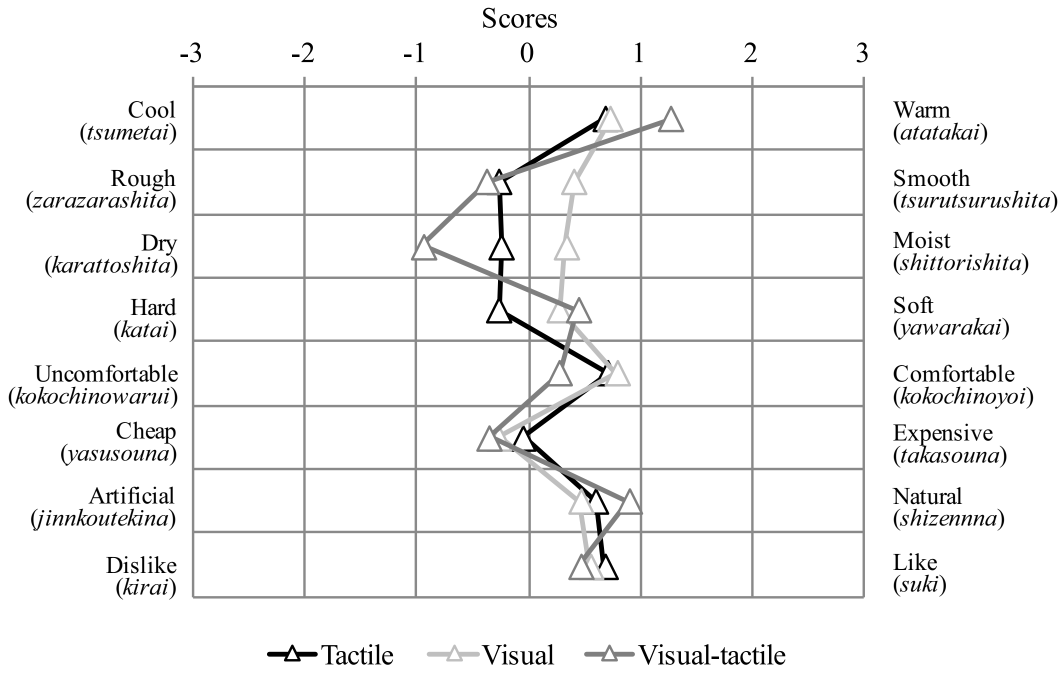


Figure 2-10. SD profiles of three impressions of Japanese cedar - oil coating

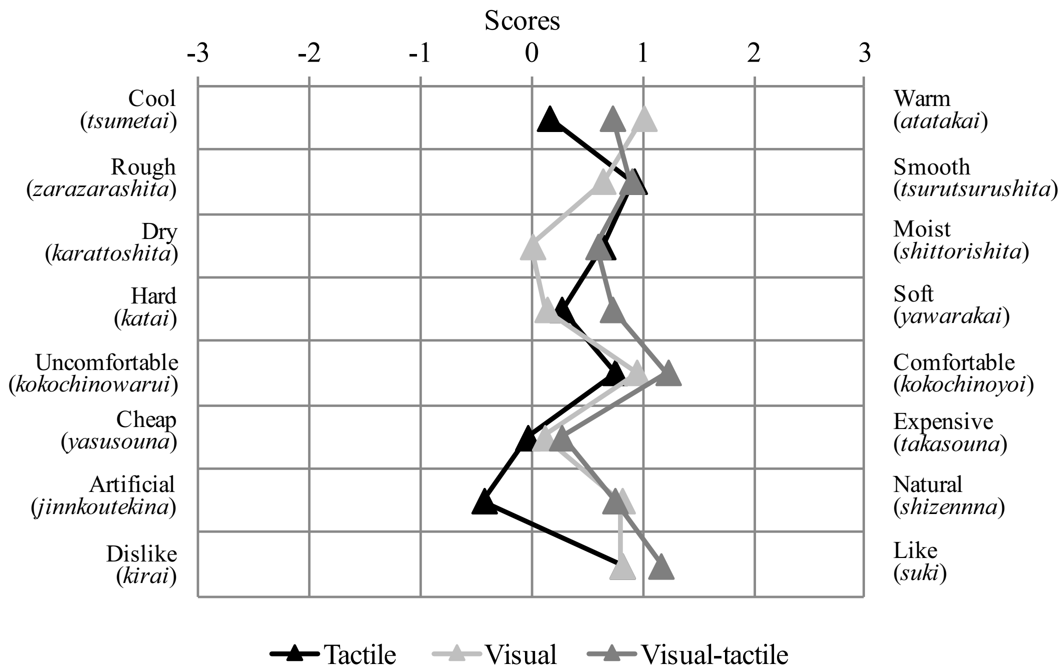


Figure 2-11. SD profiles of three impressions of Japanese cedar - urethane coating

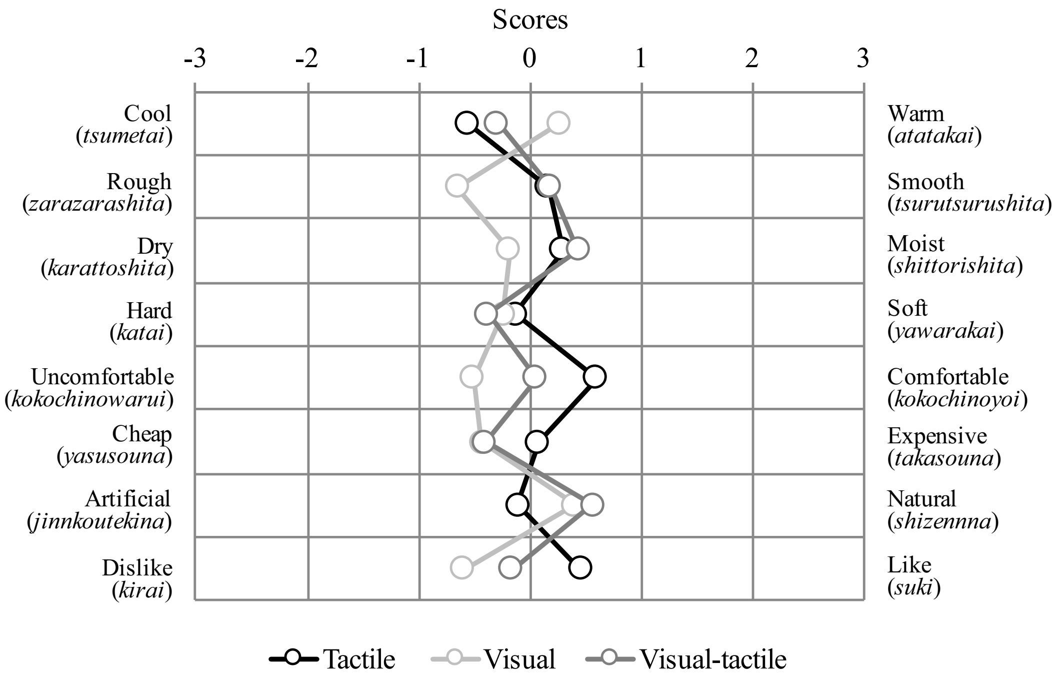


Figure 2-12. SD profiles of three impressions of Oak - oil coating

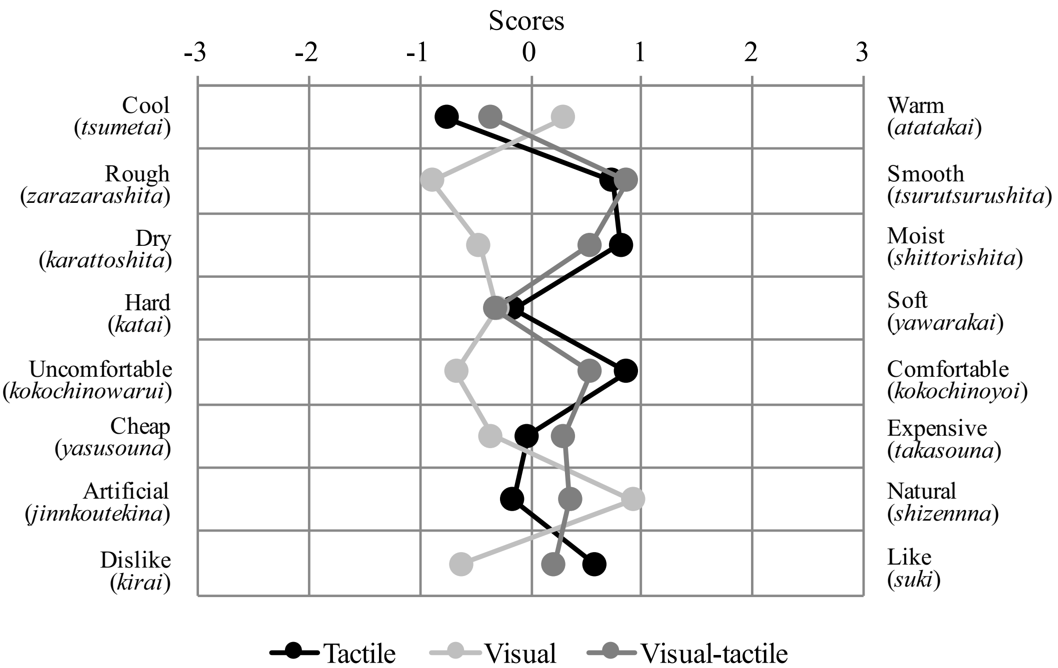


Figure 2-13. SD profiles of three impressions of Oak - urethane coating

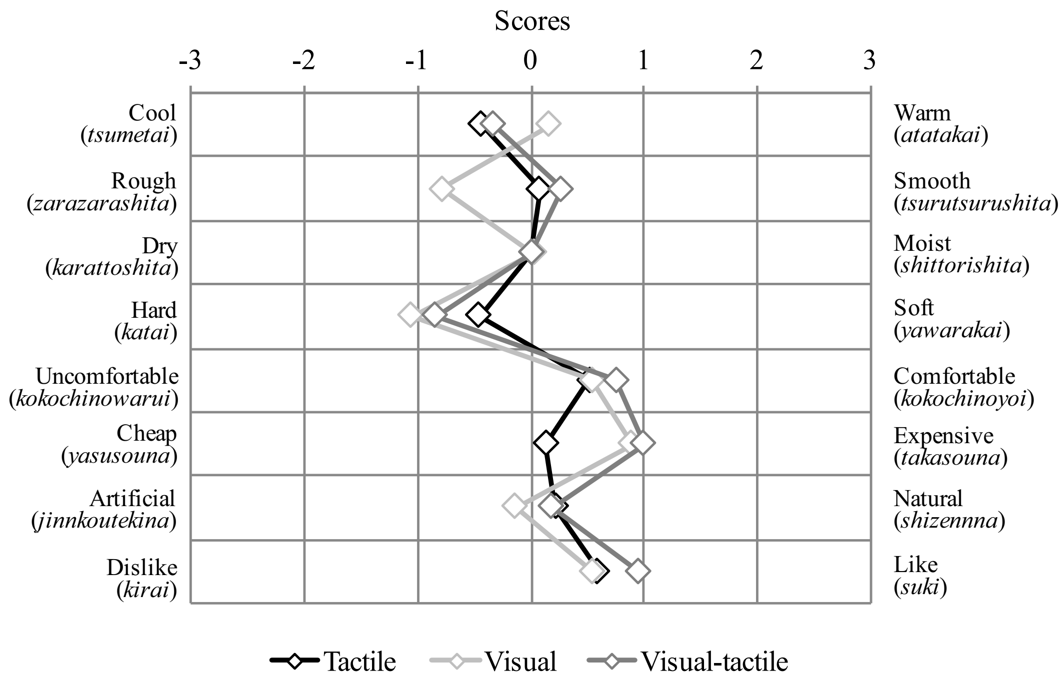


Figure 2-14. SD profiles of three impressions of Black walnut - oil coating

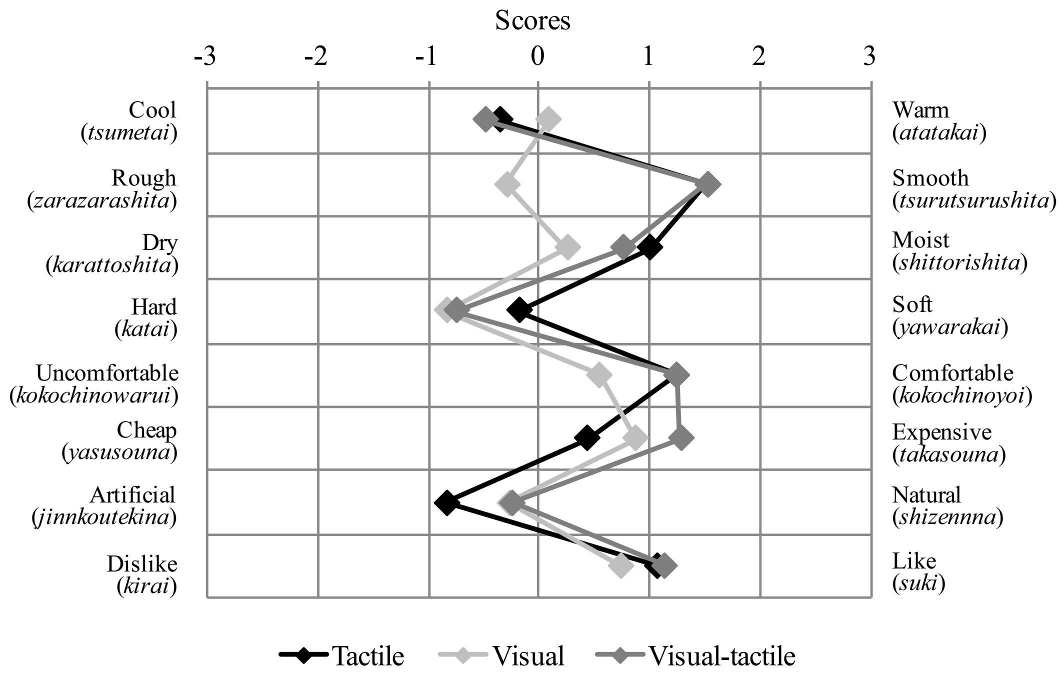


Figure 2-15. SD profiles of three impressions of Japanese cedar - urethane coating

The results of the sensory tests shown in Tables 2-2 and 2-3 suggest that tactile perception influenced participants' impressions related to fundamental terms of material properties, while visual perception influenced impressions related to emotional terms. The results revealed significant differences between coatings when assessing tactile impressions and visual-tactile impressions, and there were significant differences between wood species when assessing visual impressions and visual-tactile impressions. There was no significant difference between wood species in terms of comfort and preference when evaluating only via tactile impressions. However, there were significant differences in comfort and preference when assessing via visual impressions and visual-tactile impressions. Thus, the results suggested that visual perception plays an important role in evaluating emotional terms.

Table 2-2. Statistical analyses were performed using the Wilcoxon signed-rank test to examine the difference in three impressions (tactile, visual, and visual-tactile) between coating types

Sensory terms	Tactile	Visual	Visual-tactile
Cool-warm (*tsumetai-atatakai*)	*		*
Rough-smooth (*zarazarashita-tsurutsurushita*)	**		**
Dry-moist (*karattoshita-shittorishita*)	**		**
Hard-soft (*katai-yawarakai*)			
Uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)	**		**
Cheap-expensive (*yasusouna-takasouna*)			**
Artificial-natural (*jinkoutekina-shizenna*)	*		**
Dislike-like (*kirai-suki*)	*		**

Note: **: $p < 0.01$; *: $p < 0.05$. Scores of each term were rated from −3 to +3, and arithmetical means of every adjective pair were calculated.

Table 2-3. Statistical analyses were performed with the Friedman test to examine differences among species in three impressions (tactile, visual and visual-tactile)

Sensory terms	Tactile	Visual	Visual-tactile
Cool-warm (*tsumetai-atatakai*)	**	**	**
Rough-smooth (*zarazarashita-tsurutsurushita*)	**	**	**
Dry-moist (*karattoshita-shittorishita*)			*
Hard-soft (*katai-yawarakai*)		**	**
Uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)		**	*
Cheap-expensive (*yasusouna-takasouna*)		**	**
Artificial-natural (*jinkoutekina-shizenna*)		**	**
Dislike-like (*kirai-suki*)		**	**

Note: **: $p < 0.01$; *: $p < 0.05$. Scores of each term were calculated as noted in the footnote of Table 2-2.

2.5.2 Relationship between tactile or visual impressions and material properties

To reduce the numbers of material properties and summarize the characteristics of wood, PCA was performed, and new variables representing the features of material properties were extracted as principal components. The material properties were as follows; Brinell hardness, q-max score, coefficient of dynamic friction (two directions; parallel and perpendicular to grain) and color properties; L^*, a^* and b^*. The cumulative contribution ratio reached 80.35% by summing the first two principal components. Because this was an acceptably large percentage, two principal components were utilized to summarize the features of the material properties. The loadings of principal components are shown in Table 2-4. Since the loadings of L^*, $b^*$and friction were positive values greater than 0.5 for the first principal component, this was interpreted as a "surface texture from coating" component. Since the loading of q-max was positive and that of a^* was negative, and greater than |0.5| for the second principal component, this was interpreted as a "wood species" component. Principal component scores of each specimen are shown in Table 2-5.

Table 2-4. Principal component loadings of material properties determined by principal component analysis (PCA)

Material properties	First principal component	Second principal component
Hardness	−0.400	0.564
q-max	−0.172	0.951
Coefficient of dynamic friction (parallel to grain)	0.797	0.552
Coefficient of dynamic friction (perpendicular to grain)	0.808	0.432
L^*:0 (dark)–100 (light)	0.943	−0.027
a^*:−60 (green)–+60 (red)	0.377	−0.837
b^*:−60 (blue)–+60 (yellow)	0.833	−0.070

Table 2-5. Principal component scores of specimens by principal component analysis (PCA)

Specimens	First principal component	Second principal component
Beech-oil coating	1.359	0.971
Beech- urethane coating	2.321	2.275
Japanese Cedar-oil coating	0.997	−2.197
Japanese Cedar- urethane coating	1.491	−2.242
Oak-oil coating	−0.933	0.529
Oak- urethane coating	−0.607	0.631
Black walnut-oil coating	−2.459	0.399
Black walnut- urethane coating	−2.168	−0.364

Multiple regression analysis was conducted, with tactile and visual impression scores as objective variables, and principal components scores for material properties as explanatory variables. Table 2-6 shows the results of multiple regression analysis for all specimens, and Table 2-7 shows the results of multiple regression analysis with two coating types.

Significant regression coefficients were found in the evaluation terms "cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)," "hard-soft (*katai-yawarakai*)," and "cheap-expensive (*yasusouna-takasouna*)", and some terms could not be explained by principal components of material properties.

Table 2-6. Results of multiple linear regression analysis (No.1)

Impression	Perception	First principal component		Second principal component		R^2
		Partial regression coefficient	Standardized partial regression coefficient	Partial regression coefficient	Standardized partial regression coefficient	
Cool-warm (*tsumetai-atatakai*)	Visual					
	Tactile			−0.304*	−0.762	0.580
Rough-smooth (*zarazarashita-tsurutsurushita*)	Visual	0.330**	0.868			0.753
	Tactile					
Dry-moist (*karattoshita-shittorishita*)	Visual					
	Tactile					
Hard-soft (*katai-yawarakai*)	Visual	0.289**	0.891			0.794
	Tactile			−0.146	−0.543	0.294
Uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)	Visual					
	Tactile					
Cheap-expensive (*yasusouna-takasouna*)	Visual	−0.221*	−0.701			0.491
	Tactile					
Artificial-natural (*jinkoutekina-shizenna*)	Visual					
	Tactile					
Dislike-like (*kirai-suki*)	Visual					
	Tactile					

Note: **: $p < 0.01$; *: $p < 0.05$; objective variables are visual or tactile sensory scores and explanatory variables are principal component scores from material properties. The first principal component is "surface texture from coating" component and the second principal component is the "wood species" component.

Table 2-7. Results of multiple linear regression analysis (No. 2)

Impression	Coating		First principal component: Partial regression coefficient	First principal component: Standardized partial regression coefficient	Second principal component: Partial regression coefficient	Second principal component: Standardized partial regression coefficient	R^2
Cool-warm (*tsumetai-atatakai*)	Oil	Visual					
		Tactile			−0.387*	−0.889	0.791
	Urethane	Visual					
		Tactile					
Rough-smooth (*zarazarashita-tsurutsurushita*)	Oil	Visual	0.357*	0.956			0.914
		Tactile			0.123*	0.930	0.865
	Urethane	Visual	0.308	0.801			0.642
		Tactile					
Dry-moist (*karattoshita-shittorishita*)	Oil	Visual					
		Tactile			0.111	0.723	0.522
	Urethane	Visual					
		Tactile					
Hard-soft (*katai-yawarakai*)	Oil	Visual	0.388**	0.987			0.975
		Tactile					
	Urethane	Visual	0.213	0.820			0.672
		Tactile			−0.220	−0.857	0.733
Uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)	Oil	Visual					
		Tactile					
	Urethane	Visual					
		Tactile					
Cheap-expensive (*yasusouna-takasouna*)	Oil	Visual	−0.264	−0.752			0.566
		Tactile					
	Urethane	Visual					
		Tactile					
Artificial-natural (*zinnkoutekina-shizenna*)	Oil	Visual					
		Tactile					
	Urethane	Visual					
		Tactile					
Dislike-like (*kirai-suki*)	Oil	Visual					
		Tactile					
	Urethane	Visual					
		Tactile					

Note: **: $p < 0.01$; *: $p < 0.05$; objective variables are visual or tactile sensory scores and explanatory variables are principal component scores from material properties when considering two different coating types. The first principal component is the "surface texture from coating" component and the second principal component is the "wood species" component.

2.5.3 Relationship between visual-tactile impressions and visual or tactile impressions

Multiple regression analysis was used to investigate the relationships between tactile impressions, visual impressions, and visual-tactile impressions. Explanatory variables were tactile and visual impression scores for each evaluation term, and objective variables were visual-tactile impression scores for each evaluation term. Table 2-8 shows the results of multiple regression analysis for all specimens. Table 2-9 shows the results of multiple regression analysis with two coating types, and Table 2-10 shows the results of multiple regression analysis with each wood species (beech, Japanese cedar, oak and black walnut).

The results in Tables 2-8 and 2-9 indicate that both tactile impression and visual impression influenced visual-tactile impression, except for the "dry-moist (*karattoshita-shittorishita*)" and "artificial-natural (*jinkoutekina-shizenna*)" terms. The tactile impression affected the terms related to material properties. However, the results revealed that visual impression significantly affected the emotional terms. As shown in Table 2-10, the influence of visual or tactile impressions on the visual-tactile impression depended on each term related to material properties, and visual impressions were significantly affected by the emotional terms. Therefore, the findings suggested that visual impression influenced visual-tactile impressions for emotional terms.

Table 2-8. Results of multiple linear regression analysis (No.3)

Impression	Visual		Tactile		R^2
	Partial regression coefficient	Standardized partial regression coefficient	Partial regression coefficient	Standardized partial regression coefficient	
Cool-warm (*tsumetai-atatakai*)	0.761**	0.698	0.821**	0.808	0.935
Rough-smooth (*zarazarashita-tsurutsurushita*)	−0.177*	−0.113	0.983**	1.009	0.993
Dry-moist (*karattoshita-shittorishita*)			0.885**	0.896	0.802
Hard-soft (*katai-yawarakai*)	0.677*	0.683	0.576	0.417	0.737
Uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)	0.372	0.296	0.804**	0.771	0.906
Cheap-expensive (*yasusouna-takasouna*)	0.852**	0.718	1.125*	0.409	0.851
Artificial-natural (*jinkoutekina-shizenna*)	0.860**	0.840			0.706
Dislike-like (*kirai-suki*)	0.563*	0.428	0.709**	0.652	0.947

Note: **: $p < 0.01$; *: $p < 0.05$; objective variables were visual-tactile sensory scores and explanatory variables were visual and tactile sensory scores.

Table 2-9. Results of multiple linear regression analysis (No.4)

Impression	Coating	Visual: Partial regression coefficient	Visual: Standardized partial regression coefficient	Tactile: Partial regression coefficient	Tactile: Standardized partial regression coefficient	R^2
Cool-warm (*tsumetai-atatakai*)	Oil	0.852**	0.668	0.967**	0.775	0.999
	Urethane					
Rough-smooth (*zarazarashita-tsurutsurushita*)	Oil	−0.414*	−0.901			0.812
	Urethane	−0.137	−0.067	0.978**	1.017	0.999
Dry-moist (*karattoshita-shittorishita*)	Oil			2.431*	0.898	0.806
	Urethane			0.809**	0.992	0.984
Hard-soft (*katai-yawarakai*)	Oil	0.633	0.739			0.546
	Urethane	0.949	0.795			0.633
Uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)	Oil	0.608	0.783			0.613
	Urethane	0.450*	0.288	0.904**	0.828	0.993
Cheap-expensive (*yasusouna-takasouna*)	Oil	0.999	0.937	0.988	0.172	0.995
	Urethane			1.609	0.735	0.540
Artificial-natural (*jinkoutekina-shizenna*)	Oil	1.544*	0.931			0.868
	Urethane	0.629*	0.914			0.835
Dislike-like (*kirai-suki*)	Oil	0.943	0.854			0.730
	Urethane	0.464*	0.325	0.853**	0.754	0.994

Note: **: $p < 0.01$; *: $p < 0.05$; objective variables were visual-tactile sensory scores and explanatory variables were visual and tactile sensory scores, with two different coating types.

Table 2-10. Results of multiple linear regression analysis (No.5)

Impression	Specimen	Visual		Tactile		R^2
		Partial regression coefficient	Standardized partial regression coefficient	Partial regression coefficient	Standardized partial regression coefficient	
Cool-warm (*tsumetai-atatakai*)	Beech	0.172	0.192	0.162	0.175	0.071
	Japanese cedar	0.542**	0.526	0.226	0.188	0.349
	Oak			0.179*	0.248	0.062
	Black walnut	0.212*	0.230	0.275**	0.299	0.122
Rough-smooth (*zarazarashita-tsurutsurushita*)	Beech	0.469**	0.372	−0.272	−0.207	0.168
	Japanese cedar	0.305**	0.305			0.093
	Oak	−0.193*	−0.241	−0.188	−0.213	0.116
	Black walnut			−0.245	−0.194	0.038
Dry-moist (*karattoshita-shittorishita*)	Beech	0.294*	0.267	0.250*	0.251	0.151
	Japanese cedar			0.434**	0.407	0.165
	Oak			0.272**	0.310	0.096
	Black walnut	0.373**	0.381	0.214	0.210	0.189
Hard-soft (*katai-yawarakai*)	Beech	0.378**	0.318	0.389**	0.422	0.280
	Japanese cedar	0.364**	0.421	0.289**	0.334	0.285
	Oak			0.255*	0.272	0.074
	Black walnut	0.409**	0.413	0.288*	0.265	0.291
Uncomfortable- comfortable (*kokochinowarui-kokochinoyoi*)	Beech	0.283**	0.294	0.436**	0.434	0.331
	Japanese cedar	0.489**	0.548			0.300
	Oak			0.310**	0.332	0.110
	Black walnut	0.187	0.186	0.551**	0.539	0.403
Cheap-expensive (*yasusouna-takasouna*)	Beech	0.476**	0.469			0.220
	Japanese cedar	0.517**	0.528			0.279
	Oak	0.168	0.179	0.286*	0.245	0.098
	Black walnut	0.718**	0.695	0.147	0.114	0.534
Artificial-natural (*jinkoutekina-shizenna*)	Beech	0.356**	0.361			0.130
	Japanese cedar	0.622**	0.648			0.420
	Oak	0.432**	0.511			0.260
	Black walnut	0.450**	0.467			0.218
Dislike-like (*kirai-suki*)	Beech	0.562**	0.524	0.263**	0.264	0.420
	Japanese cedar	0.596**	0.574			0.330
	Oak	0.193*	0.230			0.053
	Black walnut	0.374**	0.355	0.508**	0.479	0.507

Note: **: $p < 0.01$; *: $p < 0.05$; objective variables were visual-tactile sensory scores and explanatory variables were visual and tactile sensory scores, with four different species.

2.5.4 Discussion of the formation of the visual-tactile impressions when assessing wood specimens

The results presented in the previous sections verified the initial hypothesis with four terms (“cool-warm (*tsumetai-atatakai*),” “rough-smooth (*zarazarashita-tsurutsurushita*),” “hard-soft (*katai-yawarakai*),” and “cheap-expensive (*yasusouna-takasouna*)”), supporting the proposed hypothetical model combining information in a linear way. The experiment described in this chapter examined how material properties contribute to visual or tactile impressions, and investigated whether visual or tactile impressions strongly contribute to visual-tactile impressions.

The results shown in Table 2-6 and Table 2-7 revealed that significant regression coefficients were obtained for smoothness with visual impressions, and hardness with tactile impressions, for the first principal component with both coating types. The results shown in Table 2-8 and Table 2-9 revealed that significant regression coefficients were obtained in all visual impression conditions except moistness, and the feeling of naturalness in tactile impressions. Therefore, the results with both coating types were employed in Table 2-7 and Table 2-9, and are discussed in detail below.

The results of the regression coefficients of the first principal component in Table 2-7 indicated that feelings of smoothness and hardness affected visual perception in the first principal component. This first principal component, which was interpreted as the “surface texture with coating” component, was affected by the material properties of brightness, color and friction. These findings suggest that surface properties and brightness influenced visual impressions. Specifically, the results indicated that the impression of hardness could be explained by following regression equations:

Hardness based on visual impression (oil coating)

= 0.388 × the first principal component (R^2: 0.975) (2.1)

Hardness based on visual impression (urethane coating)

= 0.213 × the first principal component (R^2: 0.672) (2.2)

A previous study reported that the brightness of wood influenced on hardness [34], suggesting that the brightness of wood influences visual impressions. The current results revealed that impressions of "cheap-expensive (yasusouna-takasouna)" was influenced by visual impressions in the first principal component, including $L*$. A previous study of formal black clothes reported that $L*$ was an important factor in the impression of expensiveness, revealing that low $L*$ scores were associated with impressions of greater expensiveness [35]. The results of the current experiment revealed a similar tendency, suggesting that this method can be applied to the assessment of the characteristics of wood.

Based on the results of the regression coefficient in Table 2-9, the visual impression mainly affected the visual-tactile impression when assessing emotional terms, as mentioned above. When assessing the terms of material properties, warmness, smoothness and moistness could be explained by the following regression equations:

Warmness (oil coating)

$= 0.852 \times$ visual impression $+ 0.967 \times$ tactile impression (R^2: 0.999)   (2.3)

Smoothness (urethane coating)

$= -0.137 \times$ visual impression $+ 0.978 \times$ tactile impression (R^2: 0.999)   (2.4)

Moistness (oil coating)

$= 2.431 \times$ tactile impression (R^2: 0.806)   (2.5)

Moistness (urethane coating)

$= 0.809 \times$ tactile impression (R^2: 0.984)   (2.6)

The results revealed that the regression coefficients of the tactile impression were larger than those of the visual impression, indicating that the visual-tactile impression when assessing the terms of material properties was influenced by the tactile impression. When assessing the smoothness of the urethane coating, the visual impression regression coefficient was negative. The visual information included the grain and texture of the external appearance, and the unique grain of oak (torafu). This grain type appeared to have a negative influence on the impression of smoothness.

To examine the relationship between the terms when evaluating warmness, smoothness and moistness in the tactile impression and material properties in Table 2-7, the following regression equations were obtained:

Warmness with the tactile impression (oil coating)

$= -0.387 \times$ the second principal component (R^2: 0.791)   (2.7)

Smoothness with the tactile impression (oil coating)

= 0.123 × the second principal component (R^2: 0.865)   (2.8)

Moistness with the tactile impression (Oil coating)

= 0.111 × the second principal component (R^2: 0.522)   (2.9)

As shown in the results of the second principal component in Table 2-4, these values were strongly correlated with the specific characteristics, such as q-max, for each wood species. Warmness, smoothness and moistness are generally perceived when touching a surface. At the same time, a previous study reported that yellow-red color (YR) is considered a warm color, suggesting that it is associated with the impression of warmth [36]. However, thermal properties, such as q-max, which can be directly felt when touching a material, influenced the impression of warmth in the current study.

The results of the visual-tactile impression in Table 2-10 suggest that the terms of material properties were influenced by tactile impressions, while the emotional terms were influenced on visual impressions. Since impressions of the terms related to material properties were obtained by direct contact, these influenced tactile perception. The emotional terms were significantly influenced on visual impressions, as mentioned above, because variation of wood species affected visual impressions.

The results of multiple regression analysis revealed no relationship between emotional terms, such as comfort and preference, and material properties. Comfort and preference are comprehensive sensations, and are strongly affected by visual perception. However, the tactile impression also influenced on the visual-tactile impression, especially with urethane coating. The process of perception is complex, and it is difficult for these terms to be explained by material properties.

Thus, the formation of visual-tactile impressions is not only influenced by visual impressions, but also by tactile impressions, even to a limited extent, which can be shown in the hypothetical model in Figure 2-1.

2.6 Conclusions

The current experiment focused on human feelings regarding tactile perception, visual perception and visual-tactile perception when assessing wooden products, using a subjective evaluation method. The relationships between visual impressions, tactile impressions, visual-tactile impressions, and material properties were examined using sensory tests and multiple regression analysis. The results suggested the following conclusions:

1) Terms related to material properties were significantly affected by tactile impressions. However, emotional terms were significantly affected by visual impressions.
2) Visual-tactile impressions were affected by both tactile perception and visual perception.
3) Tactile impression was affected by surface friction, and visual impressions were affected by brightness.
4) When assessing visual-tactile impressions, visual impressions had a stronger effect than tactile impressions. However, feelings acquired from tactile receptors, such as warmness, smoothness and moistness, were strongly influenced by tactile impressions.

The current findings indicate the importance of tactile perception for the formation of visual-tactile impressions. The results revealed an influence of surface texture based on the coating type, and the material properties, such as thermal properties, also affected tactile impressions. Therefore, further investigation of tactile perception is warranted. In Chapter 3, the relationship between tactile perception and the characteristics of wood was investigated using analysis of hand movements while assessing visual-tactile perception. In addition, impressions of comfort and preference were determined not only by visual impressions, but also tactile impressions. This suggests that tactile information is important for feelings of comfort and preferences for different characteristics of wood. Therefore, "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" were focused on as high-level concepts in Chapter 4.

Chapter 3

Investigation into hand movements when assessing material properties of wood

3.1 Introduction

When using a wooden product or when in a room made from wood, people tend to feel comfortable because of the presence of this natural material. When encountering wooden products, people tend to instinctively handle them and feel their surface. It is considered that watching and touching are important behaviors to the visual-tactile impression. By the investigation of the relationship between the visual-tactile perception and characteristics of wood in the previous Chapter 2, it was revealed that the evaluation terms of material properties associated with the tactile perception and the emotional terms affected the visual perception. In this Chapter 3, the tactile perception was focused on and investigated the relationship between the tactile perception, which strongly affects the terms of material properties; "Cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)," and "dry-moist (*karattoshita-shittorishita*)," and characteristics of wood. Moreover, in Chapter 2, I performed only sensory tests, that is, subjective evaluation, not objective or quantitative assessment. Thus, in this Chapter 3, I focused on hand movements that is direct relation with the tactile perception and measured hand movement as objective means.

As mentioned in Chapter 1, many studies have examined the relationship between tactile perception and physiological and psychological responses when touching wood. The relationship between personal impression and hand movement when evaluating objects has also been the focus of several investigations [37-39]. For example, some participants were more easily able to distinguish materials by using active hand movements than by using non-active hand movements [37], and a strong correlation between sensory scores and active hand movement has been recorded [38]. Moreover, when evaluating textiles, participants' hand movements changed according to the property being evaluated [39].

In this Chapter 3, I focused on how tactile perception information is obtained from wood specimen, and investigated the hand movements used in doing so. Tactile perception generally consists of four impressions, described by the evaluation terms "cool-warm (*tsumetai-atatakai*)," "hard-soft (*katai-yawarakai*)" "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)" These impressions are also important with regard to characteristics of wood [9] as they correspond to the material properties of temperature, surface texture, moisture content and hardness. There being multiple tactile impressions, it is assumed that hand movement changes according to these evaluation terms when assessing each material property of wood. Therefore, a 3D real-time motion measurement system and a pressure distribution measurement system were used for examination about the relationship between the above evaluation terms pertaining to the four impressions and the hand movements used to carry out the associated evaluations on wooden objects.

3.2 Purpose

The purpose of this study was to focus on how tactile impression information is obtained from wood. In order to investigate the hand movement in real time, a 3D real-time motion measurement system and a pressure distribution measurement system were used. Additionally, I examined these specifics whether effects for the sensory tests, which was obtained from the investigation by using the 3D motion capture system and pressure distribution measurement system

3.3 Methods

3.3.1 Participants

It is assumed that individuals have differing levels of discrimination ability when touching different wood. If a participant has low discrimination ability, the results may show wide variation, and the accuracy of the experiment may be low. Therefore, to select participants with a high discrimination ability, I carried out a preliminary experiment using sandpapers of different roughnesses.

First, twelve university students were recruited (M:6, F:6). Eight types of sandpaper (grain size: 80, 100, 120, 150, 180, 240, 320, 400) were installed in a black box that prevented the inside from being seen. Participants assessed the roughness of the sandpaper using a paired comparison method.

The coefficient of consistency was calculated from these results and examined the discrimination ability. A p-value less than 5% indicated that participants could sufficiently distinguish roughness. The preliminary results for all students gave a p-value less than 5%, therefore it was decided to select all 12 of the participating university students (M:6, F:6) as participants for the hand movement experiment.

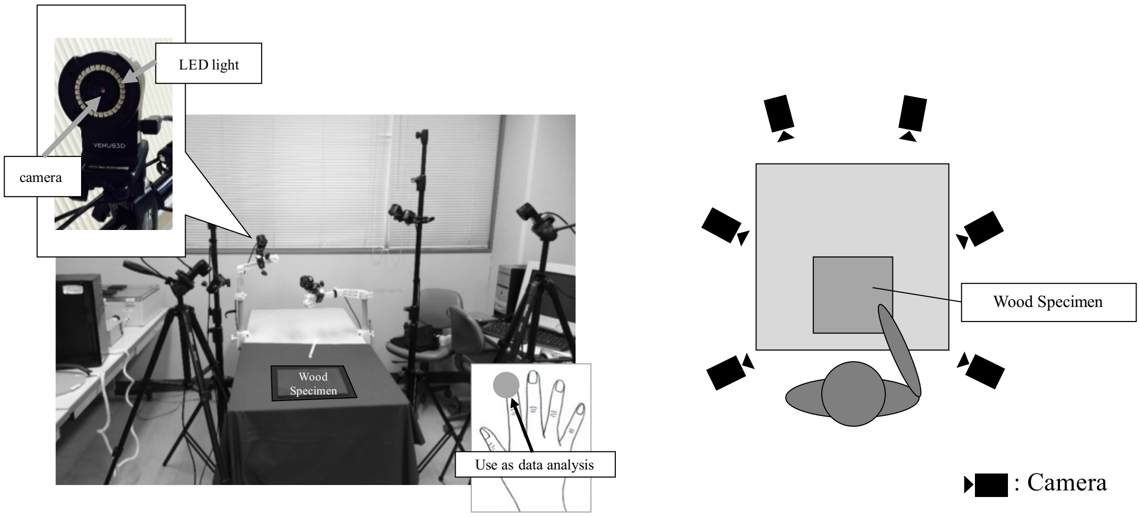
3.3.2 Wood specimens

The specimens were Japanese cedar (*Cryptomeria japonica*) and Black walnut (*Juglans nigra*). Three urethane coatings were applied to form a surface film (under, middle, and top coatings). The specimens were square with the dimensions of 280 mm （L） × 280 mm （R） × 10 mm （T）.

3.3.3 Measurement of trajectory, displacement of vertical movement and acceleration using 3-D real-time motion measurement system

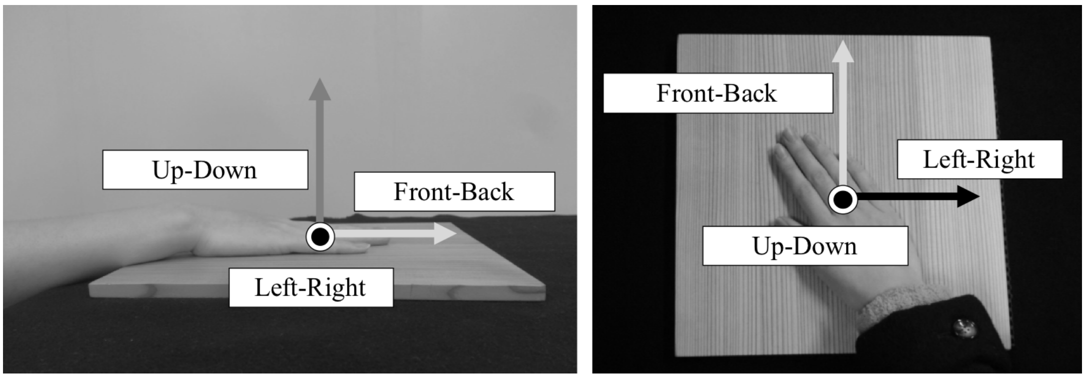
A 3D real-time motion measurement system (VENUS 3D, Nobby Tech Co., Tokyo, Japan) was used to record hand movement. The system, consisting of six cameras, irradiates the objects with infrared LED strobe lighting and receives the light reflected by markers attached to the objects. In a preliminary experiment, a total of six markers were placed, one tip of each finger and one at wrist. The experiment showed that the movements were almost the same in every marker. The spatial resolution of the fingertip is higher than that of the palm because the tactile receptors in the fingertip are more densely spaced, especially in the index finger [40]; therefore, only measurements of index finger movement were used in this study (See in Figure 3-1).

The sampling frequency was 100 Hz. The coordinate system is defined as; right-hand, front + /back -, up+/down- and right +/left –. The origin was determined at the center of wood specimens (See in Figure 3-2). The resolution of the camera was 1,300,000 pixels. The error of 3-dimentional space was 0.121 m, and the error of 2-dimational space was 0.167 pixels in this setting.



(a) Experimental environment (b) 6 cameras setting

Figure 3-1. 3D real-time motion measurement system

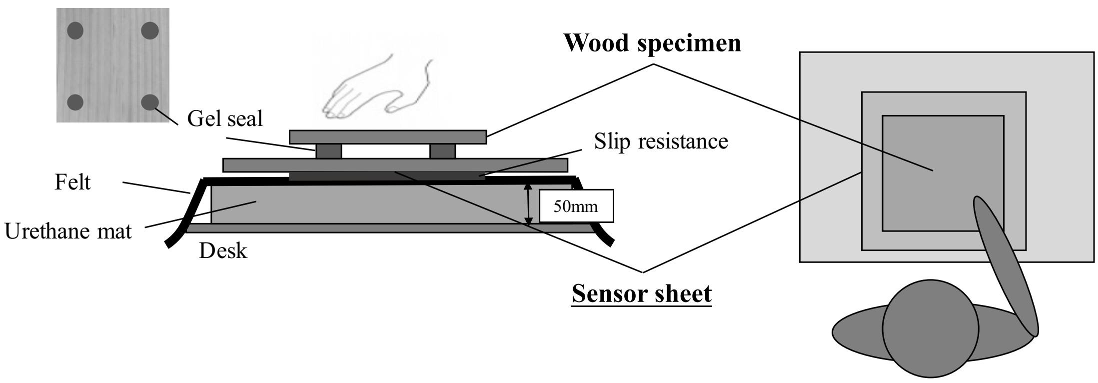


(a) A side view (b) A top view

Figure 3-2. Directions of hand movement for 3D real-time motion measurement system

3.3.4 Measurement of loading using pressure distribution measurement system

A pressure distribution measurement system (BIG MAT, NITTA Co., Osaka, Japan) was used to measure loading in the vertical direction. Normally, this sensor system would be placed directly underneath an object. As the wood specimens were harder than the sensor sheet, it was difficult to accurately measure the pressure distribution. Therefore, a soft gel seal in contact with wood specimen was applied between each of the four corners of each wood specimens and the sensor sheet. The loading was calculated from the pressure concentrated in the four gel seals which stand close to the sensor sheet. A soft urethane mat was placed under the sensor sheet, which allowed the detection of pressure distribution (See in Figure3-3). The sensor sheet was calibrated by using 200g and 500g weight before experiment.



(a) A side view (b) A top view

Figure 3-3. Diagram of pressure distribution measurement system

3.3.5 Outline

Twelve university students who passed the preliminary experiment participated in this experiment (refer to 3.3.1). The temperature and relative humidity of two experimental rooms were maintained at 20 °C and 50% RH, respectively. All wood specimens were resting for more than 24 hour in advance of the experiments.

Experiments were conducted over two days in two separate experimental rooms because of the difficulty of moving the 3D real-time motion measurement system. Participants examined these wood specimens with visual-tactile perception. On the first day, I measured the loading using the pressure distribution measurement system. The measurement was operated with assessing four fundamental terms and two emotional terms. One of the terms ("cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)", "dry-moist (*karattoshita-shittorishita*)", "hard-soft (*katai-yawarakai*)", "uncomfortable-comfortable *(kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") was indicated to participants who then touched the specimen freely to evaluate the specified term while being recorded on video for 10 s (Cyber-shot DSC-TX7, SONY, Tokyo, Japan). After one term was assessed, another term was specified and participants evaluated specimen, and repeated until all six terms were assessed. Six terms in the questionnaire were always shown in the same order, "cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)," "dry-moist (*karattoshita-shittorishita*)," "hard-soft (*katai-yawarakai*)," "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)". Two wood specimens were shown randomly to each participant. Four fundamental terms were focused in this chapter. I-SCAN Ver. 5.0 (NITTA Co., Osaka, Japan) and Excel 2013 (Microsoft, Redmond, WA, USA) were used for data acquisition and data analysis, respectively. The goal of the test was to find the characteristic increases in the amount of loading and the frequency of peaks when each participant applied force to each specimen (See in Figure 3-4).

On the second day, trajectory and acceleration of the movement of an index finger tip were measured by the 3D real-time motion measurement system. I used Motive (Nobby Tech Co., Tokyo, Japan.) as the calibration software and VENUS3D (Nobby Tech Co., Tokyo, Japan.) as the coordinate acquisition and analysis software. One of the terms ("cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)", "dry-moist (*karattoshita-shittorishita*)", "hard-soft (*katai-yawarakai*)", "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") was indicated to the participant, who then touched each specimen freely for 15 s, and repeated until all six terms were assessed. Two wood specimens were shown randomly to each participant. However, the six terms in the questionnaire were always shown in the same order, "cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)," "dry-moist (*karattoshita-shittorishita*)," "hard-soft (*katai-yawarakai*)," "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)". The first and last 2.5 s of data were eliminated to minimize the influence of measurement error to give a total of 10 s. The accelerogram was shown in the range from -50 m/s^2 to 50 m/s^2. The trajectory of the index finger was converted to acceleration using Excel 2013 (Microsoft, Redmond, WA, USA). 1-s data (4.5s-5.5s) was extracted from the 10-s data to observe the wave detail in section 3.4.1 and 3.4.2. One period wave was difficult to evaluate because of free touching, which had been the test method in this experiment. Therefore, the 4.5s–5.5s middle data, which tended to be more stable than the other parts, was used as representative of the data to be observed in detail. Additionally, the ratio of the amount of hand movement for each direction was calculated in order to find vertical movement. The goal of test was to find the characteristic raised shape of the trajectory graph, and showed sparseness or density of peaks from accelerogram. (See in Figures 3-5 and 3-6).

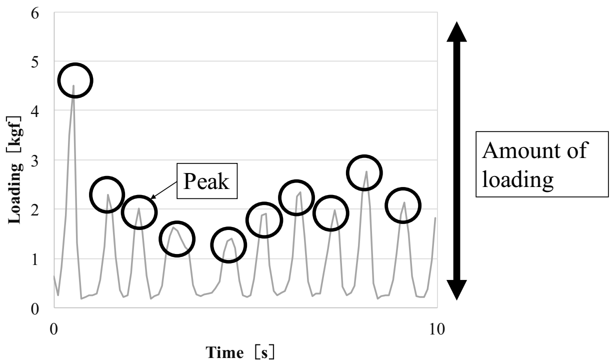
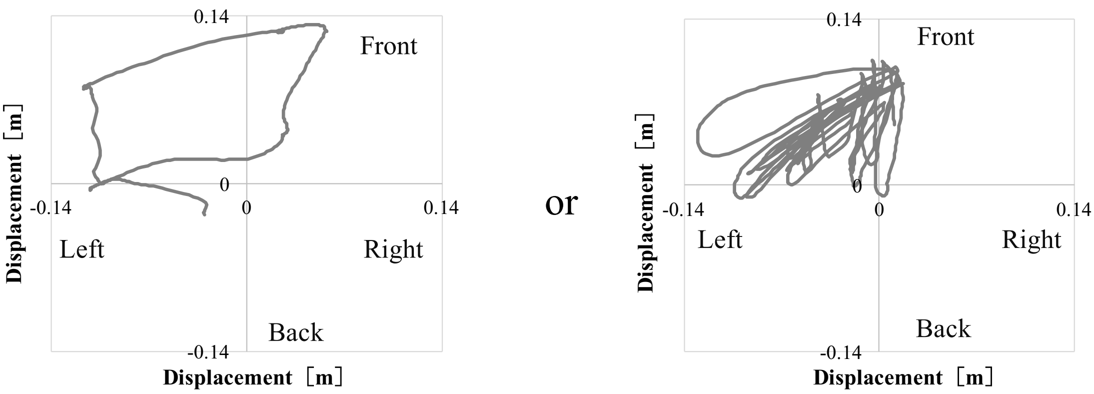
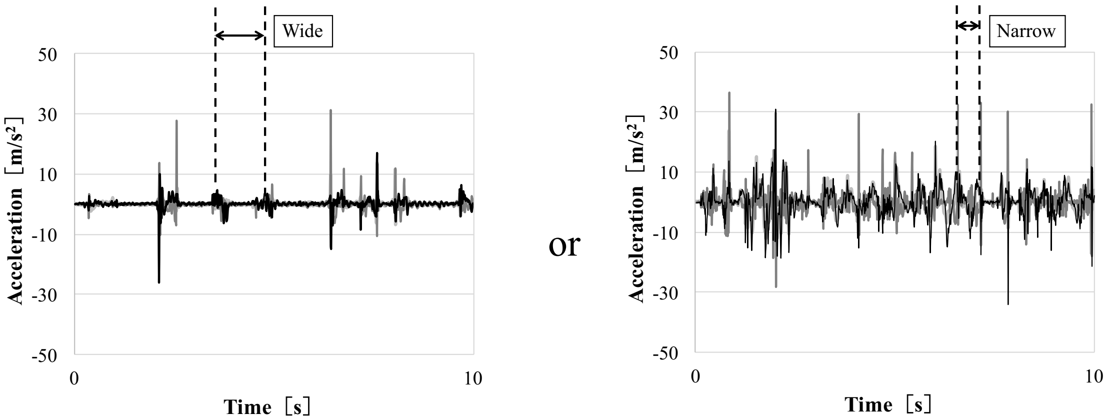


Figure 3-4. Specimen data of loading by pressure distribution measurement system



(a) Figure movement (b) Constant movement

Figure 3-5. Sample data of trajectory



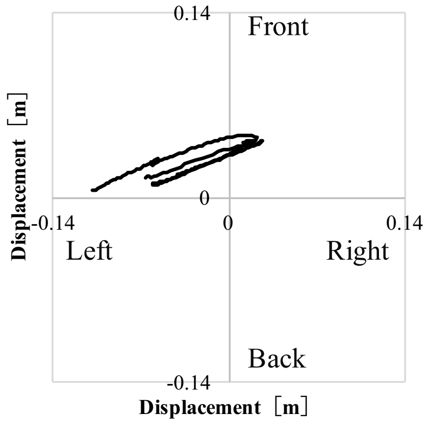
(a) Wide peak interval (b) Narrow peak interval

Figure 3-6. Sample data of acceleration

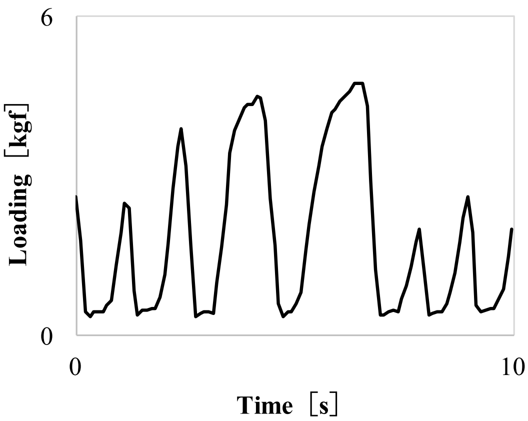
3.4 Results and discussion

3.4.1 Characteristics of hand movement when assessing "cool-warm (*tsumetai-atatakai*)," and "hard-soft (*katai-yawarakai*)"

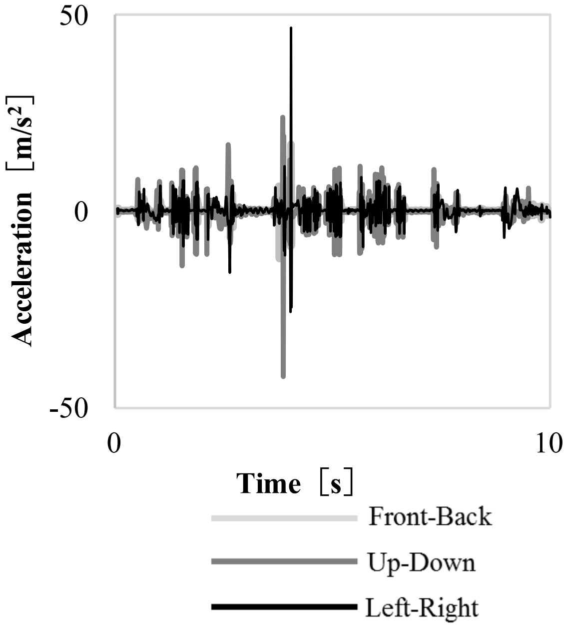
Figure 3-7 shows the trajectory, loading and acceleration when assessing "cool-warm (*tsumetai-atatakai*)," by participant No.1. Figure 3-8 shows the results for "hard-soft (*katai-yawarakai*)" by participant No.1. The trends were similar among most participants and they touched the wood surface in a square rectangular motion; i.e., the participants followed the specimen's shape. When assessing temperature and hardness, individuals tend to place their hands at different locations in a random manner, which was evident in the recorded hand movements. However, the results of loading and acceleration in the vertical direction were different. The loading amounts for “cool-warm (*tsumetai-atatakai*),” and “hard-soft (*katai-yawarakai*)” were larger than both “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*)” This result showed that participants applied more force when assessing the “cool-warm (*tsumetai-atatakai*),” and “hard-soft (*katai-yawarakai*)” terms than they did when assessing the “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*)” terms. Moreover, focusing on the accelerogram of the “hard-soft (*katai-yawarakai*)” and “cool-warm (*tsumetai-atatakai*),” terms, both were somewhat sparse. However, when comparing frequency of peaks of loading, the loading of “hard-soft (*katai-yawarakai*)” had more often peaks than that of “cool-warm (*tsumetai-atatakai*),” The Ruffini corpuscles act as the skin’s tactile receptor for heat. As the heat transfer of wood is slow and perceived the warmness is also slow. Hands must be in contact with the wood surface for a period of time [41]. When assessing “cool-warm (*tsumetai-atatakai*),” some of the participants’ hands stayed on one spot for a longer time before moving to another spot to check the transfer of heat. In contrast, in the results of acceleration and frequency of the peaks of loading for “hard-soft (*katai-yawarakai*)” the hands moved relatively quickly over the surface and there were also many upward-downward movements. Humans assess hardness by small displacements in the skin surface [42]. When participants evaluated “hard-soft (*katai-yawarakai*)” they pushed and tapped to check the hardness of the wood.



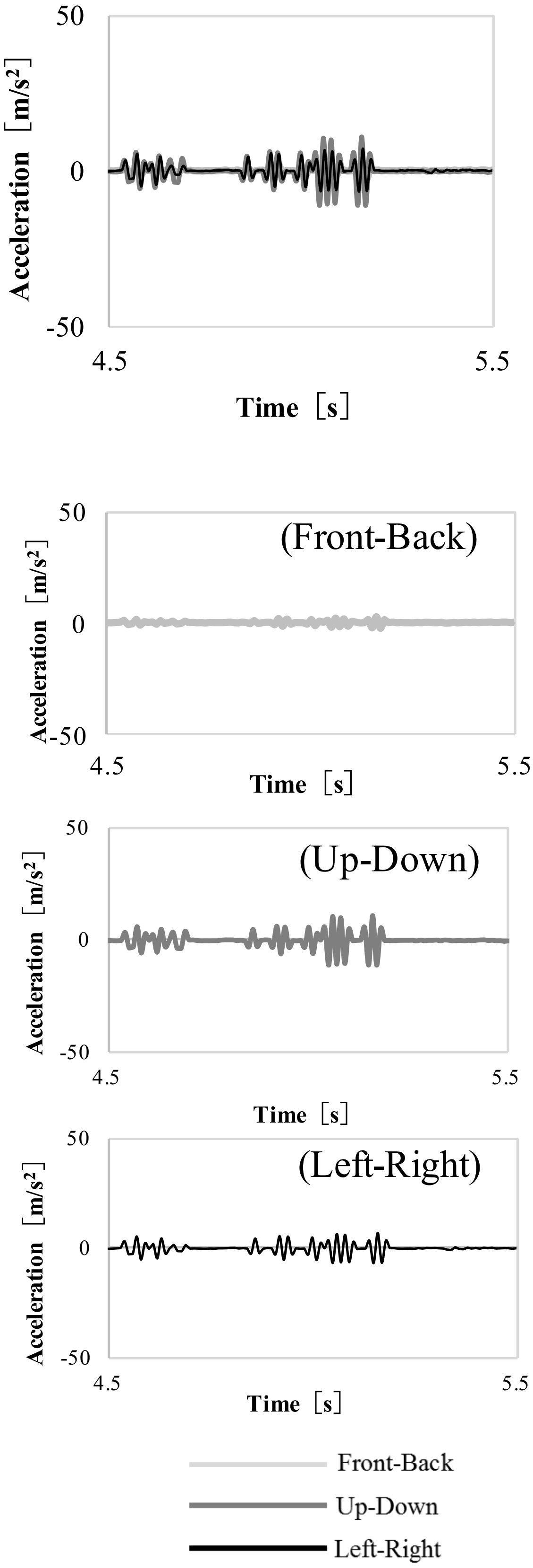
(a) Trajectory of “cool-warm (*tsumetai-atatakai*),”



(b) Loading of “cool-warm (*tsumetai-atatakai*),”

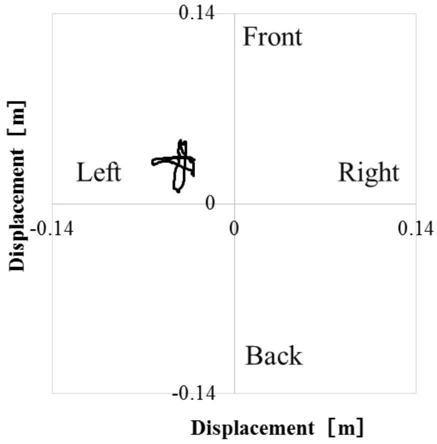


(c) Acceleration of “cool-warm (*tsumetai-atatakai*),” (10s)

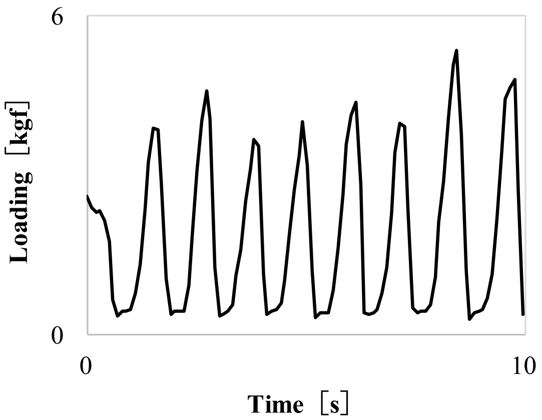


(d) Acceleration of “cool-warm (*tsumetai-atatakai*),” (1s)

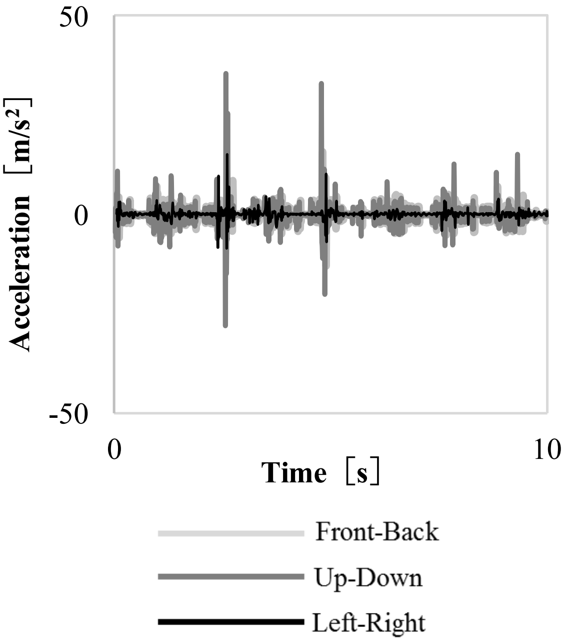
Figure 3-7. Results of hand movement for assessing “cool-warm (*tsumetai-atatakai*),” (Participant No.1)



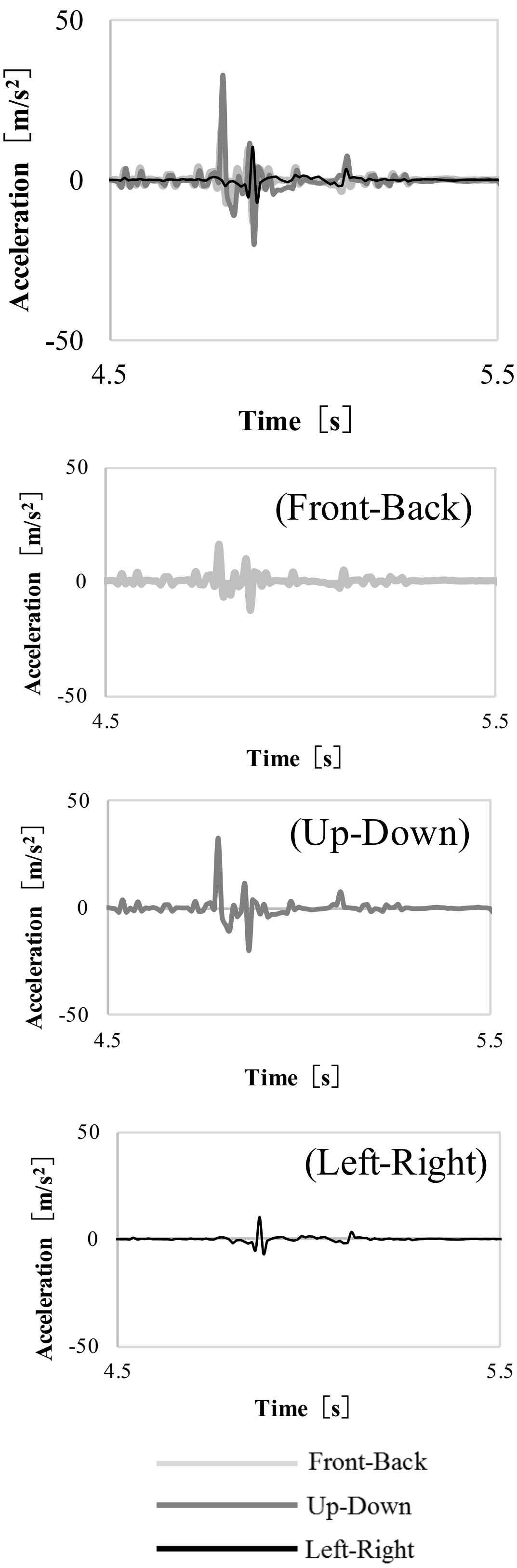
(a) Trajectory of “hard-soft (*katai-yawarakai*)”



(b) Loading of “hard-soft (*katai-yawarakai*)”



(c) Acceleration of “hard-soft (*katai-yawarakai*)” (10s)



(d) Acceleration of “hard-soft (*katai-yawarakai*)” (1s)

Figure 3-8. Results of hand movement for assessing “hard-soft (*katai-yawarakai*)” (Participant No.1)

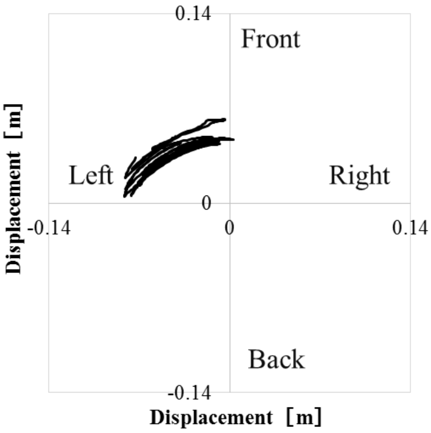
3.4.2 Characteristics of hand movement when assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita -shittorishita*)"

Figure 3-9 shows the results for trajectory, loading and acceleration when ev aluating "rough-smooth (*zarazarashita-tsurutsurushita*)." Figure 3-10 shows the results of these for "dry-moist (*karattoshita-shittorishita*)." The trends were similar among most participants with touching the wood surface in a consistent manner with front/back or left/right movement. When assessing friction and moisture, participants tend to use moisture, slight movements between the wood surface and the skin.

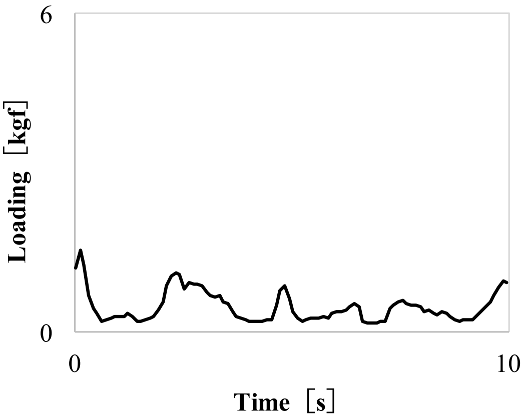
Vertical movements on the acceleration and loading graph were observed when participants evaluated the feature "dry-moist (*karattoshita-shittorishita*)." However, they were absent when evaluating "rough-smooth (*zarazarashita-tsurutsurushita*)" because the participant used their whole hand without applying any force on the surface. Their hands were also moving quickly in a consistent manner with front/back or left/right movements.

The Meissner corpuscles and Merkel cells act as skin tactile receptors to obtain information about roughness. The Meissner corpuscle is the more sensitive of the two to detect a very small change [43]. Additionally, it has been reported that strain energy distribution (SED) at the tactile receptor is an index for estimating the reactions in tactile perception, and the fingerprint increases SED near the Meissner corpuscles. This means that receptor's detection ability in the fingerprint increased [44]. Thus, participants touched the wood surface without applying force in the vertical direction.

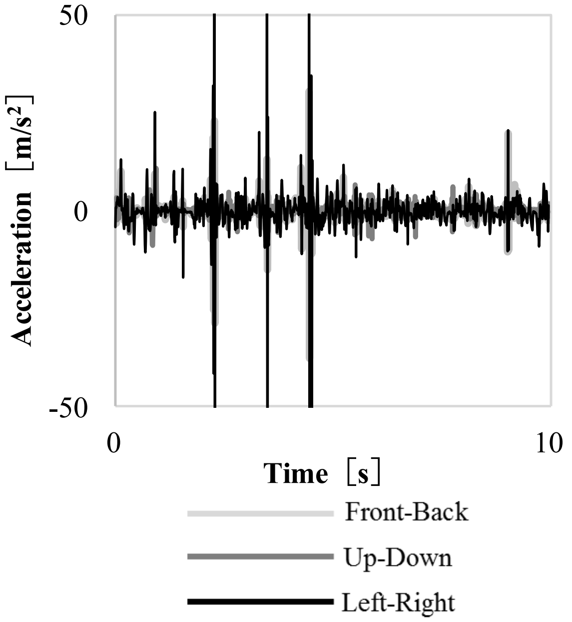
When assessing “dry-moist (*karattoshita-shittorishita*)” vertical movements were observed (See in Figures 3-10(b) and (d)). Impression “dry-moist (*karattoshita-shittorishita*)” is from simplicity of dispersion of moisture from skin between skin and a material. If that moisture does not escape from gap between skin and a material, the participant feels moistness [45]. Therefore, when checking for moisture content, it is necessary to press the surface of the wood and see how it feels for the hand to tear away from the surface. In other words, participants touched the wood surface with a slight force in the vertical direction.



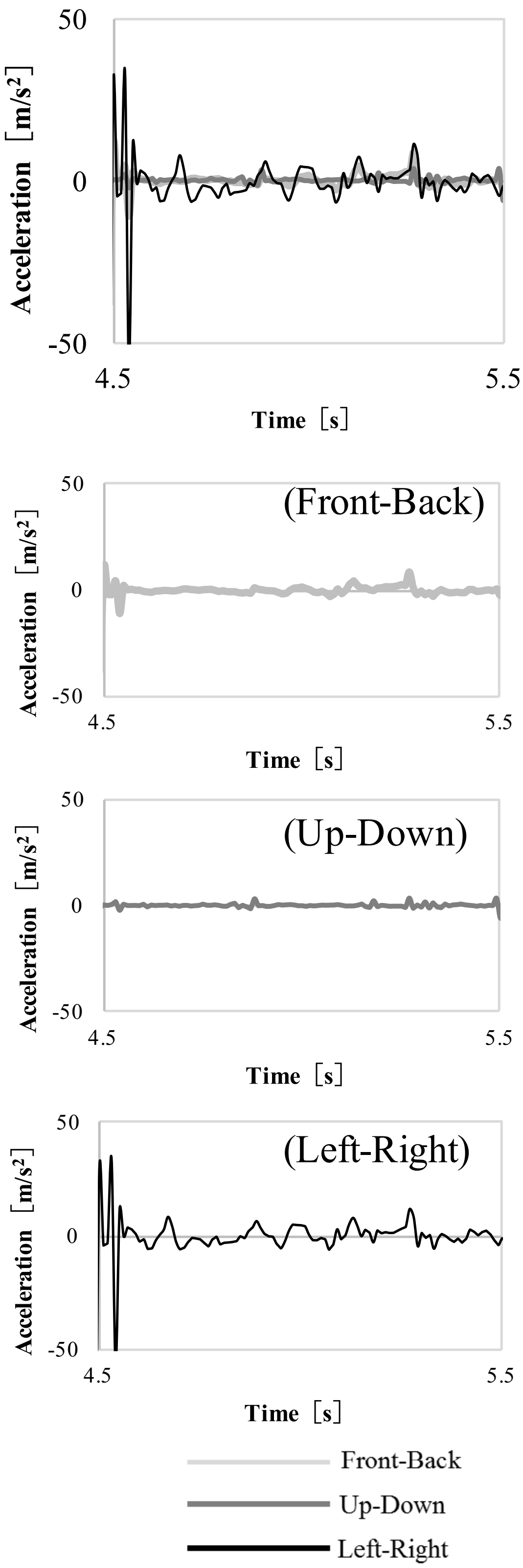
(a) Trajectory of "rough-smooth (*zarazarashita-tsurutsurushita*)"



(b) Loading of "rough-smooth (*zarazarashita-tsurutsurushita*)"

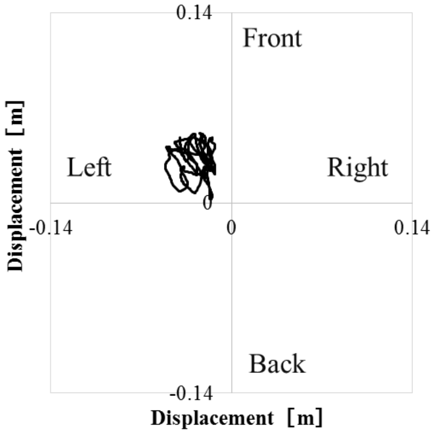


(c) Acceleration of "rough-smooth (*zarazarashita-tsurutsurushita*)" (10s)

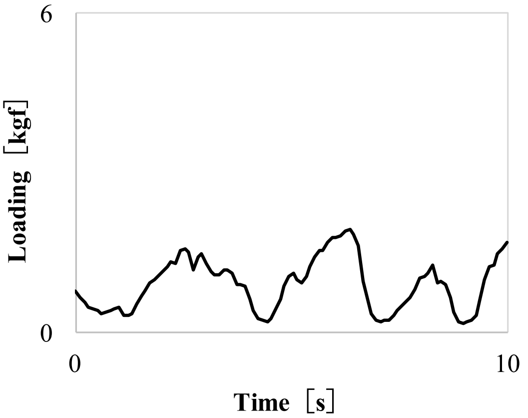


(d) Acceleration of "rough-smooth (*zarazarashita-tsurutsurushita*)" (1s)

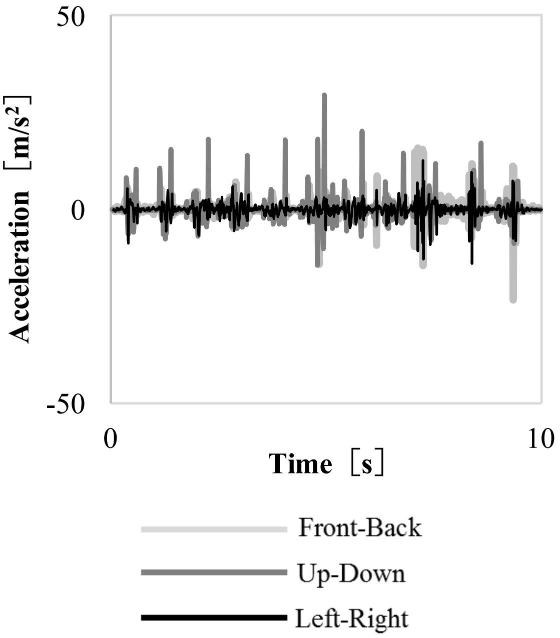
Figure 3-9. Results of hand movement for assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" (Participant No. 3)



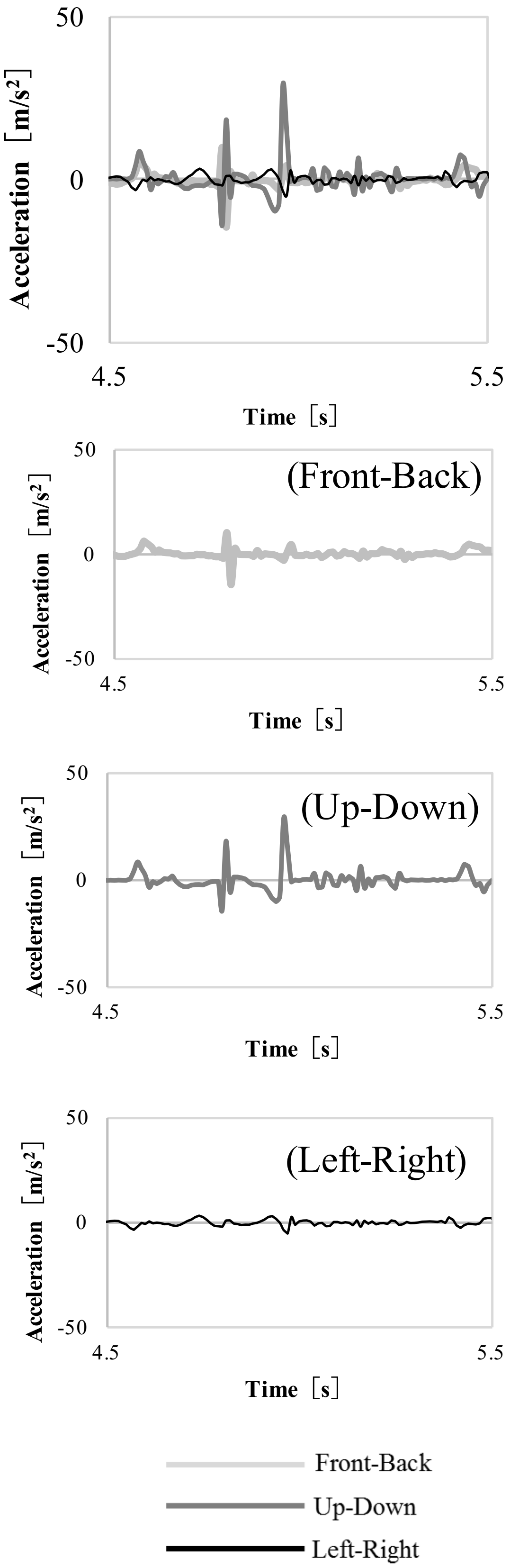
(a) Trajectory of “dry-moist (*karattoshita-shittorishita*)”



(b) Loading of “dry-moist (*karattoshita-shittorishita*)”



(c) Acceleration of “dry-moist (*karattoshita-shittorishita*)” (10s)



(d) Acceleration of “dry-moist (*karattoshita-shittorishita*)” (1s)

Figure 3-10. Results of hand movement for assessing “dry-moist (*karattoshita-shittorishita*)” (Participant No.3)

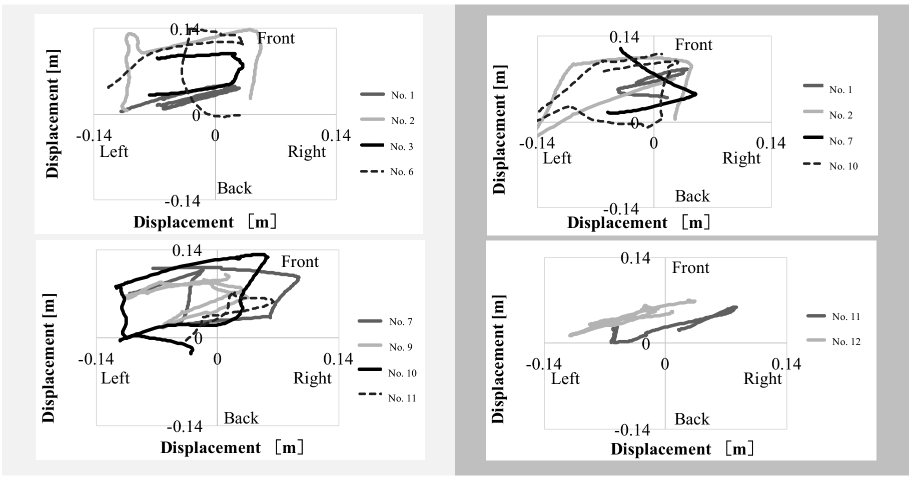
3.4.3 Individual different of hand movement

Table 3-1 and Figures from 3-11 to 3-20 show the hand movement results for each participant. A circle marker (○) in Table 3-1 indicates that the hand movements described in Sections 3.1 and 3.2 were observed when assessing the evaluation term. More than half of the participants exhibited such movements, especially when assessing "rough-smooth (*zarazarashita-tsurutsurushita*)"; in this case, most participants evaluated the wood in the same manner. This can be attributed to all participants having passed the preliminary experiment described in Section 3.3. Therefore, I consider the friction property to be easy to assess accurately and in a reproducible manner.

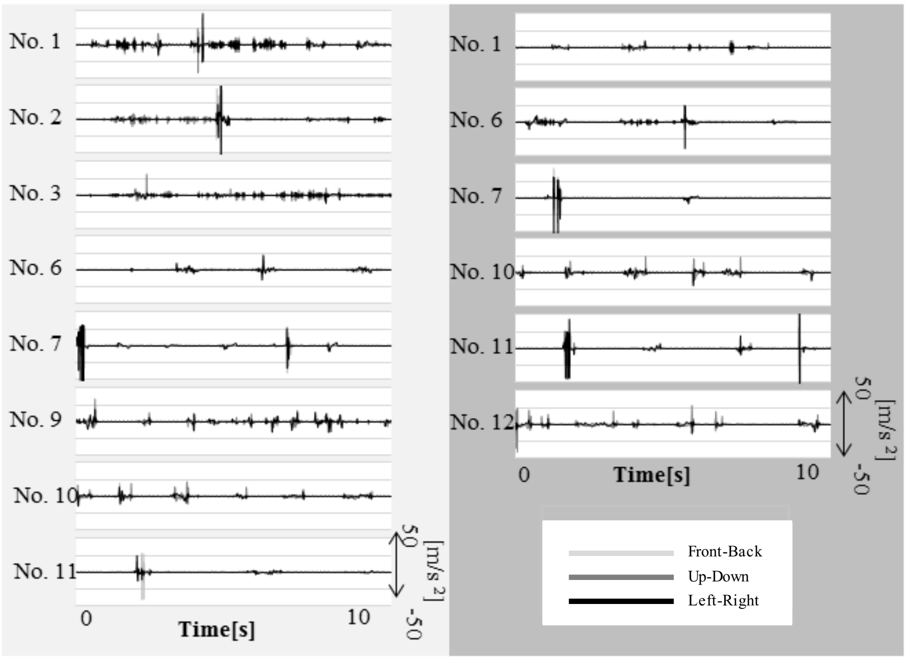
When assessing "hard-soft (*katai-yawarakai*)," most participants operated their hands in the same manner. When being reminded of the terms "hardness" or "softness," participants tended to push or tap repeatedly with a slight force in the vertical direction and check the stiffness of an object. On this basis, the hand movement of most participants would be similar. However, when assessing "cool-warm (*tsumetai-atatakai*)," and "dry-moist (*karattoshita-shittorishita*)" only half of the participants displayed a similar tendency. When assessing these two terms, the hand must remain on the wood surface for a short period and then be torn away to check thermal and moisture properties. The vertical movement when assessing "cool-warm (*tsumetai-atatakai*)," was a few comparing with assessing "hard-soft (*katai-yawarakai*)" (See in Figures 3-14 and 3-15), because participants assessed "hard-soft (*katai-yawarakai*)" with relatively quickly movement over the surface. Comparing the vertical movement between "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)," it tended to that there are many vertical movement when assessing "dry-moist (*karattoshita-shittorishita*)". However, some of the students' hand movements have no differences between assessing them (See in Figures 3-19 and 3-20). Thus, participant who hand no mark in Table 3-1 in assessing "dry-moist (*karattoshita-shittorishita*)" tend to be moved a few their hand for vertical direction. Therefore, vertical movement is important for evaluating these terms. Nonetheless, for participants who had no mark in Table 3-1, no vertical movement was observed when evaluating "cool-warm (*tsumetai-atatakai*)," and "dry-moist (*karattoshita-shittorishita*)" Therefore, these two sensory tests exhibited a wide variation, and a message such as "please take vertical hand motion into consideration" would be instructive.

Table 3-1. Results of hand movements (trajectory, acceleration and loading) for each participant; ○ indicates that the hand movements described in Sections 3.4.1 and 3.4.2 were observed

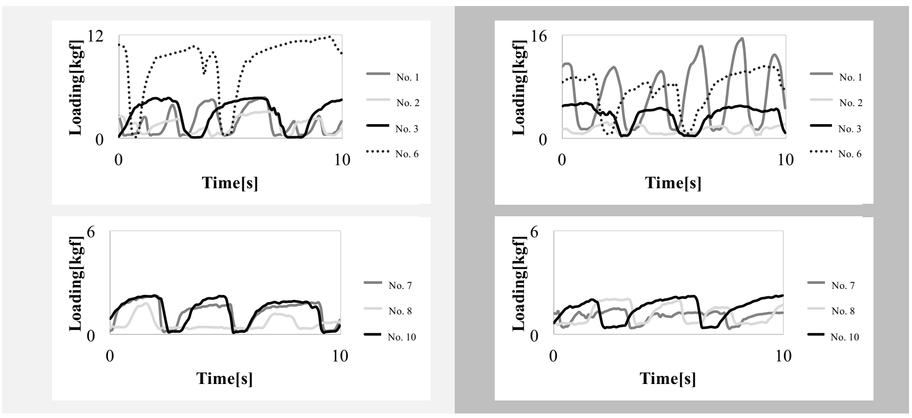
			Trajectory and Acceleration				Loading			
			cool-warm	hard-soft	rough-smooth	dry-moist	cool-warm	hard-soft	rough-smooth	dry-moist
Japanese cedar	No. 1	Male	○	○	○	○	○	○	○	○
	No. 2		○	○	○		○	○	○	
	No. 3		○	○	○	○	○	○	○	○
	No. 4				○				○	
	No. 5			○		○			○	
	No. 6		○	○	○		○			
	No. 7	Female	○		○		○	○	○	○
	No. 8				○		○		○	○
	No. 9		○		○	○		○	○	○
	No. 10		○	○	○	○	○	○	○	○
	No. 11		○	○	○				○	
	No. 12			○		○				
Black walnut	No. 1	Male	○	○	○	○	○	○	○	○
	No. 2			○	○		○	○	○	
	No. 3			○	○	○	○	○	○	○
	No. 4			○	○	○				
	No. 5			○	○	○			○	
	No. 6		○	○	○		○			
	No. 7	Female	○		○		○	○	○	○
	No. 8				○		○		○	
	No. 9			○	○	○		○	○	
	No. 10		○	○	○	○	○	○	○	○
	No. 11		○	○	○				○	
	No. 12		○		○	○				
Both	No. 1	Male	○	○	○	○	○	○	○	○
	No. 2			○	○		○	○	○	
	No. 3			○	○	○	○	○	○	○
	No. 4				○					
	No. 5			○		○			○	
	No. 6		○	○			○			
	No. 7	Female	○		○		○	○	○	○
	No. 8				○		○		○	
	No. 9				○	○		○	○	
	No. 10		○	○	○	○	○	○	○	○
	No. 11		○	○	○					
	No. 12					○				



(a) Japanese cedar　　　(b) Black walnut

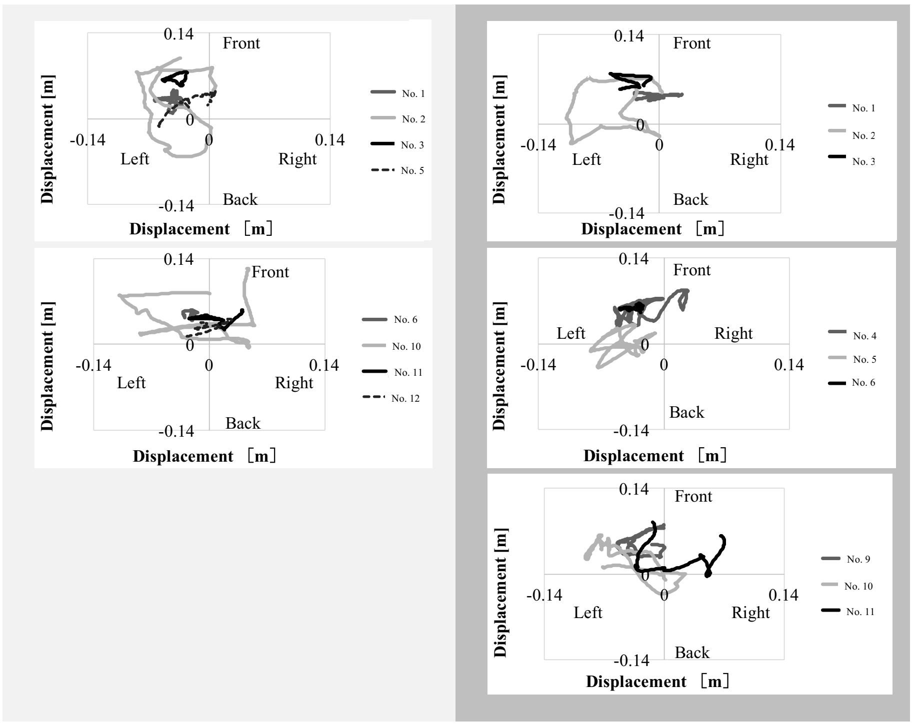


(c) Japanese cedar　　　(d) Black walnut

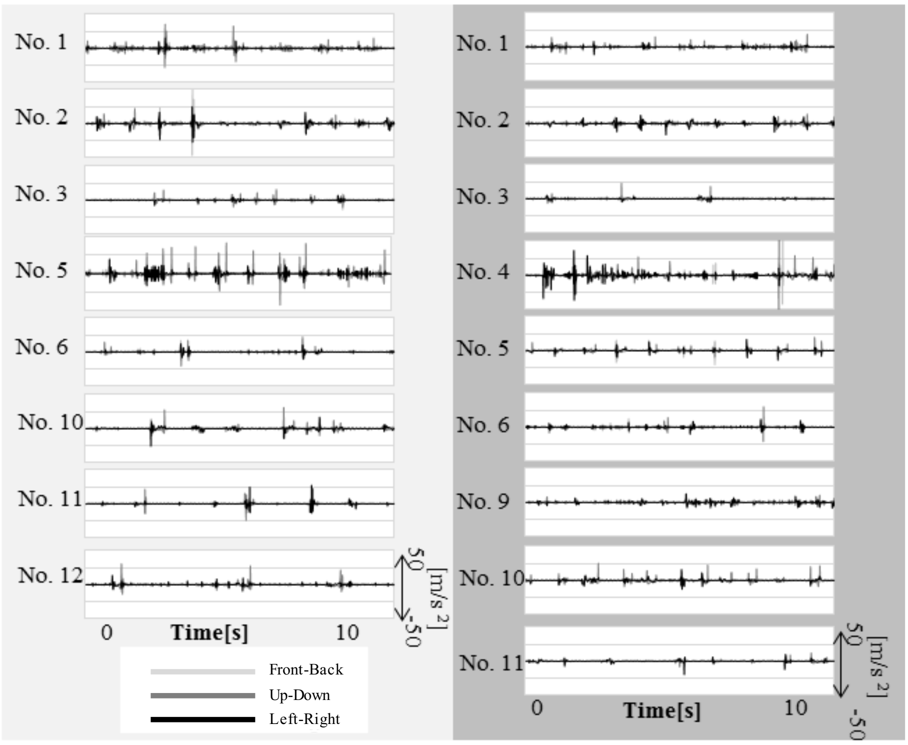


(e) Japanese cedar　　　(f) Black walnut

Figure 3-11. Results of hand movement for assessing “cool-warm (*tsumetai-atatakai*),” (Japanese cedar: Left (light gray), Black walnut: Right (dark gray), (a), (b): trajectory, (c), (d): acceleration (10s), (e), (f): loading)

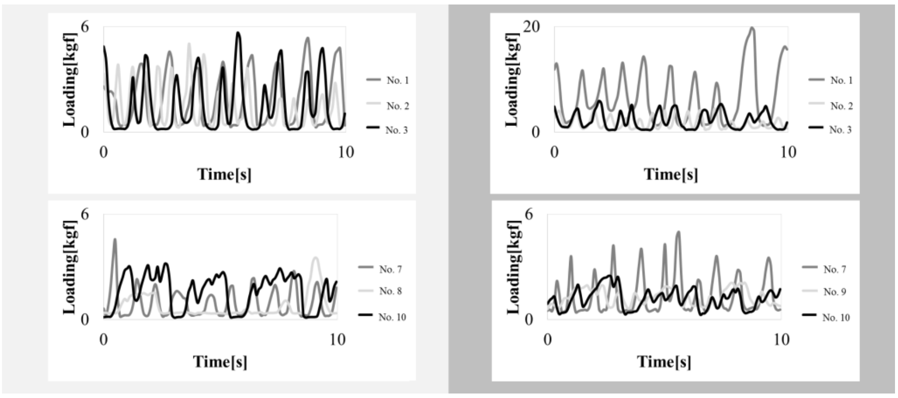


(a) Japanese cedar　　(b) Black walnut



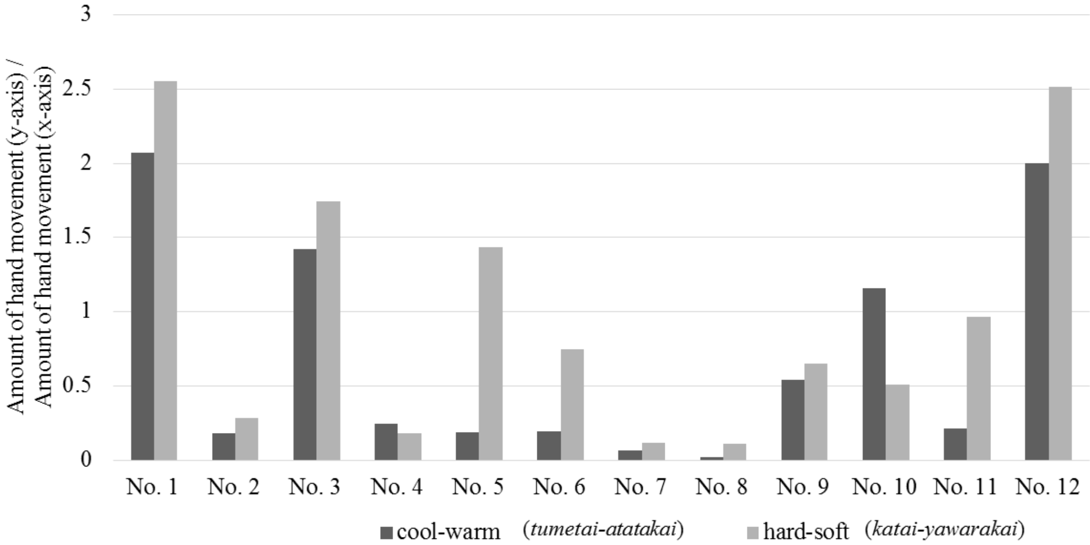
(c) Japanese cedar　　(d) Black walnut

Figure 3-12. Results of hand movement for assessing “hard-soft (*katai-yawarakai*)” (Japanese cedar: Left (light gray), Black walnut: Right (dark gray), (a), (b): trajectory, (c), (d): acceleration (10s))

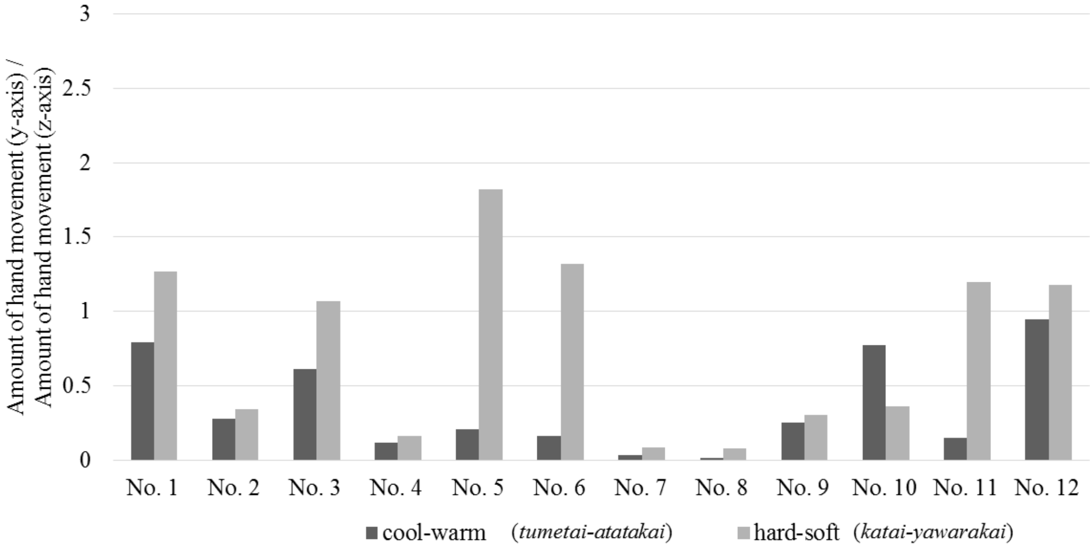


(e) Japanese cedar (f) Black walnut

Figure 3-13. Results of hand movement for assessing “hard-soft (*katai-yawarakai*)” (Japanese cedar: Left (light gray), Black walnut: Right (dark gray), (e), (f): loading)

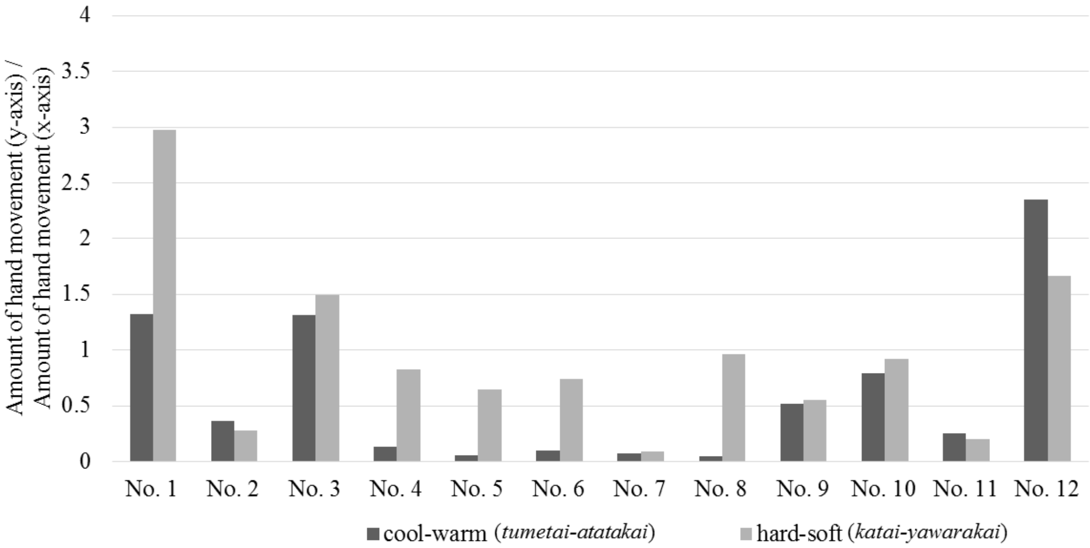


(a) Ratio of the amount of hand movement for Up-Down (y-axis) and Front-Back(x-axis) direction

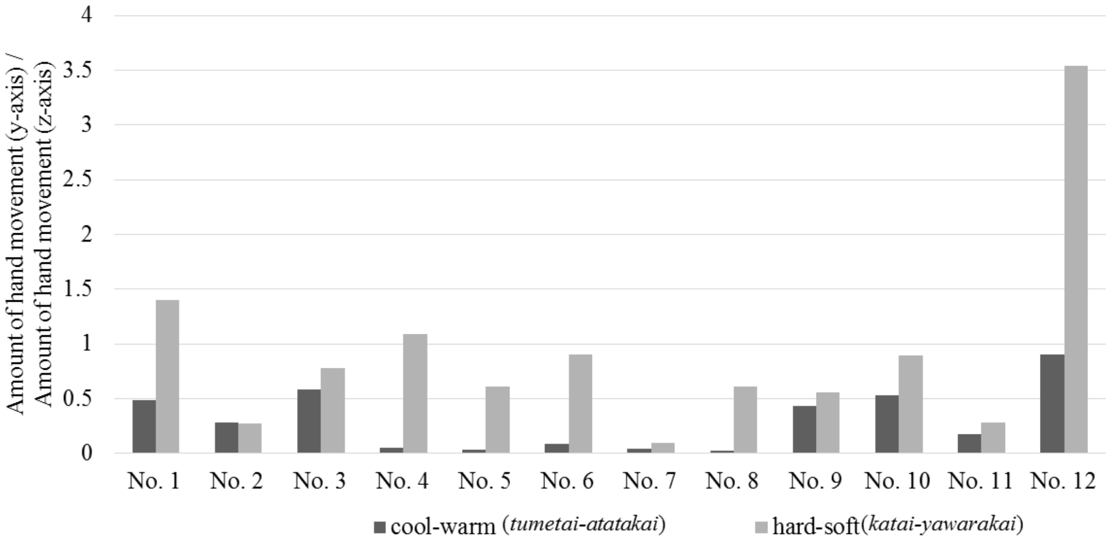


(b) Ratio of the amount of hand movement for Up-Down(y-axis) and Left-Right(z-axis) direction

Figure 3-14. Ratio of the amount of hand movement for each direction (No.1, Japanese cedar)

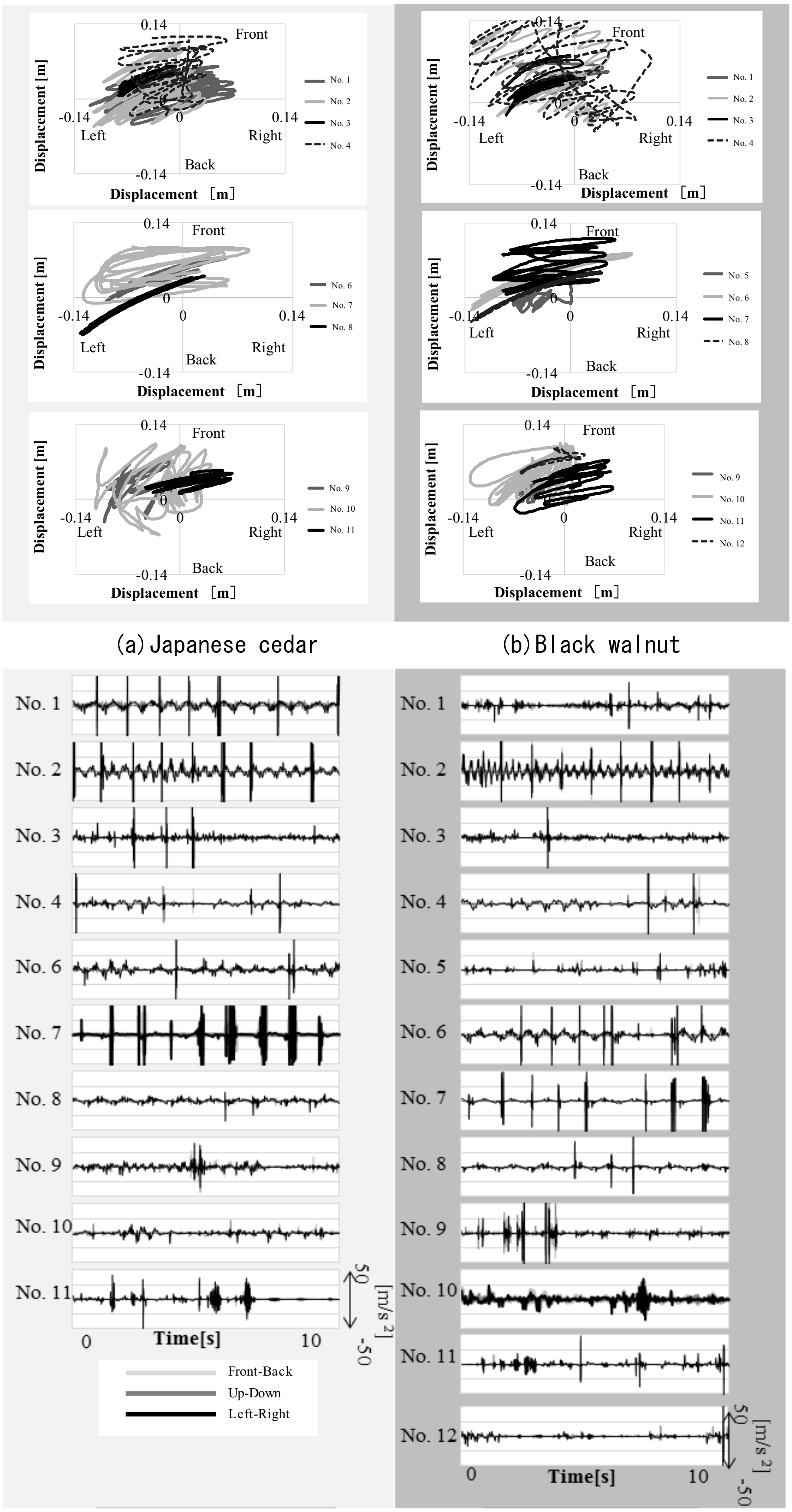


(a) Ratio of the amount of hand movement for Up-Down (y-axis) and Front-Back (x-axis) direction



(b) Ratio of the amount of hand movement for Up-Down (y-axis) and Left-Right (z-axis) direction

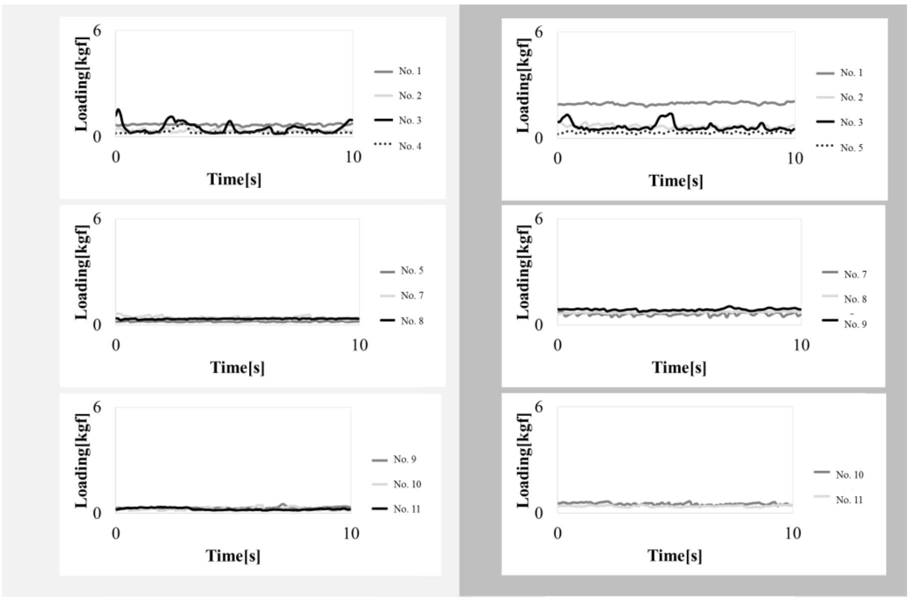
Figure 3-15. Ratio of the amount of hand movement for each direction (No. 2, Black walnut)



(a) Japanese cedar (b) Black walnut

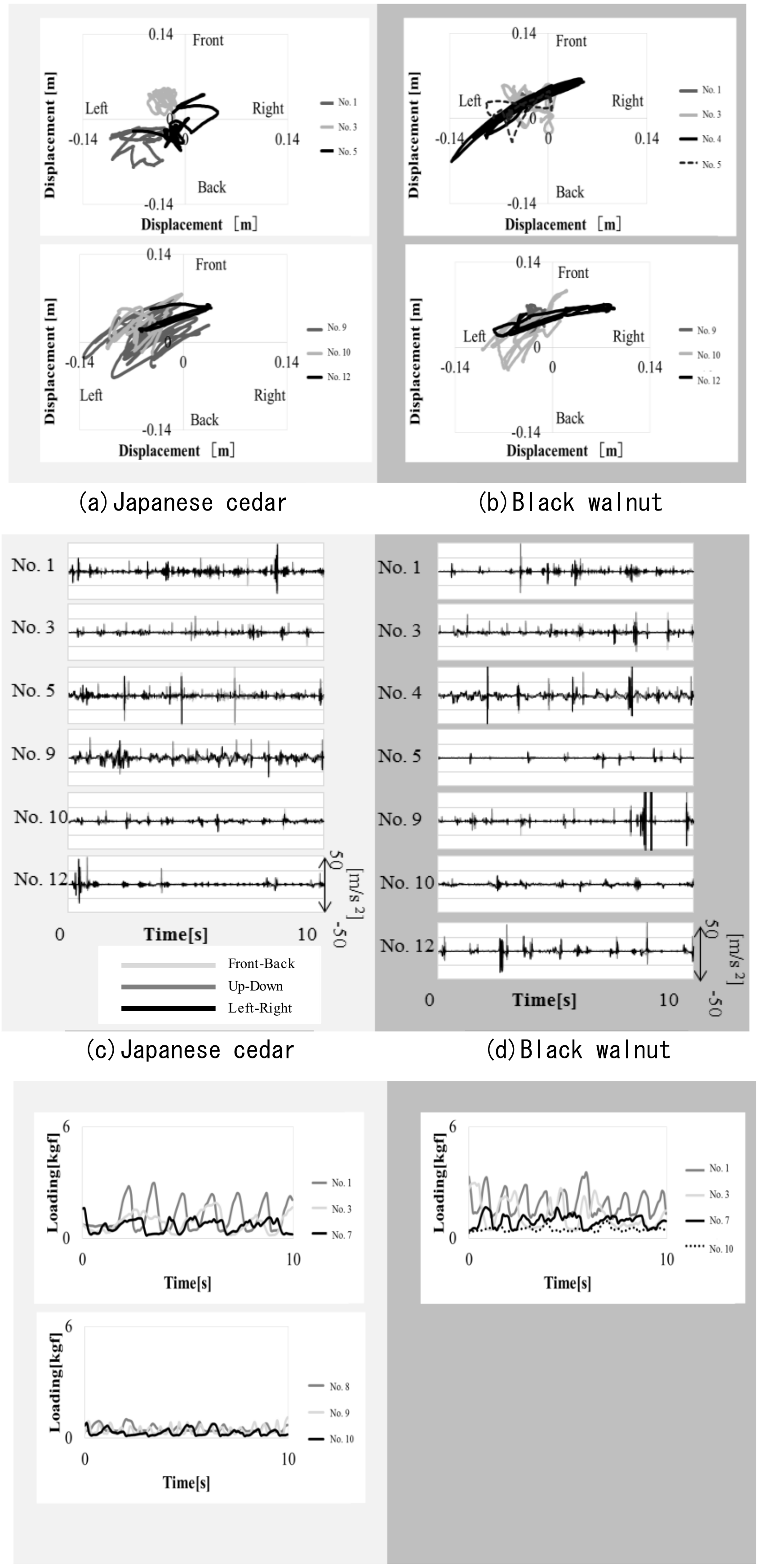
(c) Japanese cedar (d) Black walnut

Figure 3-16. Results of hand movement for assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" (Japanese cedar: Left (light gray), Black walnut: Right (dark gray), (a), (b): trajectory, (c), (d): acceleration (10s))



(e)Japanese cedar (f)Black walnut

Figure 3-17. Results of hand movement for assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" (Japanese cedar: Left (light gray), Black walnut: Right (dark gray), (e), (f): loading)

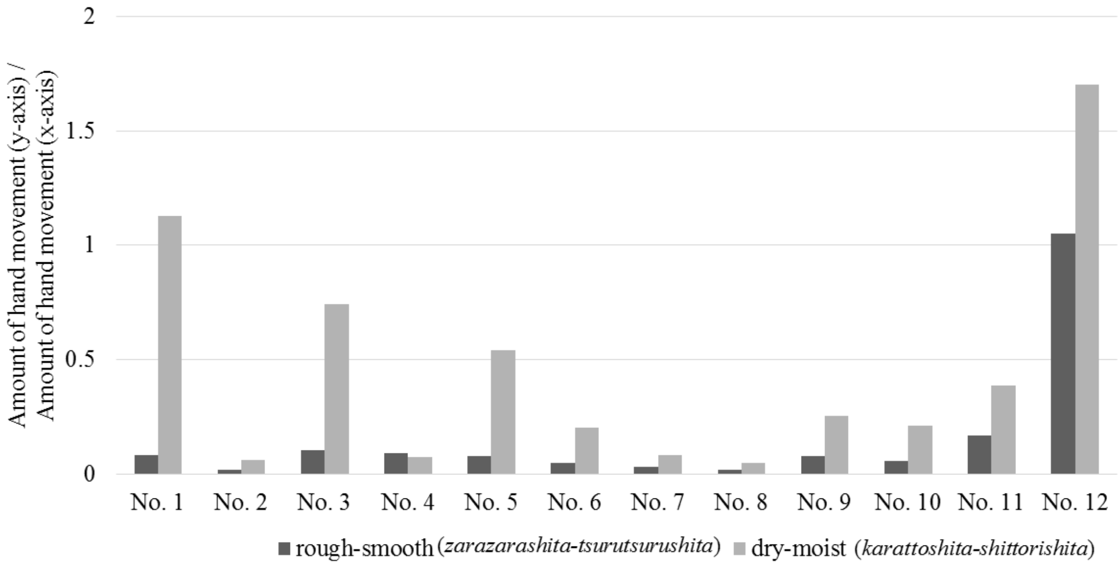


(a) Japanese cedar (b) Black walnut

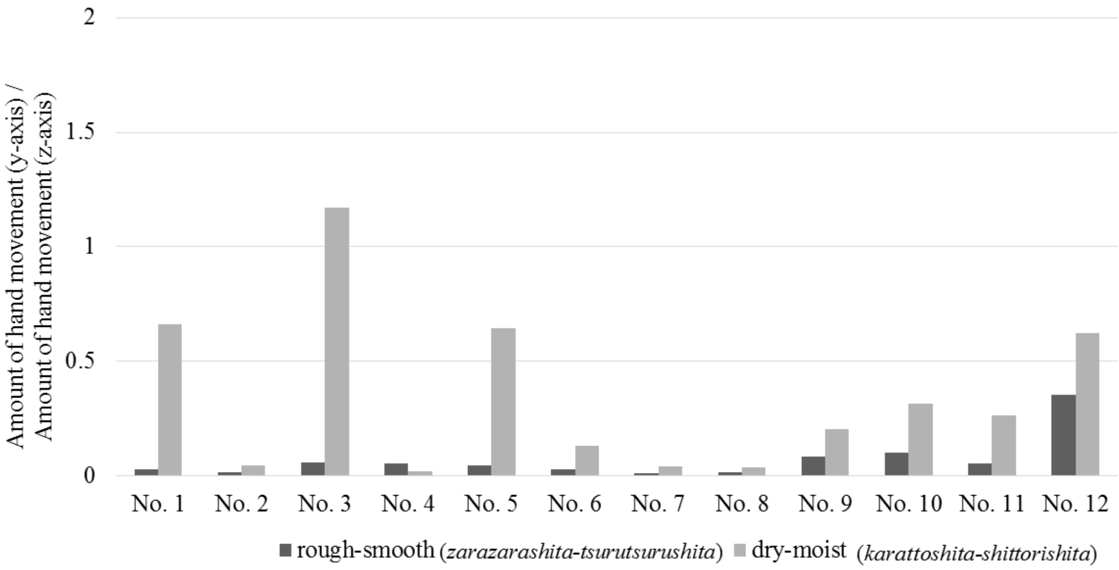
(c) Japanese cedar (d) Black walnut

(e) Japanese cedar (f) Black walnut

Figure 3-18. Results of hand movement for assessing "dry-moist (*karattoshita-shittorishita*)" (Japanese cedar: Left (light gray), Black walnut: Right (dark gray), (a), (b): trajectory, (c), (d): acceleration (10s), (e), (f): loading)

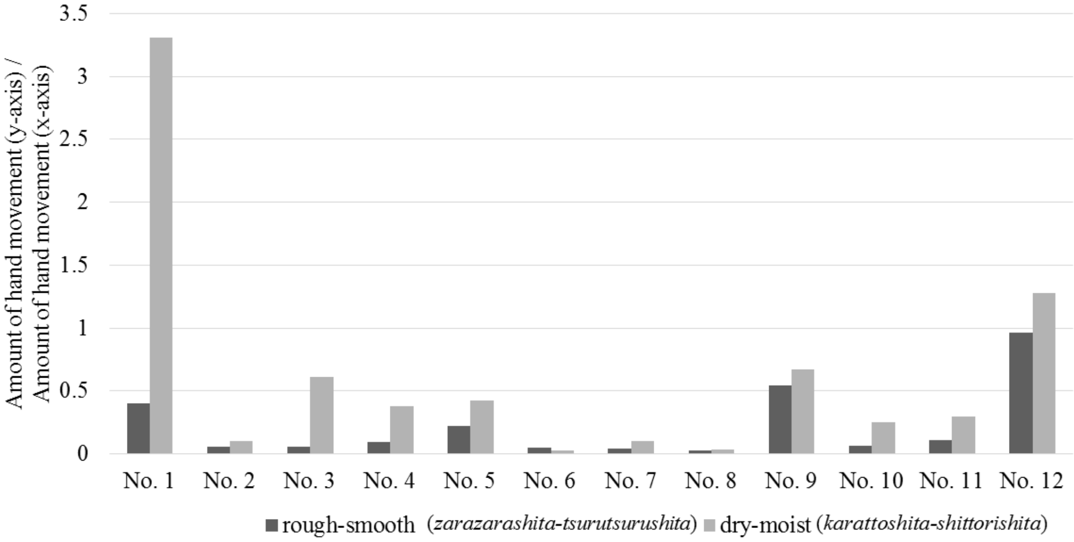


(a) Ratio of the amount of hand movement for Up-Down (y-axis) and Front-Back(x-axis) direction

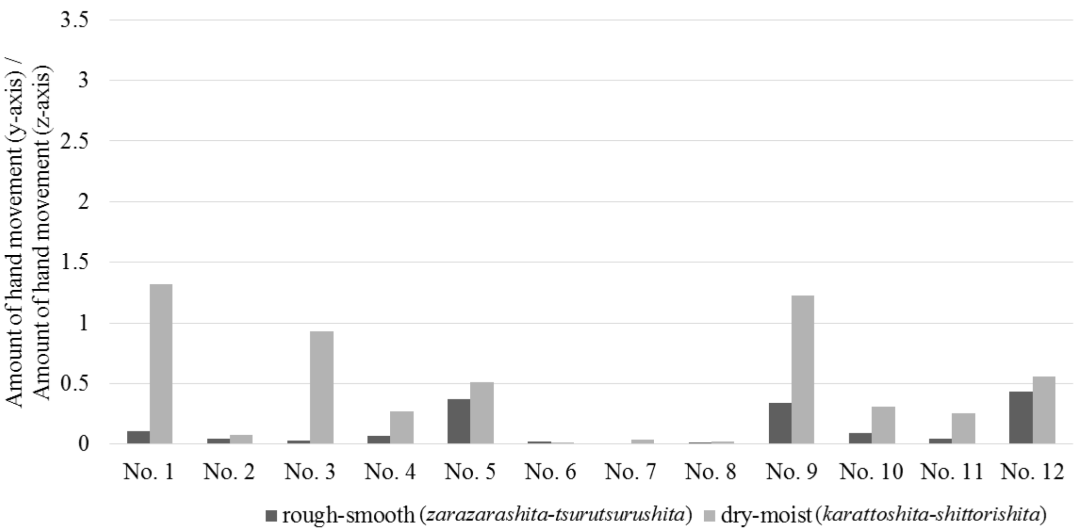


(b)Ratio of the amount of hand movement for Up-Down(y-axis) and Left-Right(z-axis) direction

Figure 3-19. Ratio of the amount of hand movement for each direction (NO.3, Japanese cedar)



(a) Ratio of the amount of hand movement for Up-Down (y-axis) and Front-Back (x-axis) direction



(b) Ratio of the amount of hand movement for Up-Down (y-axis) and Left-Right (z-axis) direction

Figure 3-20. Ratio of the amount of hand movement for each direction (No.4, Black walnut)

3.4.4 Investigation into the relationship between hand movement and impressions

In section 3. 4. 1 and 3. 4. 2, I obtained results of each hand movement when the participants touched the specimen freely to evaluate each term. However, it cannot be concluded from the results of the uncontrolled hand movement what the impressions are evoked into the participants. Moreover, the relation between hand movement and human impressions has not been clarified. Therefore, an additional experiment was carried out to investigate the relation between hand movement and human impressions.

The semantic differential (SD) method as sensory tests was used to investigation whether these hand movement patterns could help participants' evaluate of each material property when assessing the characteristics of wood. Wood specimens were Japanese cedar and Black walnut as in section 2.3 and 3.3.2 (See in Figure 2-2). Two wood test specimens were shown randomly to each participant, and participants were asked to rate the impression in four material terms in the same order, "cool-warm (*tsumetai-atatakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)," "dry-moist (*karattoshita-shittorishita*)" and "hard-soft (*katai-yawarakai*)" on a 7-point equal-interval ordinal scale (e.g.: extremely cool: -3, moderately cool: -2, slightly cool: -1, extremely warm: +3, moderately warm: +2, slightly warm: +1 and neither: 0). When assessing these terms for each material obtained from section 3. 4. 1 and 3. 4. 2, a specific hand movement was explained and used;

"cool-warm (*tsumetai-atatakai*)": "Touch slowly while tracing the square specimen. Just put your hand on the specimen to feel the transfer of heat at the same time as you apply a small force. As soon as the heat transfer is total, you move to the next area."

"rough-smooth (*zarazarashita-tsurutsurushita*)": "Touch the surface with a constant manner without force."

"dry-moist (*karattoshita-shittorishita*)": "Touch the surface in a constant manner, but apply force to the surface."

"hard-soft (*katai-yawarakai*)": "Touch slowly while tracing the square specimen and push with force."

All statistical analyses for the evaluation of sensory data were performed using Excel 2013 (Microsoft, Redmond, WA, USA). The data were analyzed using the Student-t test. Participants for this test were 20 university students (M:10, F:10). These 20 students did not take the discrimination ability test. The temperature and relative humidity in the experimental environment were maintained at 20 °C and 50% RH, respectively.

The result from the sensory tests is shown in Figure 3-21. When participants followed a specific hand movement, which was described in section 3. 4. 1 and 3. 4. 2, they could distinguish the specimen in each term. Significant differences were found in "cool-warm (*tsumetai-atatakai*)," and "hard-soft (*katai-yawarakai*)" This confirms that in terms of material properties; q-max, coefficient of dynamic friction (Perpendicular to grain), density and hardness, Japanese cedar is warmer, rougher, drier and softer than

Black walnut (See in Table 2-1). When comparing sensory tests results and material properties, they had the same tendency. The hand movement used in this test was helpful not only to distinguish material properties but also to evaluate the ranking of each property. Furthermore, I found that guiding instructions on hand movement helped participants to easily give the characteristic properties of each specimen. Therefore, a hand movement pattern demonstrated by another person can help them to evaluate surface properties of wooden products effectively.

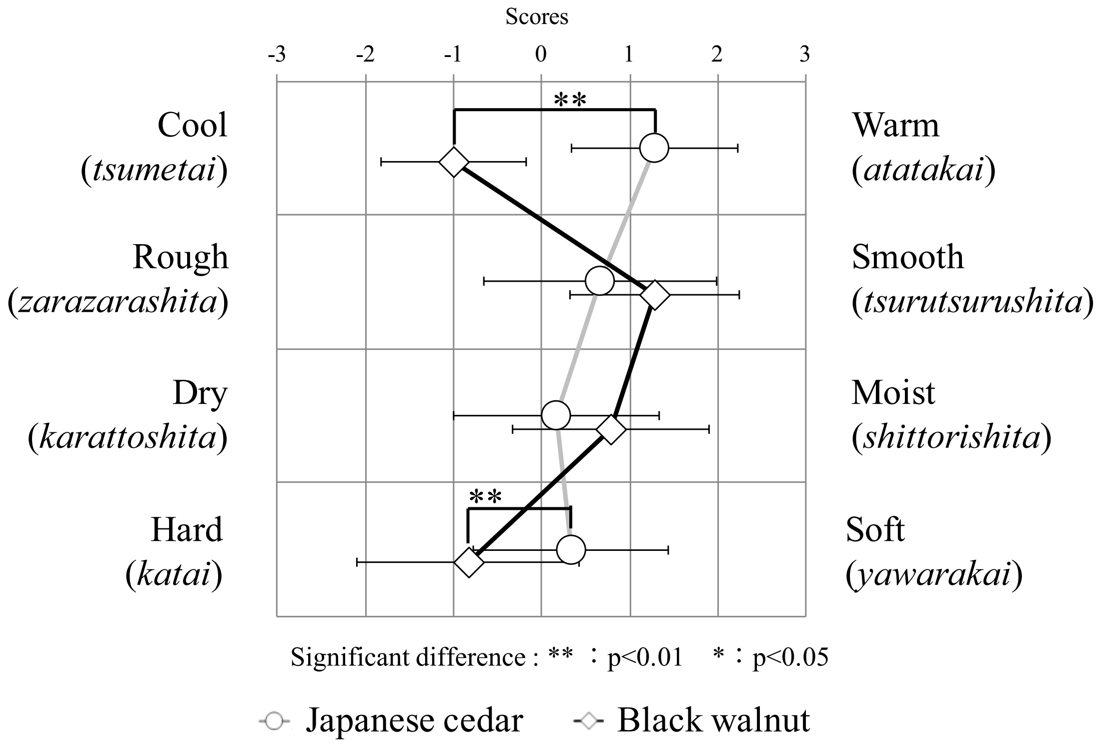


Figure 3-21. SD profiles of specific hand movement with definition.

3.5 Conclusion

In this Chapter 3, I investigated hand movements when assessing four material properties of wood, "cool-warm (*tsumetai-atatakai*)," "hard-soft (*katai-yawarakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)" by using a 3D real-time motion measurement system and a pressure distribution measurement system. Through measuring the hand movement when assessing each term with wood, I conclude the following;

1) When participants evaluated "cool-warm (*tsumetai-atatakai*)"and "hard-soft (*katai-yawarakai*)," they traced the square specimen with a rectangular motion. When evaluating "cool-warm (*tsumetai-atatakai*)" participants' hands remained on one spot for a short period to check the transfer of heat, whereas when evaluating "hard-soft (*katai-yawarakai*)" their hands moved vertically to ascertain the hardness.

2) When participants evaluated "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)" they touched the surface of the wood in a constant manner. When evaluating "rough-smooth (*zarazarashita-tsurutsurushita*)" they used a slight rubbing movement between the surface of the wood and the skin. Participants evaluated "dry-moist (*karattoshita-shittorishita*)" by checking moisture with movement in the vertical direction.

3) The participants assessed these terms for each material with a specific hand movement that was specified in this research. Each of these hand movement patterns

can help participants to evaluate the material properties of wooden products.

The findings of this study indicate that the hand movement for assessing each material term were different. It was also indicated that hand movement patterns were specified and can help participant who assesses wood. These results can use for classification of the hand movement when assessing emotional terms; comfort and preference. I focus on that in the next chapter.

Chapter 4

Investigation into hand movements when assessing comfort and preference of wood

4.1 Introduction

People often feel comfort by touching wooden products, and view them favorably. Many studies have examined the relationship between the human feeling and wood. It is important to investigate people's hand movements while assessing the quality of wood because understanding consumer behavior helps to enhance the quality of wooden products. The purpose of this thesis is to investigate the comfortable feeling of wood. In the previous Chapter 3, I examined the hand movements when assessing the evaluation terms concerning material properties. Thus, through studying hand movements, I attempted to discuss the relationship between the comfortable feeling and wood in this Chapter 4.

That is, what of the wood provides the feeling of comfort or preference? How do touch wooden products evoke these emotions?

In Chapter 2, four emotional terms in sensory test were used. However, the both "cheap-expensive (*yasusouna-takasouna*)" and "artificial-natural (*jinkoutekina-shizenna*)" was influenced by visual impression stronger than tactile impression. Therefore, I put emphasis on the hand movement when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" as high-level concepts in Chapter 4. It is generally assumed that emotions such as comfort and preference are high-level concepts that are combined with several subordinate concepts. In this case of assessing characteristics of wood, the subordinate concepts are hypothesized to correspond to four material properties; warmness, smoothness, moistness, and hardness. In the previous Chapter 3, the hand movements were investigated that participants used to evaluate four fundamental terms related to the material properties of warmness, smoothness, moistness, and hardness, and found that each was associated with a different hand movement.

The two emotional terms ("uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") are high-level concepts and that participants tended to use different hand movements to evaluate the four subordinate concepts of warmness, smoothness, moistness and hardness. Therefore, I propose that the comparison the pattern in the hand movements and classification of them for searching relationship between the hand movements for distinguishing between the two emotional terms and the four fundamental terms related to the material properties. In this Chapter 4, the hand movements were examined and compared to evaluate two emotional terms ("uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") and four fundamental terms ("cool-warm (*tsumetai-atatakai*)," "hard-soft (*katai-yawarakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)") when touching wooden samples in order to find out the difference of hand movements when assessing two emotional terms.

4.2 Purpose

In this Chapter 4, I examined and compared the hand movements to evaluate two emotional terms ("uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") and four fundamental terms of material properties ("cool-warm (*tsumetai-atatakai*)," "hard-soft (*katai-yawarakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)") when touching wood specimens in order to find out the difference of hand movements when assessing two emotional terms.

4.3 Methods

4.3.1 Outline

The experimental outline was the same of the Chapter 3. Twelve university students who allowed to participate through preliminary practice for this experiment (refer to 3.3.1). The experiments were conducted over two days in two separate room as the same reason as Chapter 3. The temperature and relative humidity of two experimental rooms were maintained at 20 °C and 50% RH, respectively in two experimental rooms. All wood specimens were resting for more than 24 hour in advance of the experiments.

Experiments were conducted over two days in two separate experimental rooms because of the difficulty of moving the 3D real-time motion measurement system. On the first day, I determined the loading by using the pressure distribution measurement system. The hand movement measurement was operated with four fundamental term and two emotional terms. One of the terms ("cool-warm (*tsumetai-atatakai*)", "rough-smooth (*zarazarashita-tsurutsurushita*)", "dry-moist (*karattoshita-shittorishita*)", "hard-soft (*katai-yawarakai*)", "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") was indicated to participants who then touched the sample freely to evaluate the specified term while being recorded on video for 10 s (Cyber-shot DSC-TX7, SONY, Tokyo, Japan). After one term was assessed, another term was specified and participants evaluated specimen, and repeated until all six terms were assessed. Two wood specimens were shown randomly to each participant. However, six terms in the questionnaire were always shown in the same order, "cool-warm (*tsumetai-atatakai*)", "rough-smooth (*zarazarashita-tsurutsurushita*)", "dry-moist (*karattoshita-shittorishita*)", "hard-soft (*katai-yawarakai*)", "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)". I focused on two emotional terms in this chapter. I-SCAN Ver. 5.0 (NITTA Co., Osaka, Japan) and Excel 2013 (Microsoft, Redmond, WA, USA) were used for data acquisition and data analysis, respectively.

On the second day, measured trajectory and acceleration were measured by using the 3D real-time motion measurement system. Motive (Nobby Tech Co., Tokyo, Japan) was used as the calibration software and VENUS3D (Nobby Tech Co., Tokyo, Japan) as the coordinate acquisition and analysis software. In this chapter, trajectory was limited to the results. One of the terms ("cool-warm (*tsumetai-atatakai*)", "rough-smooth (*zarazarashita-tsurutsurushita*)", "dry-moist (*karattoshita-shittorishita*)", "hard-soft (*katai-yawarakai*)", "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)") was indicated to the participant, who then touched each sample freely for 15 s until all four terms were assessed. Two wood specimens were shown randomly to each participant. However, the six terms in the questionnaire were always shown in the same order, "cool-warm (*tsumetai-atatakai*)", "rough-smooth (*zarazarashita-tsurutsurushita*)", "dry-moist (*karattoshita-shittorishita*)", "hard-soft (*katai-yawarakai*)", "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)." The first and last 2.5 s of data were eliminated to minimize the influence of measurement error to give a total of 10 s. The goal of test was to find the characteristic raised shape of the trajectory graph and the presence.

4.3.2 Wood specimens

The specimens were the same of the Chapter 3, Japanese cedar (*Cryptomeria japonica*) and Black walnut (*Juglans nigra*). Three times urethane coatings were applied to form a surface film (top, middle and under coating). The specimens were square with the dimensions of 280 mm（L） × 280 mm（R） × 10 mm（T）.

4.4 Comparison of hand movements when assessing comfort and preference and four fundamental terms of material properties

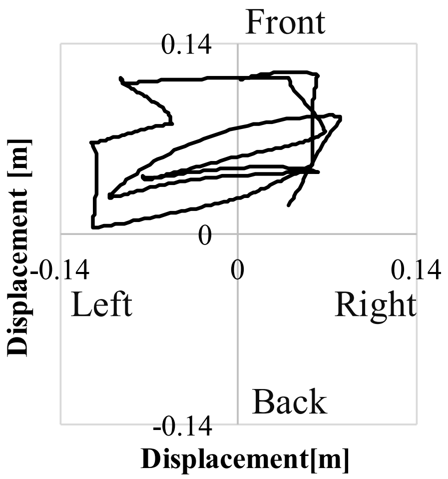
The participants' hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" were compared with those when assessing the four fundamental terms of material properties ("cool-warm (*tsumetai-atatakai*)" "hard-soft (*katai-yawarakai*)" "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)") mentioned in Chapter 3. In this chapter, I focused on only the trajectory and the loading. This is an example of the result which was obtained when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" or "dislike-like (*kirai-suki*)". Similar hand movements were also observed between the individual participants in some cases, but somebody of the participants result showed in this section.

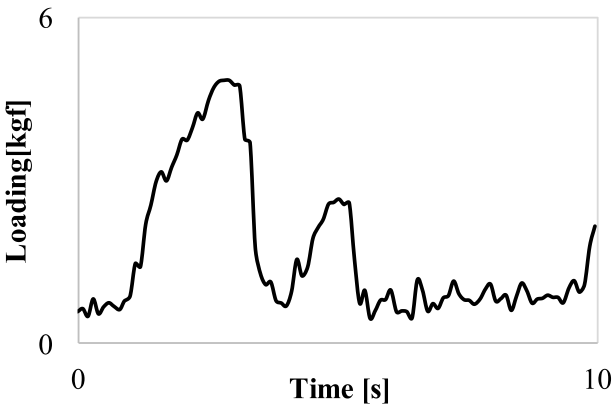
I could find the trajectory from Figure 4-1(a), which the participant put on their hand in one place for a short period and traced the square sample with a rectangular motion. Figure 4-1(b) shows the vertical movement loading results. The loading was large, indicating that the participant pressed hard on the wood specimen; however, the loading peaked infrequently. Because this hand movement characteristic was similar to that for "cool-warm (*tsumetai-atatakai*)", it seems that the participant assessed "dislike-like (*kirai-suki*)" according to investigations about "cool-warm (*tsumetai-atatakai*)".

From Figure 4-2(a) which shows the trajectory, participants' hand movements followed the profile of the wood specimens. Figure 4-2(b) shows the loading result for vertical movement. The amount of loading was large, and the loading peaks were frequent. Because this hand movement characteristic was similar to that for “hard-soft (*katai-yawarakai*)”, it seems that the participant assessed “uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)” according to investigations about “hard-soft (*katai-yawarakai*)”.

From Figure 4-3(a) which shows the trajectory, constant movement was observed. However, the loading results in Figure 4-3(b) show no vertical movement. Because this hand movement characteristic was similar to that for “rough-smooth (*zarazarashita-tsurutsurushita*)”, it seems that the participant assessed “uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)” according to investigations about “rough-smooth (*zarazarashita-tsurutsurushita*)”.

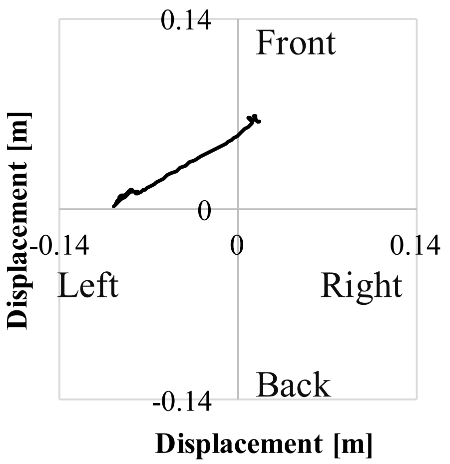
The trajectory result for “dislike-like (*kirai-suki*)” in Figure 4-4 (a) shows constant movement. The loading result in Figure 4-4(b) also shows vertical movement; however, the pressure was not strong and the loading was lower than that when assessing “cool-warm (*tsumetai-atatakai*)” and “hard-soft (*katai-yawarakai*)”. Because this hand movement characteristic was similar to that for “dry-moist (*karattoshita-shittorishita*),” it seems that the participant assessed “dislike-like (*kirai-suki*)” according to investigations about “dry-moist (*karattoshita-shittorishita*)”.

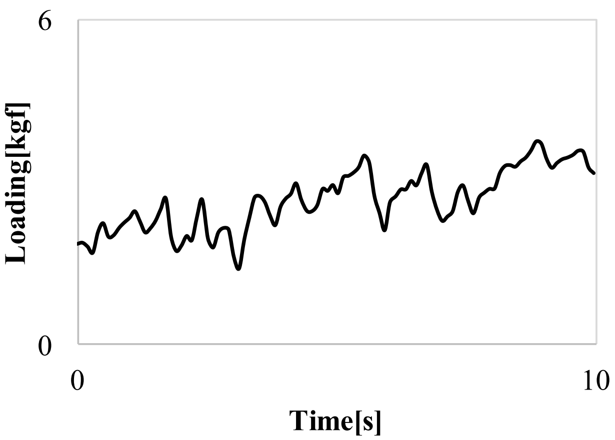




(a) Trajectory (Participant No. 7)　　(b) Loading (Participant No. 6)

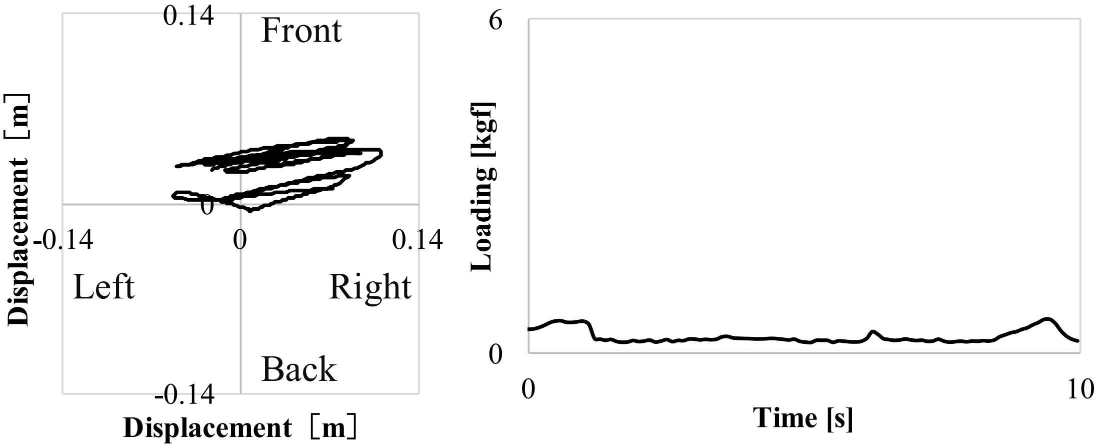
Figure 4-1. Hand movements when assessing "dislike-like (*kirai-suki*)" for Japanese cedar; the movements were similar to those when investigating "cool-warm (*tsumetai-atatakai*)"





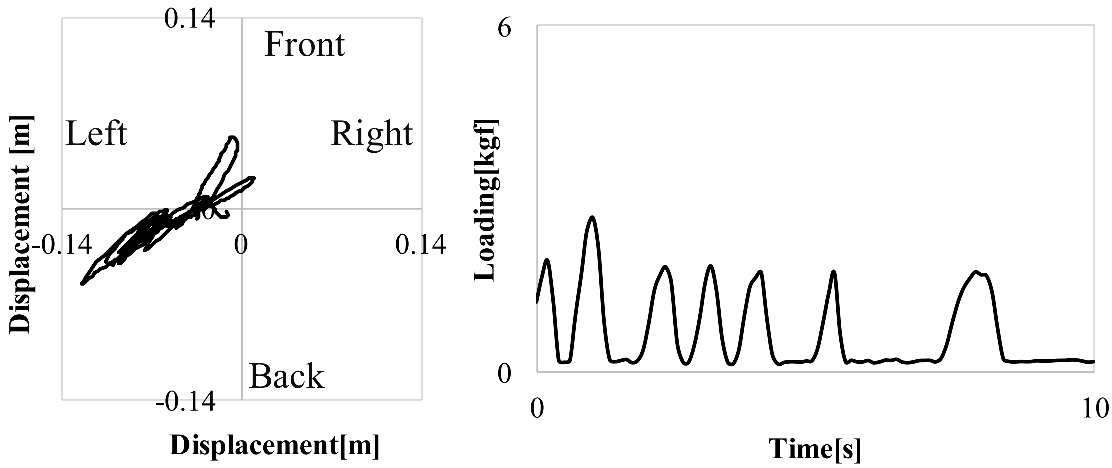
(a) Trajectory (Participant No.12)　　(b) Loading (Participant No.12)

Figure 4-2. Hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" for Japanese cedar; the movements were similar to those when investigating "hard-soft (*katai-yawarakai*)"



(a) Trajectory (Participant No. 11)　　(b) Loading (Participant No. 11)

Figure 4-3. Hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" for Japanese cedar; the movements were similar to those when investigating "rough-smooth (*zarazarashita-tsurutsurushita*)"



(a) Trajectory (Participant No. 5)　　(b) Loading (Participant No. 5)

Figure 4-4 Hand movements when assessing "dislike-like (*kirai-suki*)" for Japanese cedar; the movements were similar to those when investigating "dry-moist (*karattoshita-shittorishita*)"

Thus, hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" were similar tendency for each hand movements when assessing four fundamental terms of material properties. However, some of the participants' hand movement was difficult to classify into four fundamental terms of material properties with qualitative index since the hand movements varied widely between individuals e.g. the hand movement tended to adopt constant movement and tracing the wood specimen shape. Therefore, classification with some quantitative index was discuss in the next section.

4.5 Classification of hand movements when assessing two emotional terms by hand movements when assessing four fundamental terms of material properties

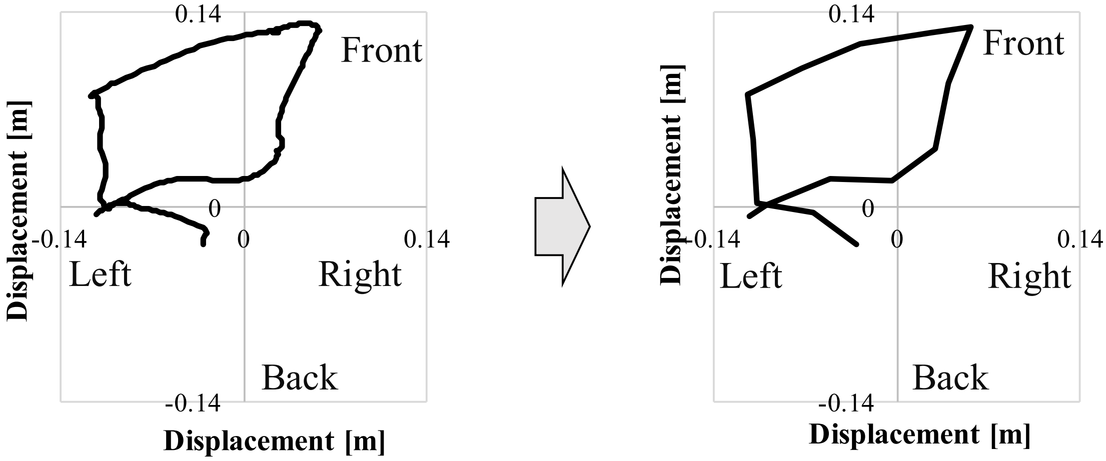
4.5.1 Rule of classification

From the discussion in Section 4.4, I hypothesized that participants' hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" could be classified by comparing them with the hand movements when assessing the four fundamental terms of material properties. However, this classification was based on a subjective and qualitative evaluation. Using quantitative information makes it easier to classify the two evaluation terms into the four fundamental terms of material properties. In this section, the trajectory and the loading were analyzed. I referred to results from Section 3.4, and used them as a quantitative index. Each of the index was decided in reference to the results of people concerned. Table 4-1 shows the list of characteristics of hand movements when assessing four fundamental terms of material properties using a quantitative index, however, the explanation add more in detail.

Table 4-1. The rule of characteristics of hand movements when assessing four fundamental terms

terms	Relative frequency	Kinds of hand movement	Distance of trajectory	Vertical movement	Maximum loading	Count number of peaks	Standard Deviation
cool-warm	not less than 0.15	figure movement	not less than 0.17m	observed	not less than 3kgf	6 or less than	-
hard-soft	not less than0.15	figure movement	not less than 0.17m	observed	not less than 3kgf	more than 6	-
rough-smooth	less than 0.15	constant movement	less than 0.17m	none	less than 3kgf	-	less than 0.1
dry-moist	less than 0.15	constant movement	not less than 0.17m	observed	less than 3kgf	-	not less than 0.1

I used the direction cosine for signature analysis for trajectory and decided the following rule: If the hand movement is constant in one direction, the angle between trajectory lines is 0 or 180 degrees. If the hand movement follows the profile of the square samples, the trajectory includes several 90 degree angles for this analysis. Based on this rule, if the direction cosine was around -1 or 1, the hand movement was defined “constant movement”. If the direction cosine was around 0, the hand movement was defined “figure movement”. These movements were sampled every 0.05 m (see Figure 4-5), which was decided as the standard distance to distinguish the movements from left to right and front to back. First, trajectory which was measured in 100 Hz was resampled by each 0.05 m. Numbers of resampled data were counted and I called the total count “Count All.” Second, if the direction cosine was 0, the hand movement followed the profile of the wood specimen, so I counted the times a cosine of 0 occurred every 0.05 m and called it “Count 0”. Finally, the value was obtained by dividing Count 0 by Count All and this value was used as the “relative frequency” to judge whether there was constant movement or figure movement, meaning it followed the sample shape. In the preliminary analysis using the result of the Chapter 3, if a hand movement was constant, the relative frequency was less than 0.15, and if the hand movement followed the shape, the relative frequency was not less than 0.15. Based on the results, hand movements were classified into two groups: constant movement and figure movement.



(a) The original date (b) The resampling date

Figure 4-5. Method of resampling of trajectory (Trajectory which was measured in 100 Hz: Left, Resampled by each 0.05 m: Right)

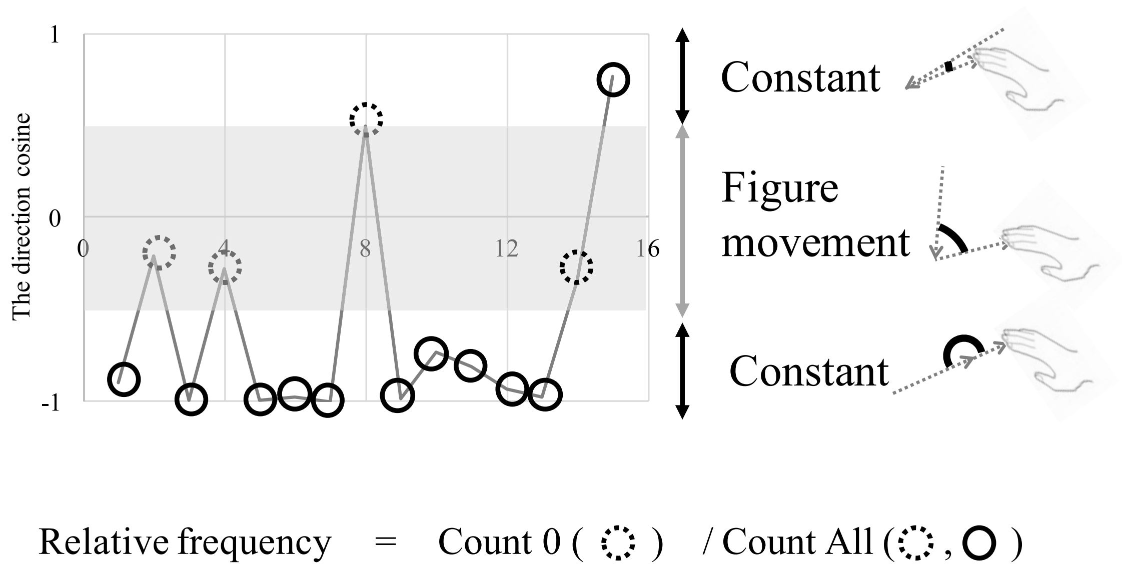


Figure 4-6. Method of calculation for Relative frequency

The distance of the trajectory was also calculated in the up-down direction. In our previous study, I found that a movement in the up-down direction indicated the assessment of "cool-warm (*tsumetai-atatakai*)," "dry-moist (*karattoshita-shittorishita*)," and "hard-soft (*katai-yawarakai*)". The average of the distance of the trajectory was calculated from the results of four terms of people concerned, and I determined that if the distance of the trajectory was not less than the average of 0.17 m, the hand moved in the vertical direction.

The loading results from our previous study when assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)" was never above 3 kgf. Therefore, the rule was decided if the maximum loading was less than 3 kgf, the hand movement was classified as the hand movement group of "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)". Additionally, the hand movement when assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" was not in the vertical direction and the loading was constant. Therefore, if the standard deviation of the loading, which was calculated from 10 s of loading data, was less than 0.1, it was classified as the hand movement group of "rough-smooth (*zarazarashita-tsurutsurushita*)". If the maximum loading was 3 kgf or more, it was classified into the hand movement group of "cool-warm (*tsumetai-atatakai*)" and "hard-soft (*katai-yawarakai*)". In the previous study, the loading when assessing "hard-soft (*katai-yawarakai*)" was large and the loading peaks were frequent. However, the loading when assessing "cool-warm (*tsumetai-atatakai*)" was large and there were six loading peaks at most (see in Figure 4-7). Therefore, in this Chapter 4, if the counts of peaks were six or less, we classified it as the "cool-warm (*tsumetai-atatakai*)" hand movement group.

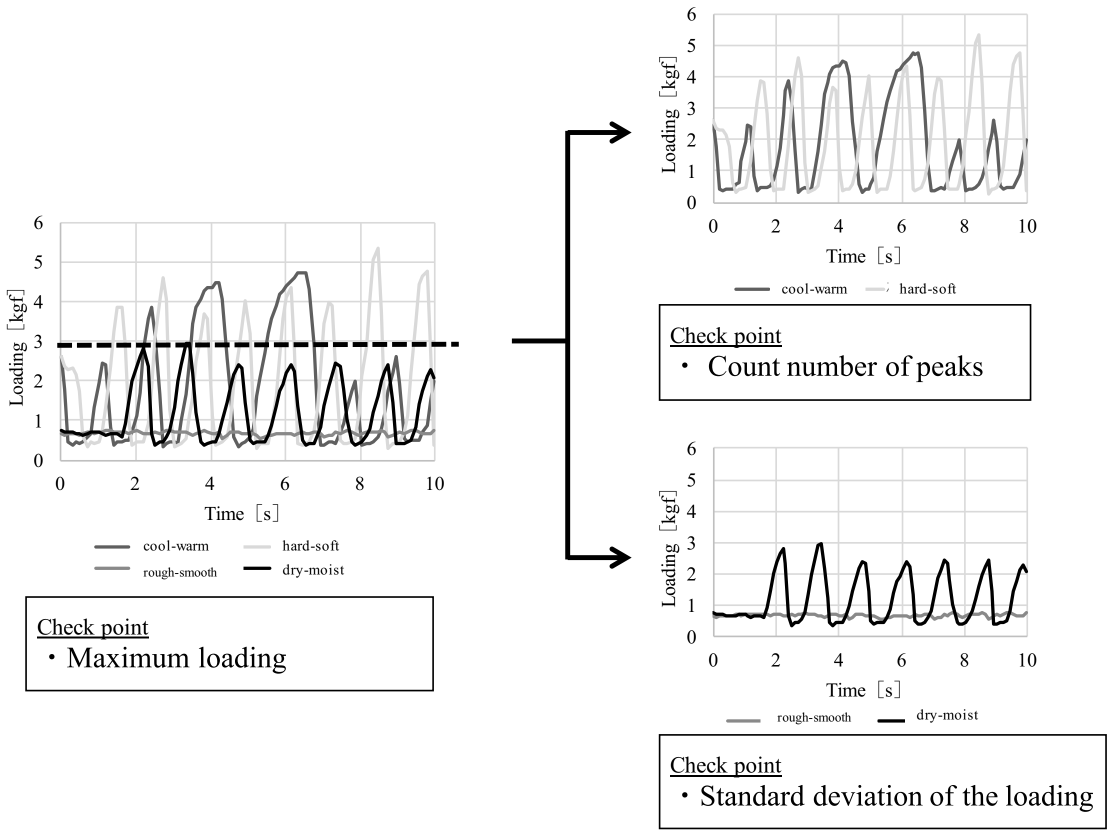


Figure 4-7. Check point of the classification of the loading result

4.5.2 Results of classification

Figures 4-8 and 4-9 show that the results of relative frequency. Many participants' hand movements were classified as constant movement. This type of hand movement was observed when assessing "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)". These results are consistent with those in Section 4.4.

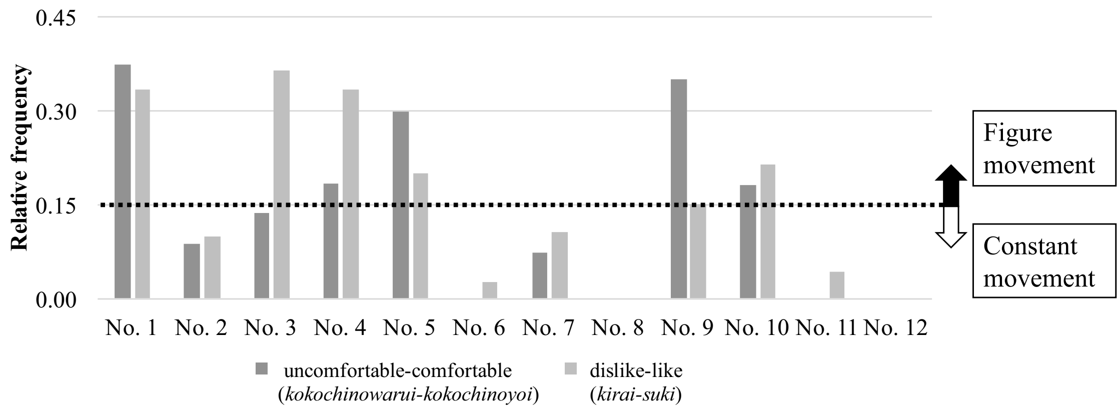


Figure 4-8. Relative frequency of the angle for Japanese cedar

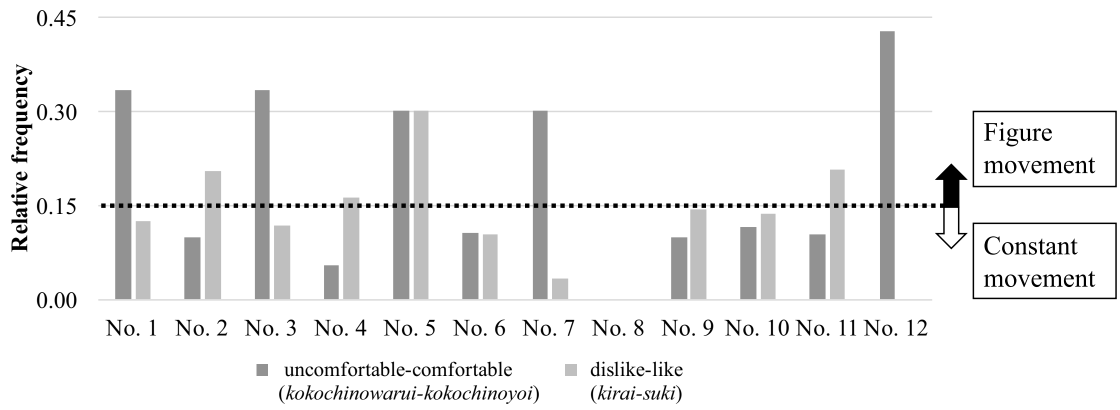


Figure 4-9. Relative frequency of the angle for Black walnut

The distance of the trajectory in the up-down direction was also calculated. The results in Figures 4-10 and 4-11 show that some participants moved their hands in the up-down direction, which our previous study showed to be important when evaluating "cool-warm (*tsumetai-atatakai*)" and "dry-moist (*karattoshita-shittorishita*)". The trajectory results show that hand movements followed only either figure or constant movement, sometimes with vertical movement. Therefore, I focus on the loading results.

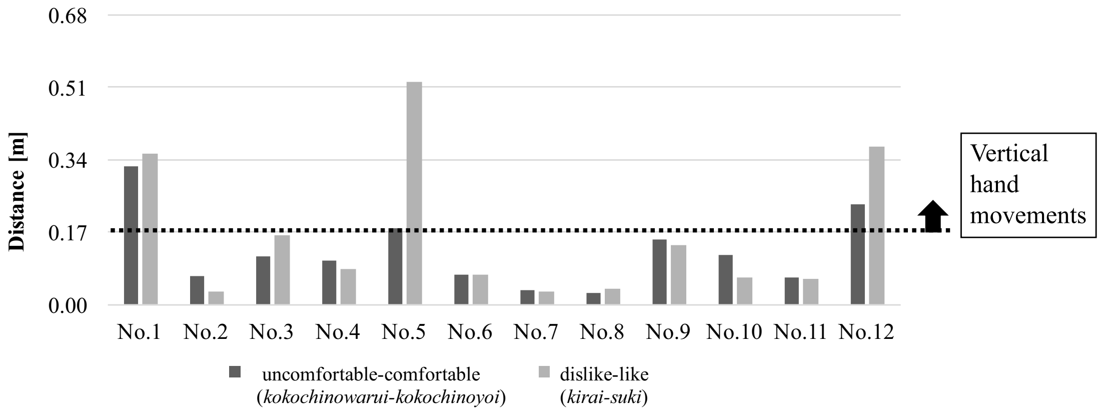


Figure 4-10. Amount of distance in hand movements assessing Japanese cedar

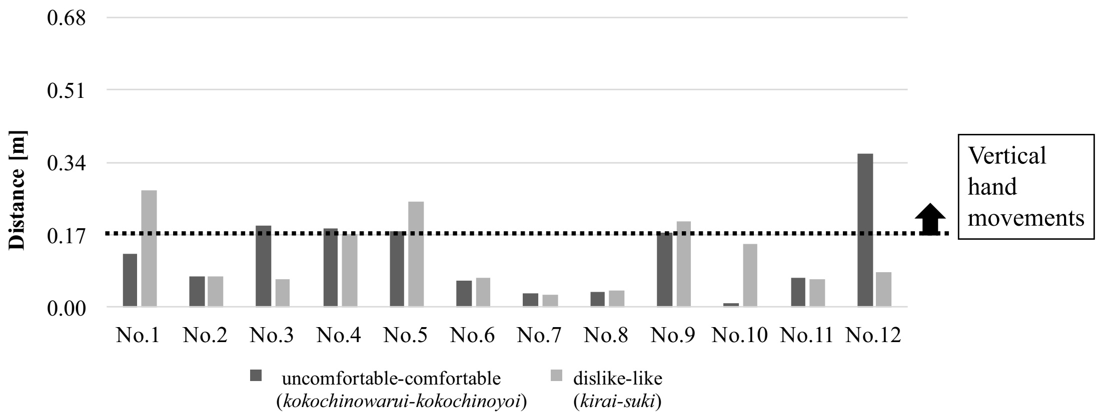


Figure 4-11. Amount of distance in hand movements assessing Black walnut

Figures 4-12 and 4-13 and Tables 4-2 and 4-3 show the maximum loading results, count number of peaks, and standard deviation of loading. Participants were classified into the “dry-moist (*karattoshita-shittorishita*)” hand movement group, therefore they assessed comfort and preference from moistness and roughness. This result was similar to the tendency reported in Section 3.4. However, the results also suggest that participants combined hand movements when assessing the wood specimen.

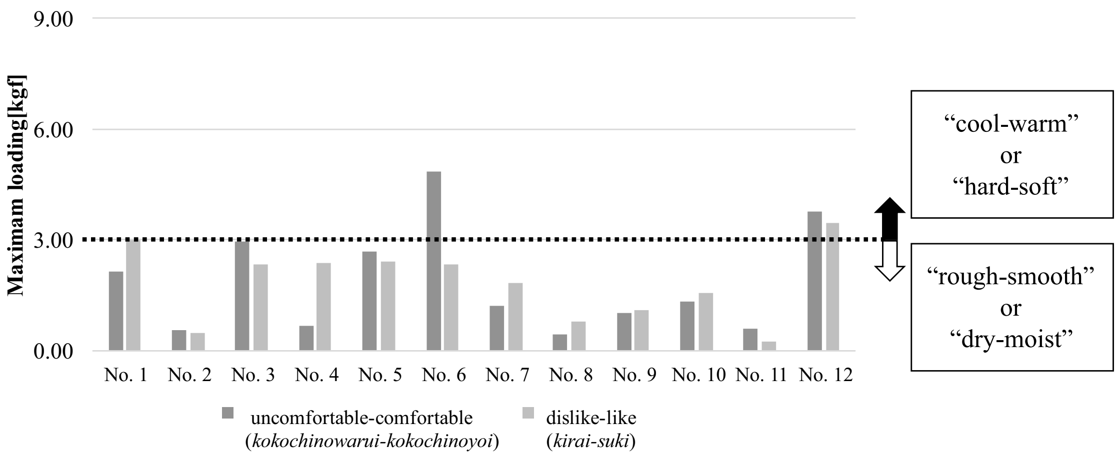


Figure 4-12: Maximum loading for Japanese cedar

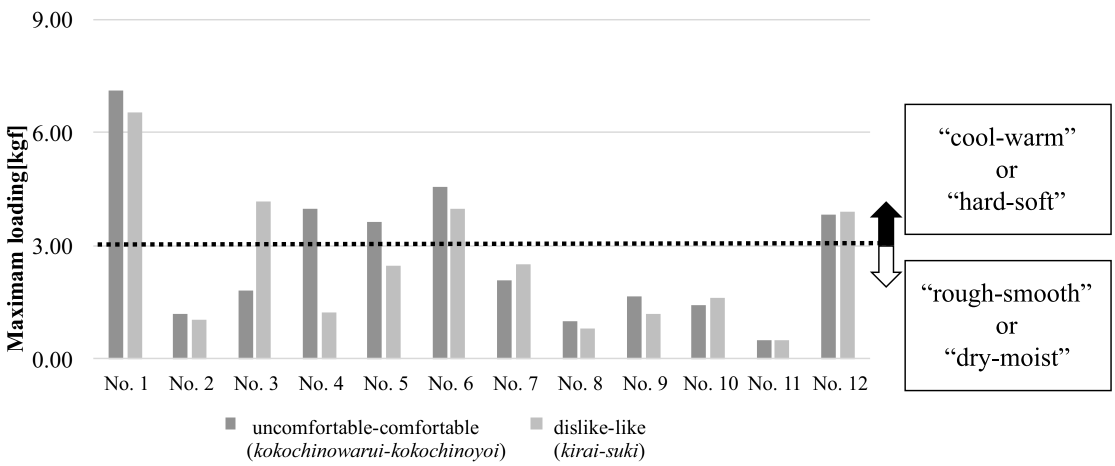


Figure 4-13: Maximum loading for Black walnut

Table 4-2. Loading results (count number of peaks and standard deviation) for Japanese cedar

Participant	uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*) Count number of peaks	Standard Deviation	Hand Movement	dislike-like (*kirai-suki*) Count number of peaks	Standard Deviation	Hand Movement
No. 1		0.54	dry-moist	1	0.69	cool-warm
No. 2		0.07	rough-smooth		0.06	rough-smooth
No. 3		0.66	dry-moist		0.63	dry-moist
No. 4		0.09	rough-smooth		0.65	dry-moist
No. 5		0.67	dry-moist		0.39	dry-moist
No. 6	1	1.30	cool-warm		0.42	dry-moist
No. 7		0.28	dry-moist		0.34	dry-moist
No. 8		0.02	rough-smooth		0.11	dry-moist
No. 9		0.11	dry-moist		0.17	dry-moist
No. 10		0.30	dry-moist		0.37	dry-moist
No. 11		0.12	dry-moist		0.02	rough-smooth
No.12	6	0.55	cool-warm	9	0.48	hard-soft

Table 4-3. Loading results (Count number of peaks and standard deviation) for Black walnut

Participant	uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*) Count number of peaks	Standard Deviation	Hand Movement	dislike-like (*kirai-suki*) Count number of peaks	Standard Deviation	Hand Movement
No. 1	8	1.59	hard-soft	6	1.11	cool-warm
No. 2		0.13	dry-moist		0.11	dry-moist
No. 3		0.26	dry-moist	2	0.86	cool-warm
No. 4	2	0.91	cool-warm		0.19	dry-moist
No. 5	2	1.29	cool-warm		0.70	dry-moist
No. 6	6	0.60	cool-warm	1	0.60	cool-warm
No. 7		0.26	dry-moist		0.38	dry-moist
No. 8		0.08	rough-smooth		0.05	rough-smooth
No. 9		0.19	dry-moist		0.11	dry-moist
No. 10		0.23	dry-moist		0.25	dry-moist
No. 11		0.04	rough-smooth		0.05	rough-smooth
No.12	10	0.61	hard-soft	12	0.52	hard-soft

Many participants assessed “uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)” and “dislike-like (*kirai-suki*)” in the same way as those in the “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*)” groups; that is, their hand movements were constant and easily followed the surface with no vertical movement. In past study, Kappers and Douw also measured hand movements and asked participants to “describe the relief” while assessing different materials [46]. The results showed that hand movements covered a small area while constantly moving from left to right. The hand movements of many participants were classified as “rough-smooth (*zarazarashita-tsurutsurushita*)” because many of the materials used in the study, especially wood, tend to have smooth surfaces. In another study [47], young people were asked to assess oak using their sense of touch according to its warmness, moistness, roughness, concave and convex impression, and comfort. A multiple regression analysis indicated that the relationship between perceived comfort and warmness, moistness, roughness, and embossed feeling can be expressed by a formula comfortable feeling = -0.60 × moistness feeling (coefficient of determination R^2 = 0.98) [47]. The hand movements when assessing “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*)” were simple because they consisted of constant movement. The researchers concluded that the constant hand movements used when assessing the two emotional terms were similar to those used when assessing “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*)”.

Comparing the result from Sections 4.4 and 4.5, it seems that the quantitative results were more important for classification for hand movements. The participants' hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" were classified into four fundamental terms of material properties. Because touching was not controlled, some of the participants touched the wood with hand movements that both constantly moved and followed the shape. Therefore, almost all of the participants' hand movements were classified into the four fundamental terms of material properties. Many participants also seemed to be investigating smoothness and moistness when they were assessing comfort and preference.

In this Chapter 4, however, few participants' hand movements were similar to that of "cool-warm (*tsumetai-atatakai*)" or "hard-soft (*katai-yawarakai*)" assessments. A strong red-yellow gives a feeling of warmth [36], whereas brightness gives the impression of hardness [34]. Because warmness and hardness are influenced by these visual properties, the hand movements when assessing "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" were speculated by roughness and moistness rather than warmness and hardness.

4.6 Conclusion

In this Chapter 4, I investigated participants' hand movements while they assessed two emotional terms, "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)", and compared with four fundamental terms of material properties, "cool-warm (*tsumetai-atatakai*)", "hard-soft (*katai-yawarakai*)", "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)", using a 3D real-time motion measurement system and a pressure distribution measurement system. Through comparison of the result of these measurement, I conclude the following;

1) The hand movements when assessing emotional terms could be classified into four fundamental hand movements relate to terms of material properties. However, some of the participants could not be classified into any of these four fundamental terms of material properties, because their hand movements were not only the similar tendency but also the differences.

2) I assessed their hand movements using several quantitative indices: the frequency of the angle, the counts number of hand movements and the loading. These indexes allowed us to classify participants' hand movements while assessing comfort and preference into four fundamental terms of material properties.

3) Many participants tended to assess "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" according to investigations about "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)", because they used simple and easily followed the surface hand movements with no vertical movement.

Through these researches, it is necessary to focus on tactile impression and the method of obtaining the consumer's high-level impression; comfort and preference. It is suggested that the smoothness and moistness influence of high-level impression.

Chapter 5

Conclusions

In this thesis, the relationship between the human feeling and characteristics of wood was investigated by using subjective and objective methods. In the Chapter 2, sensory tests were carried out to reveal the relationship between tactile impressions, visual impressions, visual-tactile impressions, and material properties. In the Chapter 3, hand movements were focused on and measured when assessing four terms related to material properties. In the Chapter 4, hand movements were measured when evaluating comfort and preference from wood.

In the Chapter 2, I focused on the human feeling with tactile impressions, visual impressions and visual-tactile impression when assessing wooden products through subjective evaluation. It was analyzed the relationship among visual or tactile impression, visual-tactile impression and material properties by using sensory tests and multiple regression analysis.

The terms of material properties were affected significantly the tactile impression. The emotional terms were affected significantly the visual impression. The visual-tactile impression was affected by both tactile perception and visual perception. Additionally, the tactile impression was affected by the surface friction, and visual impression was affected by brightness.

When assessing the visual-tactile impression, the visual impression affected strongly than the tactile impression did. However, the feeling which, can be acquired from the tactile receptors; such as warmness, smoothness and moistness, was strongly influenced by the tactile impression.

In the Chapter 3, hand movements when assessing four fundamental terms of material properties, “cool-warm (*tsumetai-atatakai*),” “hard-soft (*katai-yawarakai*),” “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*)” was investigated by using a 3D real-time motion measurement system and a pressure distribution measurement system.

When participants evaluated “cool-warm (*tsumetai-atatakai*)” and “hard-soft (*katai-yawarakai*),” they traced the square specimen with a rectangular motion. When evaluating “cool-warm (*tsumetai-atatakai*),” participants’ hands remained on one spot for a short period to check the transfer of heat, whereas when evaluating “hard-soft (*katai-yawarakai*),” their hands moved with a vertical component to ascertain the hardness.

When participants evaluated “rough-smooth (*zarazarashita-tsurutsurushita*)” and “dry-moist (*karattoshita-shittorishita*),” they touched the surface of the wood in a constant manner. However, when evaluating “rough-smooth (*zarazarashita-tsurutsurushita*),” they used a slight rubbing movement between the surface of the wood specimen and the skin. Participants evaluated “dry-moist” by checking moisture with movement in the vertical direction. Therefore, when evaluating “cool-warm (*tsumetai-atatakai*)” and “dry-moist (*karattoshita-shittorishita*)”, a vertical motion is important.

Moreover, participants assessed these terms for each material with a specific hand movement that was specified in this research. Each of these hand movement patterns can help participants to evaluate the material properties of wooden products.

In the Chapter 4, I investigated participants' hand movements while they assessed two emotional terms, "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)", and compared with four fundamental terms, "cool-warm (*tsumetai-atatakai*)," "hard-soft (*katai-yawarakai*)," "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)," by using a 3D real-time motion measurement system and a pressure distribution measurement system.

The hand movements when assessing emotional terms were compared with four fundamental hand movements and classified by them. However, because some of the participants could not be classified into any of these four fundamental terms, I assessed their hand movements using several quantitative indices: the frequency of the angle, the amount of distance in hand movements and the loading. The use of these indices finally allowed us to classify participants' hand movements while assessing comfort and preference into four fundamental terms.

Many participants tended to assess "uncomfortable-comfortable (*kokochinowarui-kokochinoyoi*)" and "dislike-like (*kirai-suki*)" according to investigations about "rough-smooth (*zarazarashita-tsurutsurushita*)" and "dry-moist (*karattoshita-shittorishita*)," because they used simple hand movements with no or not large vertical movement. Few participants assessed the emotional terms according to investigations about "cool-warm (*tsumetai-atatakai*)" and "hard-soft (*katai-yawarakai*)," because these terms are more closely related to visual information.

In the Chapter 2, I formulated a hypothetic model that impression for mention of the visual-tactile impression consist three layers in Figure 2-1. From the results of the Chapter 2, there were relationships among three layers. From the results of Chapter 3 and Chapter 4, it is considered that hand movements connected theses three layers. Since hand movements are direct relationship with the tactile perception, it is concluded that the tactile perception is important when assessing the comfortable feeling of characteristics of wood. However, in recent years due to spread of artificial wood, it is assumed that people lose the opportunity to touch "actual" material wood and are forgetting the value of characteristics of wood. From our results, it is considered that touching wood is a simple way, but it is important behavior for us.

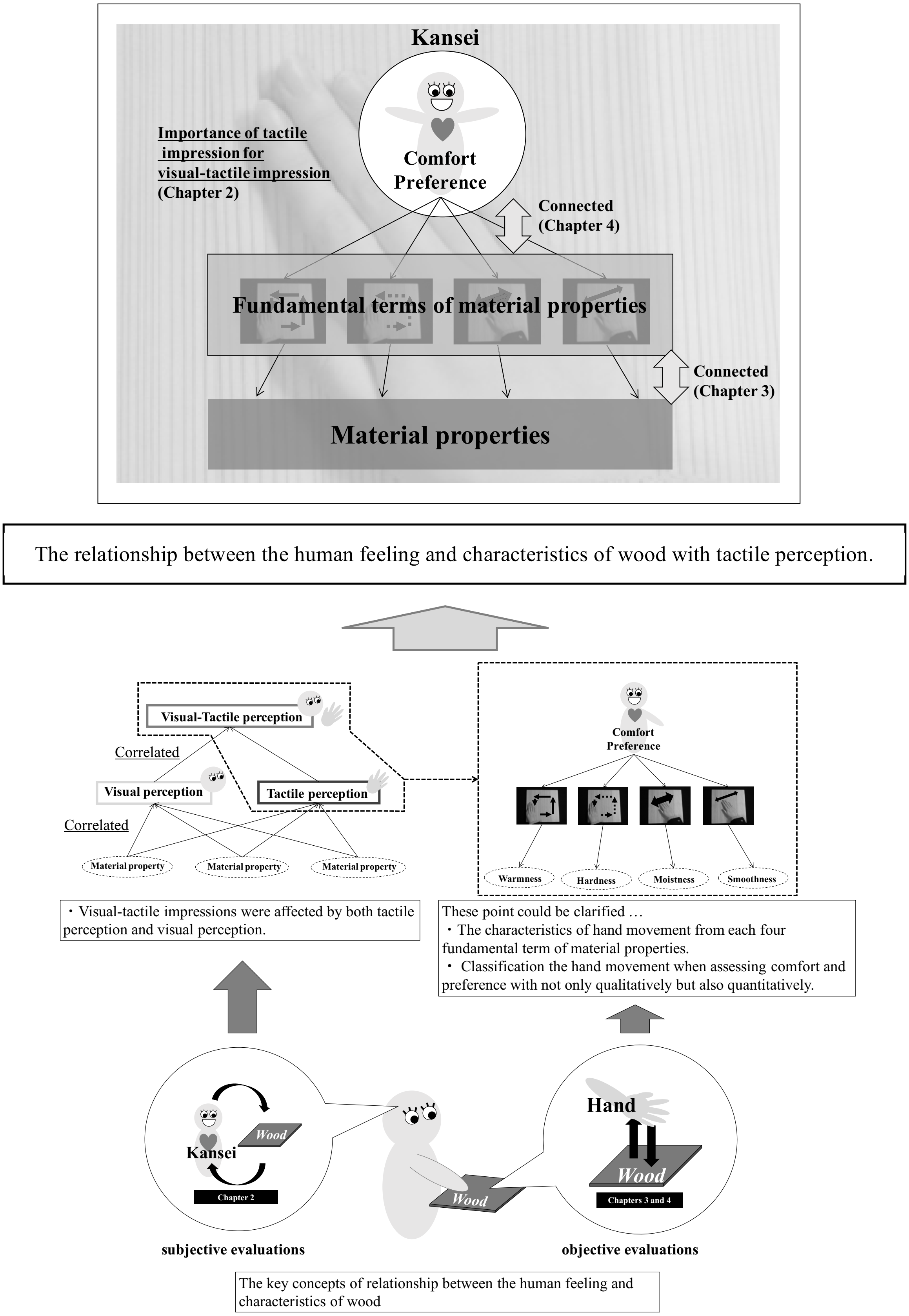


Figure 5-1. Conclusions of this thesis

There are some limitations in this thesis. Only university students were recruited and age range of the participants was limited. Since it is assured that age-group could affect tendency toward comfortable feeling of wood and hand movement when assessing wood, it is necessary to perform additional experiment at different age groups.

There is difference of experience to touch wood, that is, a professional craft person or a general consumer. If difference of the impression formation of the visual-tactile impression could be clear, it is possible for a produce of commercial wooden products introducing consumer’s feeling.

Additionally, further study about the impression including other perceptions is needed to clarify comfortable feeling of wood from the other point of view because you may have an experience that smell impression and sound impression from wooden products give us calm and soft feeling. In the future, the comfortable feeling of wood will reveal from the various perception will be promoted. Finally, I hope human realize and rediscover value of wood once again by touching “actual” natural wood, and enjoy a symbiotic relationship with forest.

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