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. Therefore, tactile perception is an important means of assessing the comfortability of wood.

Many studies have examined the relationship between tactile perception and physiological and psychological responses when touching wood [1-4]. The relationship between personal impression and hand movement when evaluating objects has also been the focus of several investigations [5-7]. For example, some subjects were more easily able to distinguish materials by using active hand movements than by using non-active hand movements [5], and a strong correlation between sensory scores and active hand movement has been recorded [6]. Moreover, when evaluating textiles, subjects’ hand movements differed according to the property being evaluated [7].

In this study, we focused on how tactile perception information is obtained from wood, and investigated the hand movements used in doing so. Tactile perception generally consists of four sensations, described by the evaluation terms “cool/warm,” “hard/soft,” “rough/smooth” and “dry/moist.” These sensations are also important with regard to wood [4] as they correspond to the material properties of temperature, surface texture, moisture content and hardness. There being multiple tactile sensations, it is assumed that hand movement changes according to these evaluation terms when assessing each material property of wood. Therefore, we use a 3D real-time motion measurement system and a body pressure distribution system to examine the relationship between the above evaluation terms pertaining to the four sensations and the hand movements used to carry out the associated evaluations on wooden objects.

2. MATERIALS AND METHODS

2.1 Materials

The test samples were Japanese cedar (Cryptomeria japonica) and Black walnut (Juglans nigra) (see in Figure 1). Both trees exhibit a straight grain, although the Japanese cedar has a clearer grain than the Black walnut. Japanese cedar is light brown and Black walnut is dark brown. Three urethane coatings were applied to form a surface film (top painting, middle painting and under painting). The samples were square with the dimensions of 280 mm × 280 mm × 10 mm. Material properties are shown in Table 1.

2.2 Measurement of material properties

2.2.1 Thermal property measurement

q-max (peak heat flux) is the value of the thermal property of the samples. It was measured using...
Kawabata Evaluation System Thermo Lab IIB (KES F7, Katotech Co., Kyoto, Japan). Nine different areas of one sample were separated and marked. All nine areas were measured when heat flux was at its highest point. Average heat flux value was calculated after 60 s from the measured results of all nine areas.

2.2.2 Hardness measurement

Hardness (Brinell hardness) of the samples was measured using a mechanical tester (AUTOGRAPH AG-1S, SHIMADZU Co., Kyoto, Japan). JIS Z2101:2009 was used as the standard method for measurements, with the exception of the sample size used in the experiment. Twelve different areas of each sample were measured in the same way as explained in 2.2.1. Average hardness was calculated from all twelve measured results.

2.2.3 Friction measurement

Coefficient of dynamic friction for the perpendicular to grain of the samples was measured using a friction evaluation meter (Tribo Mastor TL201Ts, Trinity Lab Co., Tokyo, Japan). The following specifications were used for the test: sampling frequency, 1 ms; velocity, 10 mm/s; and measurement distance, 40 mm. The contactor was rubbed with a polyurethane resin that mimicked the geometric properties of a human finger to evaluate the friction of surface. The contactor size was 32 mm × 14 mm and the fingerprint part was 15 mm × 10 mm with different depths up to 150 µm with intervals of 500 µm. Each sample was prepared and measured four times. Average hardness was calculated from the measured results.

2.2.4 Density measurement

The density of the samples was calculated by using three similar test specimens and the mean value is presented in Table 1. For measurement, an electronic weighing instrument was used and then density was calculated.

| Material          | $q_{\text{max}}$ | Coefficient of dynamic friction | Density | Hardness |
|-------------------|------------------|-------------------------------|---------|----------|
| Japanese Cedar    | 0.12             | 0.23                          | 0.38    | 21.83    |
| Black Walnut      | 0.14             | 0.16                          | 0.64    | 15.63    |

2.3 Experimental equipment

2.3.1 3D real-time motion measurement system

As shown in Figure 2, 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 markers. 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 [8]; therefore, only measurements of index finger movement were used in this study.

The sampling frequency was 100 Hz. The coordinate system is defined as; right-hand, front+/back-, up+/down- and right+/left– (see in Figure 3). The origin was determined at the center of test sample.

2.3.2 Body pressure distribution system

A body pressure distribution 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. However, as the
wood samples were harder than the sensor seat, it was difficult to accurately measure the pressure distribution. Therefore, a soft gel seal was placed between each of the four corners of each wood sample and the sensor seat. The loading was calculated from the pressure concentrated in the four gel seals. A soft urethane mat was placed under the sensor seat, which allowed the detection of pressure distribution (see in Figure 4).

2.4 Subjects

It is assumed that individuals have differing levels of discrimination ability when touching different woods. If a subject has low discrimination ability, the results may show wide variation, and the accuracy of the experiment may be low. Therefore, to select subjects with a high discrimination ability, we carried out a preliminary experiment using sand papers of different roughnesses.

First, we recruited 12 university students (Age: 22.5±0.9, M:6, F:6). Eight types of sandpaper (grit size: 80, 100, 120, 150, 180, 240, 320, 400) were installed in a black box that prevented the inside from being seen. Subjects assessed the roughness of the sandpaper using a paired comparison method.

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

2.5 Experimental procedure

Experiments were conducted over 2 days in two separate rooms because of the difficulty of moving the 3D real-time motion measurement system. The temperature was maintained at 20°C and the relative humidity at 50% in both rooms. All test samples were resting more than 24 h in advance of the experiments.

On the first day, we determined the loading from measurements from the pressure distribution system. The loading was calculated from the pressure concentrated in the four gel seals. A soft urethane mat was placed under the sensor seat, which allowed the detection of pressure distribution (see in Figure 4).

On the second day, we measured trajectory and acceleration with the 3D real-time motion measurement system. We used Motive (Nobby Tech Co.) as the calibration software and VENUS3D (Nobby Tech Co.) as the coordinate acquisition and analysis software. One of the four material terms (“cool/warm,” “hard/soft,” “rough/smooth” and “dry/moist”) was indicated to the subject, who then touched each sample freely for 15 s until all four terms were assessed. Two wood test samples were shown randomly to each subject. However, the four terms in the questionnaire were always shown in the same order, “cool/warm,” “rough/smooth,” “dry/moist” and “hard/soft.” I-SCAN Ver.5.0 (NITTA Co.) and Excel 2013 (Microsoft, Redmond, WA, USA) were used for 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 subject applied force to each sample (see in Figure 5).

On the second day, we measured trajectory and acceleration with the 3D real-time motion measurement system. We used Motive (Nobby Tech Co.) as the calibration software and VENUS3D (Nobby Tech Co.) as the coordinate acquisition and analysis software. One of the four material terms (“cool/warm,” “hard/soft,” “rough/smooth” and “dry/moist”) was indicated to the subject, who then touched each sample freely for 15 s until all four terms were assessed. Two wood test samples were shown randomly to each subject. However, the four terms in the questionnaire were always shown in the same order, “cool/warm,” “rough/smooth,” “dry/moist” and “hard/soft.” 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 trajectory of the index finger was converted to acceleration using Excel 2013 (Microsoft, Redmond, WA, USA). Additionally, 1-s data (4.5s–5.5s) was extracted from the 10-s data to observe the wave detail in Sections 3.1 and 3.2. In this case, 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.
3. RESULTS AND DISCUSSION

Hand movements varied widely between individuals. However, similar hand movements were also observed between the individual test subjects in some cases. An explanation was held with each individual test subject about the features of terms “cool/warm,” “rough/smooth,” “dry/moist” and “hard/soft,” which is shown earlier in Section 2.5. Figures 8-11 show the results for a male subject assessing Japanese cedar. Trajectory, acceleration and loading were tested and the desired features and results from this special test subject showed exactly the hand movements necessary to evaluate the test in the best way.

3.1 Hand movements for “cool/warm” and “hard/soft”

Figure 8 shows the trajectory, loading and acceleration when assessing “cool/warm.” Figure 9 shows the results for “hard/soft.” They show similar trends, and most subjects touched the wood surface in a square rectangular motion; i.e., the subjects followed the test sample’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” and “hard/soft” were larger than both “rough/smooth” and “dry/moist.” This result showed that subjects applied more force when assessing the “cool/warm” and “hard/soft” terms than they did when assessing the “rough/smooth” and “dry/moist” terms. Moreover, focusing on the accelerogram of the “hard/soft” and “cool/warm” terms, both were somewhat sparse. However, when comparing frequency of peaks of loading, the loading of “hard/soft” had more often peaks than that of “cool/warm.” The Ruffini corpuscles act as the skin’s tactile receptor for heat [9]. As the heat transfer of wood is slow, hands must be in contact with the wood surface for a period of time. When assessing “cool/warm,” some of the subjects’ 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” 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 [10]. When subjects evaluated “hard/soft,” they pushed and tapped to check the hardness of the wood.

3.2 Hand movements for “rough/smooth” and “dry/moist”

Figure 10 shows the results for trajectory, loading and acceleration when evaluating “rough/smooth.” Figure 11 shows the results of these for “dry/moist.” The trends were similar, with subjects touching the wood surface in a consistent manner with front/back or left/right movement. When assessing friction and moisture, we tend to use moisture, slight movements between the wood surface and the skin.

Vertical movements on the acceleration and loading graph were observed when subjects evaluated the feature “dry/moist.” However, they were absent when evaluating “rough/smooth,” because the subject 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 [11]. 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 [12]. Thus, subjects touched the wood surface without applying force in the vertical direction.

When assessing “dry/moist,” vertical movements were observed (see in Figures 11(b) and (d)). Impression “dry/moist” 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 subject feels moistness [13]. 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. Therefore, subjects touched the wood surface with a slight force in the vertical direction.

### 3.3 Individual difference of hand movements

Tables 2 and 3 and Figures 12-15 show the hand movement results for each subject. A circle marker (○) in Tables 2 and 3 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 subjects exhibited such movements, especially when assessing “rough/smooth”; in this case, most subjects evaluated the wood in the same manner. This can be attributed to all subjects having passed the preliminary experiment described in Section 2.3. Therefore, we consider the friction property to be easy to assess accurately and in a reproducible manner.

When assessing “hard/soft,” most subjects operated their hands in the same manner. When being reminded of the words “hardness” or “softness,” subjects 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 subjects would be similar.

#### Table 2: Results of hand movements (trajectory, acceleration) for each subject; ○ indicates that the hand movements described in Sections 3.1 and 3.2 were observed

|                | Japanese Cedar | Black walnut | Both            |
|----------------|----------------|--------------|-----------------|
|                | cool-warm      | hard-soft    | rough-smooth    | dry-moist       |
| subject1       | ○ ○ ○ ○ ○ ○   | ○ ○ ○ ○ ○ ○  | ○ ○ ○ ○ ○ ○   |
| subject2       | ○ ○ ○ ○ ○ ○   | ○ ○ ○ ○ ○ ○  | ○ ○ ○ ○ ○ ○   |
| subject3       | ○ ○ ○ ○ ○ ○   | ○ ○ ○ ○ ○ ○  | ○ ○ ○ ○ ○ ○   |
| subject4       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject5       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject6       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject7       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject8       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject9       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject10      | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject11      | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject12      | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |

#### Table 3: Results of hand movement (loading) for each subject; ○ indicates that the hand movements described in Sections 3.1 and 3.2 were observed

|                | Japanese Cedar | Black walnut | Both            |
|----------------|----------------|--------------|-----------------|
|                | cool-warm      | hard-soft    | rough-smooth    | dry-moist       |
| subject1       | ○ ○ ○ ○ ○ ○   | ○ ○ ○ ○ ○ ○  | ○ ○ ○ ○ ○ ○   |
| subject2       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject3       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject4       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject5       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject6       | ○ ○ ○ ○ ○ ○   | ○ ○ ○ ○ ○ ○  | ○ ○ ○ ○ ○ ○   |
| subject7       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject8       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject9       | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject10      | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject11      | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
| subject12      | ○ ○ ○          | ○ ○ ○        | ○ ○ ○ ○ ○ ○   |
However, when assessing “cool/warm” and “dry/moist,” only half of the subjects 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. Therefore, vertical movement is important for evaluating these terms. Nonetheless, for subjects who had no mark in Tables 1 and 2, no vertical movement was observed when evaluating “cool/warm” and “dry/moist.” Therefore, these two sensory tests exhibited a wide variation, and a message such as “please take vertical hand motion into consideration” would be instructive.

![Figure 12: Results of hand movement for assessing “cool/warm.”](image)

(Japanese Cedar: Left (light gray), Black walnut: Right (dark gray), (a): trajectory, (b): acceleration (10s), (c): loading)

![Figure 13: Results of hand movement for assessing “hard/soft.”](image)

(Japanese Cedar: Left (light gray), Black walnut: Right (dark gray), (a): trajectory, (b): acceleration (10s), (c): loading)
3.4 Investigation into the relationship between hand movement and sensations when evaluating test samples

In Sections 3.1 and 3.2, we obtained results of each hand movement when the subjects touched the sample freely to evaluate each term. However, it cannot be concluded from the results of the uncontrolled hand movement what the human sensations are. Moreover, the relation between hand movement and human sensations has not been clarified. Therefore, an additional experiment was carried out to investigate the relation between hand movement and human sensations.

We used the semantic differential (SD) method as sensory evaluation for investigation whether these hand movement patterns could help subjects to evaluate each material property when assessing the wood. Test samples were Japanese cedar and Black walnut as in Section 2.1 (see in Figure 1).
Two wood test samples were shown randomly to each subject, and subjects were asked to rate the sensation in four material terms in the same order, “cool/warm,” “rough/smooth,” “dry/moist” and “hard/soft” 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 Sections 3.1 and 3.2, a specific hand movement was explained and used; “cool/warm”: “Touch slowly while tracing the square specimen. Just put your hand on the sample 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”: “Touch the surface with constant manner without force.” “dry/moist”: “Touch the surface in a constant manner, but apply force to the surface.” “hard/soft”: “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. Subjects for this test were 20 university students (Age: 22.7±1.0, 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%, respectively.

The result from the sensory evaluation is shown in Figure 16. When subjects followed a specific hand movement, which was described in Sections 3.1 and 3.2, they could distinguish the sample in each term. Significant differences were found in “cool/warm” and “hard/soft.” This confirms that in terms of material properties, Japanese cedar is warmer, rougher, drier and softer than Black walnut (see in Table 1). When comparing sensory evaluation test 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, we found that guiding instructions on hand movement helped subjects to easily give the characteristic properties of each sample. Therefore, a hand movement pattern demonstrated by another person can help them to evaluate material properties of wooden products effectively.

There were limitations in this study. Only university students were recruited, limiting the age range of the subjects. If a wider age group had been included in this study, we might have observed age-specific hand movement tendencies. There is also a difference in the hand movements between wood-related professionals e.g., a carpenter and a cabinet maker and amateurs e.g., a consumer purchasing wood. It is suggested that differences in the features of individuals’ hand movements may be compared between each group. It is considered that the hand movements of professionals may be more specialized than those of amateurs, and that they may exhibit less variation of hand movements for each term. Moreover, we focused on just four material properties of wood. If we were to incorporate additional material properties, we might encounter other hand movement features when assessing these subjective impressions of wood.

4. CONCLUSIONS

In this study, we investigated hand movements when assessing four material properties of wood, “cool/warm,” “hard/soft,” “rough/smooth” and “dry/moist,” by using a 3D real-time motion measurement system and a body pressure distribution system.

When subjects evaluated “cool/warm” and “hard/soft” they traced the square specimen with a rectangular motion. When evaluating “cool/warm,” subjects’ hands remained on one spot for a short period to check the transfer of heat, whereas when evaluating “hard/soft,” their hands moved with a vertical component to ascertain the hardness.

When subjects evaluated “rough/smooth” and “dry/moist,” they touched the surface of the wood in a constant manner. However, when evaluating “rough/smooth,” they used a slight rubbing movement between the surface of the wood and the skin. Subjects evaluated “dry/moist” by checking moisture with movement in the vertical direction.

When evaluating “cool/warm” and “dry/moist,” a vertical motion is important.

Moreover, subjects 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 subjects to evaluate the material properties of wooden products.
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REFERENCES
1. E. Nordvik, S. Schütte and N. Olof Broman; People’s Perceptions of Visual Appearance of Wood Flooring: A Kansei Engineering Approach, Forest Product Journal, 59(11/12), pp.67-74, 2009.
2. Yoshifumi Miyazaki; Evaluation of Feeling of Comfort from Natural Stimuli Using NIRS, Journal of The Society of Instrument and Control Engineers, 42(5), pp.430-434, 2003. (in Japanese)
3. Satoshi Sakuragawa, Yoshifumi Miyazaki, Tomoyuki Kaneko and Teruo Makita; Influenced of wood wall panels on physiological and psychology responses, Journal of Wood Science, 51(2), pp.136-140, 2005.
4. Masashi Nakamura; Wood and Kansei, Mukozai Hozon, 23(3), pp.102-103, 1997. (in Japanese)
5. Toyonori Nishimatsu, Humisato Nagano, Kunitaka Maeda, Masayoshi Kamijo, Eiji Toba, Hiroaki Ishizawa; Evaluation and Discrimination of Materials Active Tactual Motion, Journal of Japan Society of Kansei Engineering, 1(1), pp.39-44, 2001. (in Japanese)
6. Masaki Hyodo, Wataru Kamura, Hiroyuki Kanai, Toyonori Nishimatsu; Tactual Motion in Evaluating Material Texture, Transactions of Japan Society of Kansei Engineering, 12(3), pp.425-430, 2013. (in Japanese)
7. Sumin LEE, Masayoshi Kamijo, Toyonori Nishimatsu, Yoshio Shimizu; Measurement of Finger Motion in Evaluating Hand of Fabric Using Accelerometer, Sen’I Kikai Gakkaishi, 58(8), pp.101-108, 2005. (in Japanese)
8. R. S. Johansson, A. B. Vallbo; Tactile sensory coding in the glabrous skin of the human hand, Trends in Neuroscience, 6, pp.27-32, 1983.
9. Takao Matsuda; Foundation of perceptual psychology, Baihuukan, p.173, 2000. (in Japanese)
10. Ichiro IIDA; The Science of the Tactile, Hyomen Kagaku, 19(12), pp.839-843, 1998. (in Japanese)
11. Naoytata, Masayuki Mori, Takashi Maeno; Method for eliciting tactile sensation using vibrating stimuli in tangential direction: Effect of frequency, amplitude and wavelength of vibrating stimuli on roughness perception, Proceedings of the 33rd ISR (International Symposium on Robotics), 2002.
12. Kazumi Kobayashi, Takashi Maeno; Relationship between the Structure of Finger Tissue and Location of Tactile Receptors. (3rd Report, Results of Contact Analysis between a Finger and a Rough Plate), Transactions of the Japan Society of Mechanical Engineers Series C, 65(636), pp.3321-3327, 1999. (in Japanese)
13. Tatsuo Okajima, Yuji Takeda; Tactile Dryness of Building Materials, Journal of Architecture and Building Engineering, 327, pp.12-19, 1985. (in Japanese)