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Analysis of Brushing Techniques for Quantitative Evaluation of Hairdresser's Skills

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***Abstract*— In some developed countries, such as Japan, transferring the skills of skilled workers is a challenge. In particular, it is unclear how skilled technicians use tools skillfully. We focus on the skills of Japanese hairdressers with the aim of analyzing the skills of expert hairdressers and applying them to the efficient training of novice hairdressers. In this study, we focus on brushing, which is one of the most important beauty techniques in diagnosing hair quality and setting up the finishing process. The brushing skills of an expert hairdresser are carefully measured and compared with those of a beginner to analyze the characteristics of brushing skills.**

I. INTRODUCTION

The skilled techniques of the technicians greatly affect the accuracy of the task. Therefore, passing it on to the next generation is an important issue. In particular, tool skills require delicate adjustment of force depending on the target task. Therefore, the information sensed from the response of the target object becomes an important factor. But skill-based training is generally sensory. There are limitations to measuring subtle changes in force during movement and to describing them verbally. Therefore, it is necessary to measure and quantitatively evaluate the information sensed from the skilled force exerted by the technician and the response from the object.

Research is being conducted into how people identify materials using the sense of touch and force they perceive when they touch an object. Human have mechanoreceptors distributed throughout the skin of their fingertips. It is the tactile perception of material hardness and surface roughness. Therefore, it is possible to estimate the material from the vibrations of the skin that occur when stroking the surface of the material with a fingertip. Syuyang et al. have investigated the correlation between finger sliding speed and load on tactile perception of hardness and surface roughness to help humans distinguish different materials [1]. They used a tactile tester with a crossed I-beam structure inspired by fingers. The vibration signals from a fingertip generated by rubbing the material surface are subjected to a fast Fourier transform. Then, they propose a method to distinguish the tactile sensation of the material based on the rate of spectral change with increasing finger sliding speed and load. The information and physical state sensed by experts and beginners from responses from the same target area are analyzed. This makes it possible to evaluate differences in skills.

In addition, material properties such as hardness and surface roughness are complex. It is difficult to establish a unified roughness index that represents the tactile sensation perceived by humans. Yicheng et al. proposed an index to evaluate the tactile roughness between materials based on the grit size used in sandpaper [2]. They have reported that the tactile sensation is consistent with human perception, even when applied to unidentified materials regardless of the material. We think that by setting a unified index, it will be possible to evaluate the differences in information perceived by experts and novices.

In this study, we focus on hairdressers. Hairdressers estimate the condition of a client's hair and scalp from haptic information they perceive while cutting, washing, styling, and performing other tasks. Hairdressers estimate the condition of hair based on differences in their sense of touch. Therefore, research is being conducted on methods to measure and quantitatively evaluate the tactile sensation of hair. Komatsubara et al. have developed a handheld hair texture scanner to quantitatively evaluate the health of hair [3]. It has been reported that it is possible to easily and accurately measure tactile sensation on the hair surface directly from the scalp. In order to quantitatively evaluate a hairdresser's skill, it is important to measure and quantify the information that the hairdresser perceives, including the sense of touch.

Hair damage is also perceived through touch. Kakizawa et al. have quantified the degree of hair damage and are studying the relationship between texture and hair surface properties [4]. They are developing artificial hair surface model plates that replicate damaged and undamaged hair. The feel of damaged hair is affected by the shape of the cuticle when dry. They reported that it was possible to quantitatively evaluate hair damage by using the artificial hair surface model plate and tactile friction meter they developed. The reason why the brush gets caught on the hair during brushing is thought to be due to the unevenness of the hair cuticle. In order to evaluate hairdressers' skills, it is important to measure how they detect and respond to hair snagging before the brush gets caught in the hair while brushing.

Research is being conducted into various measurement and analysis methods for analyzing the movements of skilled workers and evaluating their skills. It is now possible to evaluate the difference in skill between experts and novices. Amir et al. are conducting research to automatically and objectively evaluate surgical suturing skills using a hand-mounted inertial sensor [5]. They propose a performance metric that focuses on the analysis of hand rotational movements. They reported that it was possible to distinguish subtle skill differences between attending and resident groups.

Research is being conducted not only on the evaluation of skilled workers' skills but also on differences based on gender

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and occupation. Hsieh-Ching et al. conducted an experiment with male and female barbers and hairdressers [6]. They measured wrist angle and EMG of the flexor digitorum superficialis and extensor digitorum communis muscles during haircutting, washing, and blow-drying. They reported that muscle activity in female hairdressers was significantly higher than that in male hairdressers. They also reported that non-dominant wrist velocity was significantly higher in hairdressers than in barbers. Sabriye et al. conducted a study on the correlation between ergonomic risks and upper limb musculoskeletal pain levels in hairdressers, as well as differences between men and women [7]. They reported that the prevalence of pain in the neck, shoulder, right arm, and right wrist was significantly higher among female hairdressers than among male hairdressers. By analyzing muscle activity and movement patterns that differ by gender, it may be possible to evaluate skills and characteristics specific to gender and occupations.

Actions involving tools often involve the use of the hands. In order to evaluate the skills of technicians, it is important to attach sensors to their hands, measure the movements of their hands, and analyze them. Optical motion capture is commonly used to measure movements. However, there is a possibility that the reflective markers may be hidden, resulting in missing measurement data. Jason et al. proposed a measurement system that uses optical motion capture and an inertial sensor to measure a hairdresser's wrist movements [8]. It has been reported that the proposed system is capable of measuring wrist movements even when the reflective marker is hidden. In this study, the target action is a hairdresser's brushing action, and it is considered that the reflective markers may be hidden by the arms or hair. By combining multiple sensors in addition to optical motion capture, more accurate measurements are possible.

In addition, the movements of hairdressers are being measured using wearable sensors. Alessio et al. conducted a study using surface electromyography and photoelectron sensors to assess the biomechanical risks associated with expert users drying their hair with a hair dryer [9]. The latissimus dorsi, trapezius, anterior deltoid, and flexor carpi ulnaris muscles on the left side of the body, which is holding the hair dryer, contributed more than the right side. Additionally, the RoM values for shoulder horizontal abduction, elbow flexion and extension, and wrist supination and pronation were higher on the left side than on the right side. It has been reported that drying hair with a hairdryer is a demanding task for hairdressers. It is important to use wearable sensors to measure the physical state of a person performing a task that requires expert skill, such as hairdressing.

In this study, we measure and analyze hairdressers' brushing movements in order to quantitatively evaluate their skills in brushing. To evaluate brushing behavior, it is necessary to measure not only external data such as the movement and deformation (strain) of the brush, but also internal data such as the change in the force supporting the brush. The skill of a hairdresser can be evaluated based on whether the brush moves smoothly or catches. The deformation of the brush indicates the effects of hair tangling and pulling on the scalp, which is directly related to the hairdresser's skill. In addition, the change in the force with which the brush is supported when the brush gets caught or is about to get caught in hair while brushing is an important indicator of skill in untangling hair and avoiding strain on the scalp. Therefore, we developed a system to measure the movement and deformation of the brush during brushing, as well as the change in the force supporting the brush. The brush movement and deformation were measured using motion capture and strain gauges. Regarding the change in the force supporting the brush, it is expected that expert and beginner people use their bodies differently even when performing the same brushing motion. Therefore, we developed a system that combines measurement of surface electromyography (sEMG) with measurement of the body-propagating vibrations. Based on the measured data of brush movement and deformation, we analyze how the brush moves and deforms under different conditions. Furthermore, we analyze muscle activity from sEMG data and analyze the differences in the body-propagating vibrations between expert and beginner individuals.

II. OVERVIEW OF THE BODY-PROPAGATING VIBRATIONS MEASUREMENT

The propagation of vibration in a mechanical system is affected by the mechanical properties of the materials that make up the system, such as their shape, strength, and rigidity. In other words, by measuring and analyzing the propagating vibrations, it is possible to estimate mechanical properties such as rigidity. The human body is composed of various tissues, including bones that support the body, muscles, skin, fat, soft tissue, etc. The mechanical properties of each tissue affect the propagation of vibration [10]. In this study, we propose a lightweight, small, wearable measurement system that can measure the body-propagating vibrations without interfering with the movement in order to measure the movement of using a tool. The proposed method does not interfere with the action of using tools and makes it possible to build a system at low cost. Therefore, it can be used in a variety of situations. Research is being conducted to estimate the posture, movement, and mechanical load state of each part of the body by measuring and analyzing the body-propagating vibrations. Ikeda et al. conducted research into the relationship between the lower legs-propagating vibrations and physical characteristics in young men and women [11]. It has been

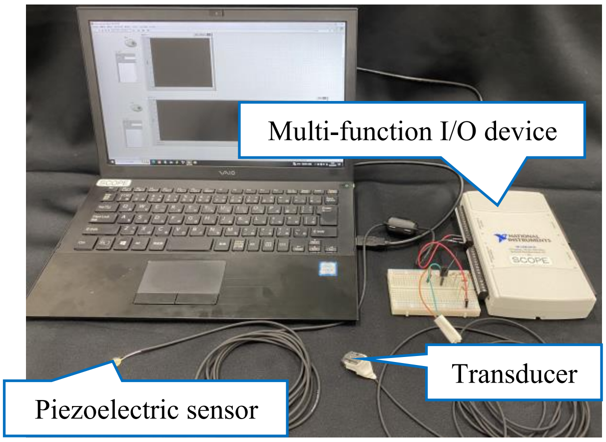

Fig. 1. Device for measuring body propagated vibration

reported that there are differences in the direction and mode of the lower leg-propagating vibrations between men and women. By measuring and analyzing the body-propagating vibrations when performing movements, it is possible to estimate and evaluate the mechanical properties of the body. However, there are few examples of its application to tool-using actions. There are no examples of this being applied to evaluating hairdresser skills. It is necessary to verify whether this can be applied to evaluating hairdresser skills.

The device used in this study to measure the body-propagating vibrations is shown in Fig. 1. A transducer (COM-10917, SparkFun) was used as an actuator to input vibration to the body. The transducer has a resonant frequency of 16,000 [Hz] and a frequency response of 300 - 19,000 [Hz]. We think that this is sufficient to reproduce the input signals used in the experiment. The dimensions are 21.5 x 14.5 x 7.9 mm and the weight is 8.9 g. Because it is small and lightweight, we think that it will be possible to input vibrations without interfering with the hairdresser's brushing action. In addition, a piezoelectric sensor (A9302, manufactured by uxcell) with a diameter of 9 mm was used as a sensor to measure the body-propagating vibrations. The resonant frequency is 3000 - 5000 [Hz]. It has a sufficient bandwidth considering the vibration propagation characteristics of the body. During the experiment, vibrations are constantly input to the body from the transducer. It is possible to measure the changes in body-propagating vibrations during a series of movements.

The transducer and the piezoelectric sensor are connected to a PC via a multi-function I/O device (USB-6216, National Instruments). In addition, the power output from the multifunction I/O device is insufficient to drive the transducer. Therefore, the signal is amplified by a DC stabilized power supply and an amplifier circuit. Transistors (TTC004B, Toshiba) were used in the amplification circuit.

The control software LabVIEW (National Instruments) was used to generate the vibration waveform input to the body, output it to the transducer, and measure the input signal from the piezoelectric sensor. The vibration waveform input from the transducer to the body is analyzed by frequency analysis of the body-propagating vibrations. For this purpose, we used uniform white noise up to 5000 [Hz] that contains all frequencies with uniform strength. The generated waveform is output from the transducer via a multi-function I/O device. The electrical signal input from the piezoelectric sensor is recorded on a PC via a multi-function I/O device. The measurement sampling frequency was set to 20,000 [Hz].

III. MEASUREMENT OF HAIRDRESSER'S BRUSHING MOVEMENTS

A. *Overview of measuring hairdresser's brushing movements*

Fig.2 shows overview of measurement in which the body-propagating vibrations during a hairdresser's brushing motion, strain on the brush, sEMG, and brush movement were measured. We measure the difference in skill between expert and beginner hairdressers. Therefore, the subjects were two people: one male (Subject A) with 30 years of experience as a hairdresser, and one female (Subject B) with no experience as a hairdresser. The subjects were informed in advance of the experiment's purpose and procedures, as well as that it would have no physical effects. The experiment was conducted only on subjects who provided consent. Regarding the body-propagating vibrations, the subjects commented that they felt the vibrations being applied from the transducer before starting the experiment, but were able to perform the brushing action without any discomfort during the experiment.

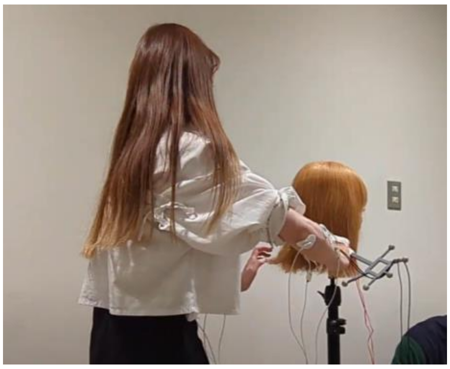
Fig. 2. Overview of brushing motion measurement

The brushing motion was performed using a mannequin that hairdressers use for practice, rather than a real human head. The mannequins are made from human hair. It is possible to reproduce the way a person's hair is tangled. In order to conduct the experiment with uniform hair entanglement, a mannequin was divided into two sections, and one subject was assigned to each section. The experiment was conducted under two conditions combing hair with a brush, and curling hair while pulling it using a hair dryer and brush. These two actions are intended to involve the brush getting caught in hair and pulling the subject's (mannequin's) hair. Therefore, we think that it is possible to evaluate the skill of a hairdresser by measuring and analyzing the amount of pressure used so that the subject does not feel pain.

When measuring two movements, it is necessary to prevent the sensor attachment position from shifting within the same subject. Therefore, subjects were instructed to perform the two conditions in succession. Although sensors and transducers are attached to the hand, it is necessary to measure movements that are as natural and comfortable as possible. Therefore, subject A was instructed to perform the same brushing motion as he normally does at work, and the skills of the expert and beginner subjects when they performed the same motion were evaluated. Therefore, subject B was instructed to watch and imitate subject A's movements before conducting the experiment. The subjects were instructed to hold the brush in a natural way that allowed them to perform brushing movements, and they were not given any instructions regarding grip strength. The subjects were instructed to perform both the action of combing their hair with a brush and the action of curling their hair while pulling it using a hair dryer and brush multiple times.

In order to perform a time-series analysis of the action of combing hair with a brush, the measurement data was also synchronized. To synchronize each measurement data, the subjects were instructed to tap the sensor three times at the start of measurement, between the two movements, and before the end of measurement. We also instructed them to clench their hands and tense their muscles at the same time as they were being hit.

B. Measurement equipment and conditions

Fig. 3 shows the positions of the transducer for inputting vibration into the body, the piezoelectric sensor for measuring the body-propagating vibrations, and the electrodes for measuring sEMG. Fig. 4 shows the position where the strain gauge was attached to measure the strain on the brush. The four measurements were hand-propagating vibrations, strain on the brush, sEMG of the muscles involved in finger flexion and extension, and brush movement.

The position of the sensor to measure the body-propagating vibrations was determined through preliminary experiments to be a position that would not interfere with the brushing action and would minimize attenuation of the body-propagating vibrations by muscles, etc. In the preliminary experiment, measurements were taken at six locations: the metacarpal heads of the thumb, index finger, middle finger, and little finger, as well as the heads of the radius and ulna. All of these areas of the hand and wrist have relatively thin skin. Based on the experimental results, in this study, we decided to measure by attaching the sensor to the metacarpal head of the little finger. The position of the transducer for inputting the vibrations from the body was determined through preliminary experiments to be a position that would not interfere with the brushing action and would minimize attenuation of the vibrations input to the body by muscles, etc. In the preliminary experiment, the sensor for measurement was positioned on the head of the metacarpal bone of the little finger. Measurements were taken by attaching transducers to five locations the metacarpal heads of the thumb, index finger, and middle finger, as well as the heads of the radius and ulna. In these preliminary experiments, the skin on the hand and wrist is relatively thin. Based on the experimental results, in this study, we decided to attach the transducer to the head of the metacarpal bone of the middle finger. To secure the sensor and transducer, we used non-elastic sports tape to prevent the body-propagating vibrations from being attenuated. To secure the sensor and transducer, we used non-elastic sports tape to prevent the body-propagating vibrations from being attenuated. The cables connected to the sensor and transducer were fixed to the forearm with elastic sports tape so as not to interfere with the measurements.

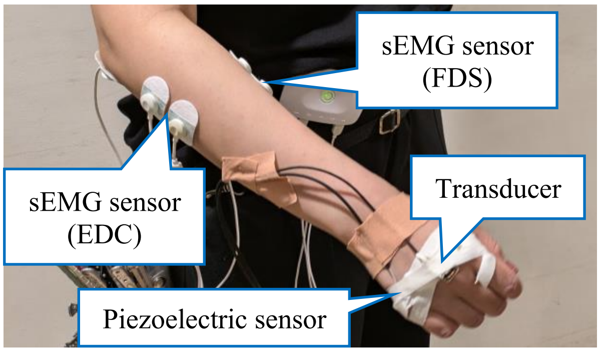

Fig. 3. Sensor attachment position

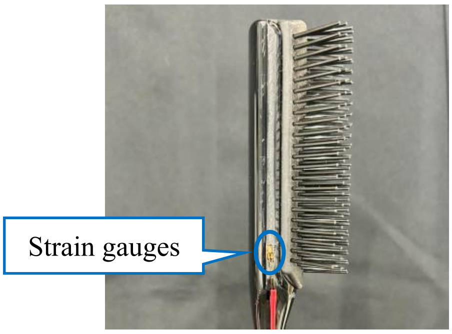

Fig. 4 Strain gauges attachment position on brush

The brush strain was measured using a two-gauge method with a strain gauge (KFGS-2-120-C1-11 L3M2R, Kyowa). By using the two-gauge method, it is possible to measure bending strain without subjecting the specimen to compressive strain. The electrical signal generated by the strain gauge is very small and difficult to measure using a multi-function I/O device. Therefore, the electrical signal was amplified using a strain gauge amplifier (SGI-100A, Kyowa). In this experiment, brush distortion was not compared between subjects. It just checks to see if the brush is warped. Therefore, we decided that there was no need to precisely amplify the signal, and used the amplifier shown above. After consulting with a hairdresser, the experiment was conducted using a half brush that is commonly used by hairdressers in their brushing movements. In the experiment, the left-right distortion when viewing the brush from the back is measured. The side of the brush was scraped flat to make it easier to attach the strain gauge. The installation position of the strain gauge was determined by preliminary experiments to be the most efficient position for measuring the strain of the brush. n the preliminary experiment, strain gauges were attached to three locations on the brush part of the half brush the tip, center, and rear end, and measurements were taken. Based on the experimental results, in this study, we decided to attach a strain gauge to the rear end of the brush part of the half brush. To fix the strain gauge, instant adhesive (CC-33A, Kyowa) was used because the strain gauge needs to be completely adhered in order to obtain accurate measurement data. During the brushing action, the brush may get caught on the hair and bend. Therefore, we decided to measure the strain on the brush during brushing. We believe that it is possible to evaluate the difference in the change in stiffness from the brush to the wrist between expert and beginner users when the brush gets caught in hair from the change in strain of the brush.

The sEMG was measured using a sEMG sensor (biosignalaplux, manufactured by Plux) at two locations the flexor digitorum profundus muscle (FDS) and the extensor digitorum communis muscle (EDC). The FDS is a muscle that contributes to flexion of the index finger, little finger, and wrist. The EDC is a muscle that contributes to the extension of the index finger to the little finger. The grip force during tool use appears to be related to stiffness changes in the tool-hand system. Therefore, we decided to measure the FDS, which is related to grip strength. In addition, humans increase joint stiffness by co-contraction of antagonistic muscles. Therefore, we decided to simultaneously measure the EDC, which contributes to finger extension. By measuring and analyzing the surface electromyograms of two muscles, we believe it is possible to evaluate how a person changes their stiffness.

The brush movements were captured using a motion capture system (OptiTrack, OptiTrack). We photographed five reflective markers attached to a base that extended about 10 cm from the tip of the brush handle. We used four PrimeX 13 cameras. By analyzing the brush movement, we believe it is possible to measure the difference in brush movement between expert and beginner users before and after the brush gets caught in the hair.

C. *Measurement and data processing*

The measurement data of the body-propagating vibrations was taken as one trial from the start to the end of combing the hair. The extracted data from one trial was subjected to frequency analysis using fast Fourier transform (FFT). Spectrograms were obtained for each of the actions of combing hair with a brush and curling hair while pulling it with a hair dryer and brush. The spectrogram data was smoothed using a Hamming window. Each measurement data is synchronized.

The sEMG data was extracted at a time corresponding to the measurement data of the vibration propagating through the body. Trend removal was performed to calculate the muscle tension evaluation value during brushing motion. Then, rectification was performed to invert negative values to positive values. After rectification, the signal was filtered using a low-pass filter set at 10 Hz to calculate the integral value for one trial. In this study, we focused on the relative differences between when the brush gets caught on the hair and before it gets caught on the hair during brushing. Therefore, we did not calculate %MVC by dividing maximum voluntary muscle strength.

The measurement data for the brush position was extracted from the start to the end of combing the hair as one trial. Three-dimensional coordinates were obtained from the five reflective markers using motion capture software (Motive, OptiTrack).

IV. BRUSHING MOTION EXPERIMENT RESULTS

Fig. 5 and Fig. 6 show the measurement results for one trial of subject A combing his hair with a brush and curling his hair while pulling it using a hair dryer and brush. From top to bottom, the figure shows a spectrogram of the body-propagating vibrations, the strain of the brush, the sEMG of the FDS, the sEMG of the EDC, and the position of the brush. Similarly, Figs. 7 and 8 show the measurement results for one trial of subject B combing his hair with a brush and curling his hair while pulling it using a hair dryer and brush. Additionally, when subject A was using a hair dryer and brush to pull and curl her hair, she sometimes divided one strand of hair into two, an upper and lower section, and curled it multiple times. Fig. 9 and 10 show the results of fast Fourier transform (FFT) and sEMG measurements for one trial in which a single strand of hair is curled multiple times. Fig. 10 shows the results after applying a 10 Hz low-pass filter to the FDS (top) and EDC (bottom). When subject B used a hair dryer and brush to curl her hair while pulling it, she curled each strand of hair once, focusing on the ends. One hair curling action was counted as one trial, and the results of FFT and sEMG measurements for five trials are shown in Figs. 11 and 12, similar to those for subject A.

A. *Consequences of the body-propagating vibrations*

In the spectrogram of the body-propagating vibrations of subject A while combing his hair with a hairbrush, there was no clear increase in signal intensity when the brush got caught on his hair. In the other trials, there was only one trial in which the signal intensity increased between when the brush got caught and when it was released. However, in most trials there was no clear increase in signal intensity when the brush caught on the hair. In the spectrograms of the body-propagating vibrations during the actions of pulling and curling hair with a hair dryer and a brush, the signal strength decreased after the tension was released. Furthermore, the signal strength increased and decreased more finely during the movement than when combing hair with a brush. In other trials, no brush snagging was observed, but there was a slight increase and decrease in signal intensity. Also, from Fig. 9, the signal strength increased in the frequency band of 0 to 20 [Hz] when the upper layer was wound for the first time, and in the frequency band of 0 to 10 [Hz] when the upper layer was wound for the second time. In other trials as well, the signal intensity increased in the first trial.

In the spectrograms of the body-propagating vibrations of subject B during both the action of combing hair with a brush and the action of curling hair while pulling it with a hair dryer and brush, there was an increase in signal strength when the brush got caught on the hair. Furthermore, the signal strength also increased when the brush was removed from the hair at the end of the session. In other trials, the signal intensity also increased when the brush got caught in the hair and when the brush was removed from the hair at the end. Furthermore, Fig. 11 shows that the signal strength increased between 0 to 30 [Hz] in three out of five trials.

B. *Surface electromyography, brush strain and brush movement results*

The sEMG results while subject A was combing his hair with a brush showed that muscle activity in the FDS decreased after the brush was released. No remarkable features were observed in the EDC. In the other trials, in only one trial did muscle activity in the FDS and EDC increase before the brush caught on the hair, but no significant changes were observed. The results of sEMG during the task of curling hair while pulling it with a hair dryer and a brush showed no notable features when the brush got caught. However, muscle activity of the FDS increased and decreased throughout the movement. In other trials, muscle activity of the FDS and EDC increased and decreased when the angle of the brush was changed by changing the way the brush was held, and while curling hair. Furthermore, in Fig. 10, no sequential increase or decrease in muscle activity was observed in either the FDS or the EDC.

The sEMG results while subject B was combing his hair with a brush showed muscle activity in the FDS when the brush got caught in the hair. In other trials, muscle activity increased in the FDS and EDC when the brush began to catch on the hair and when it was completely caught. The results of sEMG during the task of curling hair while pulling it with a hair dryer and a brush showed increased muscle activity in the FDS and EDC when the brush began to catch on the hair. In addition, muscle activity of the FDS and EDC decreased before the catch was released. In other trials, muscle activity

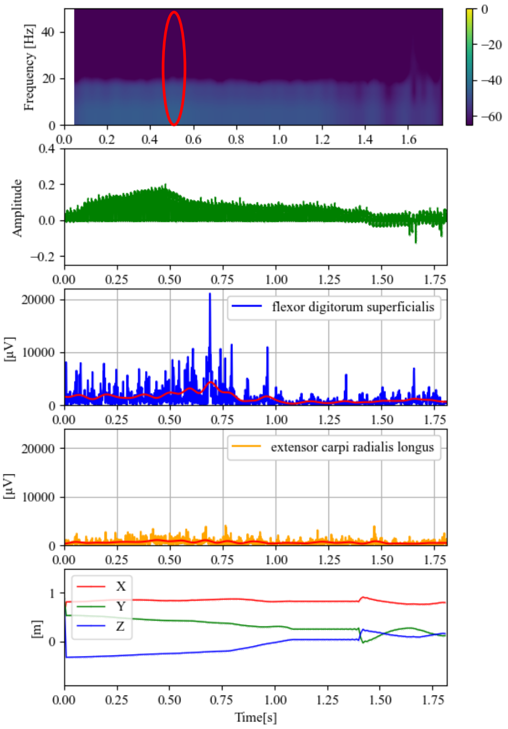

Fig. 5. Measurement results under the conditions of combing hair with a brush Subject A (1 trial)

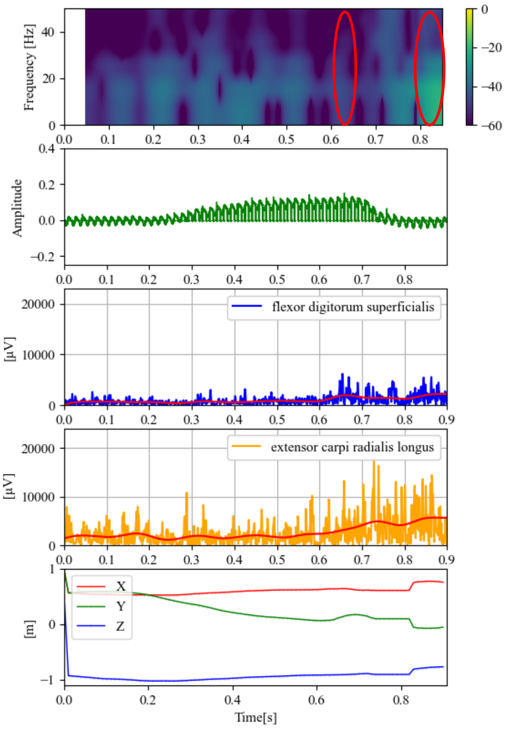

Fig. 7. Measurement results under the conditions of combing hair with a brush Subject B (1 trial)

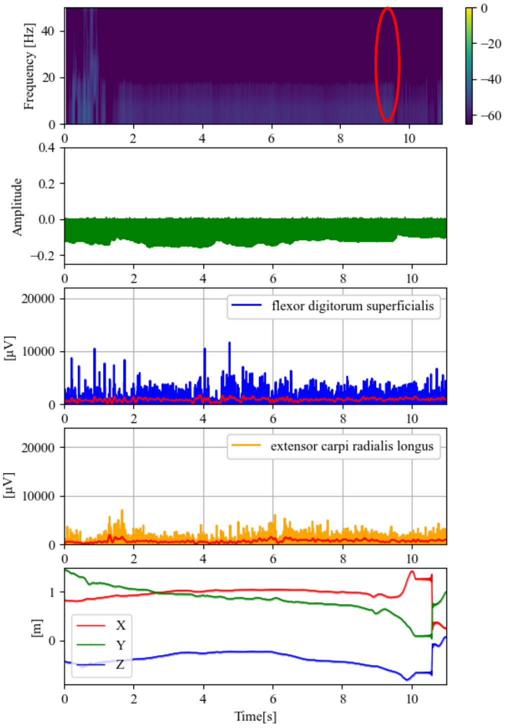

Fig. 6. Measurement results under the conditions of curling hair while pulling it with a hair dryer and a brush Subject A (1 trial)

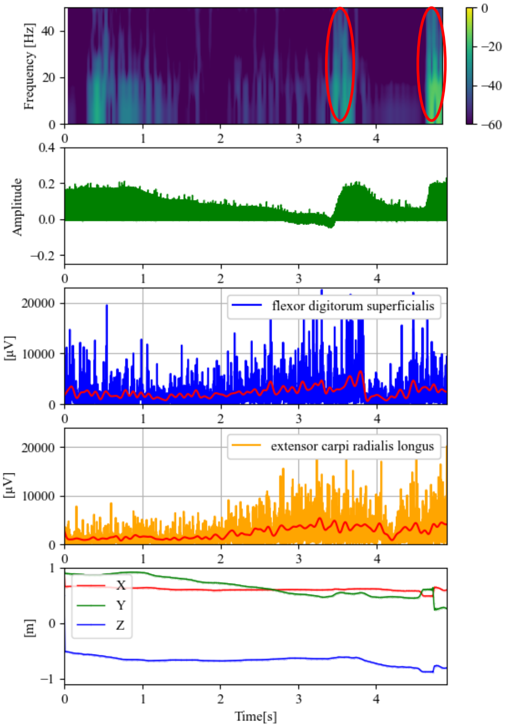

Fig. 8. Measurement results under the conditions of curling hair while pulling it with a hair dryer and a brush Subject B (1 trial)

increased in the FDS and EDC when the brush began to catch on the hair. But there were times when no notable features were apparent. Also, no prominent features were observed in Fig. 12.

The result of brush strain caused by subject A combing his hair with a brush, the strain increased when the brush began to get caught, and decreased when the brush was released from the catch. Similar trends were observed in other trials. As a result of the strain on the brush caused by pulling and curling the hair with a hair dryer and a brush, strain was observed in the opposite direction to that of the brush when combing hair. Similar strains were observed in other trials, but in the opposite direction to the strain of the brush during the hair combing action.

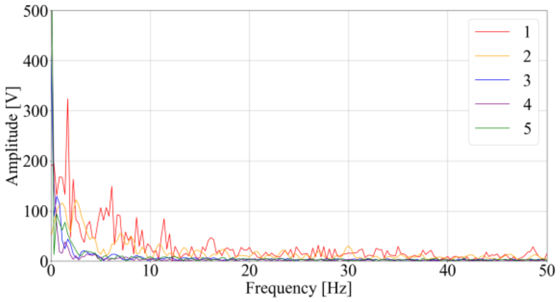

Fig. 9. Results of frequency analysis of subject A when pulling and curling hair using a hair dryer and a brush

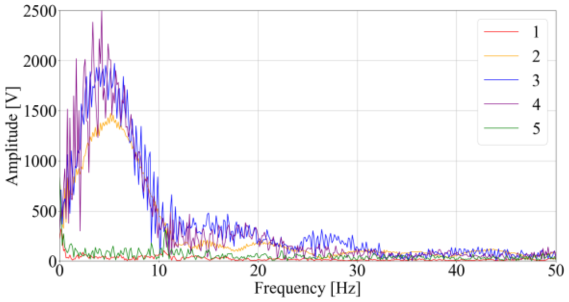

Fig. 11. Results of frequency analysis of subject B when pulling and curling hair using a hair dryer and a brush

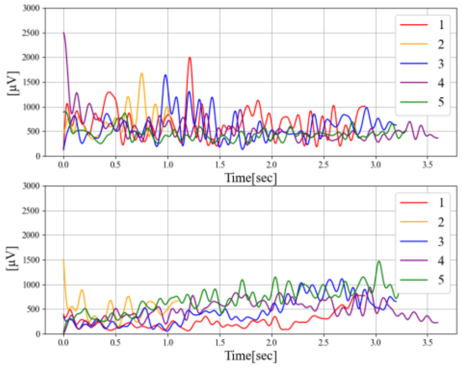

Fig.10 The sEMG results of subject A when pulling and curling hair using a hair dryer and brush

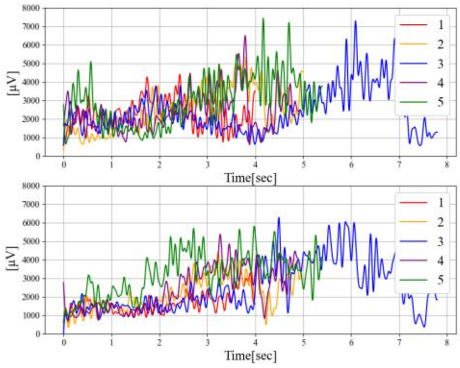

Fig.12 The sEMG results of subject B when pulling and curling hair using a hair dryer and brush

The results of the strain on the brush when subject B combed his hair with a brush and when he curled his hair while pulling it with a hair dryer and brush, the strain increased when the brush began to get caught, and decreased when the brush was released from the catch. Other trials showed similar trends but with distortions in the opposite direction.

In the results of brush movement when subject A combs his hair with a brush, no outstanding features were observed. In the action of pulling and curling the hair using a hair dryer and brush, the brush moved in a parabolic arc. We also observed the brush appearing to shake during operation. Similar fluctuations were observed in other trials.

In the results of brush movement when subject B combed his hair with a brush, vertical upward movement was observed as the brush was released from the snag. Similar behavior was observed in other trials.

V. DISCUSSION

First, we consider the body-propagating vibrations from a biomechanical perspective. In subject A, muscle activity of the FDS increased and decreased under both conditions. Therefore, it is possible that the force with which the brush is gripped is changed. In fact, muscle activity increased when the person changed hands to hold the brush. In addition, muscle activity of the FDS and EDC increased and decreased during the action of curling hair. It is thought that the stiffness of the wrist is changed by co-contraction of the antagonist muscle. In subject B, muscle activity of the FDS and EDC increased under both conditions. It is thought that the mechanism behind this is to increase the stiffness of the wrist by co-contraction of the antagonist muscle in order to release the snag. In addition, there was a temporary decrease in muscle activity of the FDS and EDC before the catch was released. During the brushing process, the patient was observed re-gripping the brush to free it from the snag. Therefore, we think that muscle activity temporarily decreased when the brush was re-gripped. As can be seen from Figs. 10 and 12, there were no notable characteristics in either subject, and it is considered that the position or order in which hair is curled does not affect the increase or decrease in muscle activity.

Next, consider the distortion of the brush. In both subjects, strain increased when the brush caught in the hair. In addition, the strain decreased when the catch was removed. Therefore, it is believed that the effect of the brush getting caught in hair can be measured. In addition, for both subjects, strain was observed in the opposite direction to the strain caused by the brush during the hair combing action. Since the brush was used upside down, it is believed that the strain increased in the opposite direction.

Next, consider the brush movement. When subject A was using a hair dryer and a brush to pull and curl her hair, the brush was moving in a curved line. It is thought that the movement of curling hair can be measured. There was also a shaking behavior during operation. This is thought to be related to increases and decreases in muscle activity of the FDS and EDC. In the results of the brush movement when subject B was combing his hair with a brush, vertical upward movement was observed as the brush was released from the snag. It is thought that the marker attached to the handle is moving upwards.

Finally, we consider the body-propagating vibrations. In subject B, the signal strength increased when the brush caught in her hair. It is thought that the wrist stiffness increases when the brush gets caught in the hair. There was no noticeable increase or decrease in signal intensity in subject A. It is thought to be because the effect of the brush getting caught on the change in wrist stiffness is small. However, it seems that the approach to preventing the brush from getting caught in hair cannot be measured. In future, when evaluating the skills of hairdressers, it is necessary to consider the location of the sensor. In addition, the FFT results showed that for subject A, the signal strength increased in the frequency bands of 0 to 20 [Hz] when the upper layer was wrapped for the first time, and 0 to 10 [Hz] when the upper layer was wrapped for the second time. In subject B, the signal strength increased between 0 to 30 [Hz] in three out of five trials. It is thought that by standardizing the order of actions and other experimental conditions in the future, it will be possible to evaluate hairdressers' skills. From these findings, it can be said that it is possible to measure the stiffness from the brush to the wrist by measuring the vibrations propagated through the body as proposed in this study.

During brushing, beginner subjects were observed to lower the brush head when the brush got caught. Regarding brush deformation, for both expert and beginner users, the deformation increased when the brush began to get caught, and decreased when the brush was no longer caught. Surface electromyography showed that beginner subjects showed increased muscle activity when the brush was released from the snag. However, expert participants did not show any increase or decrease in muscle activity in response to the snag. Regarding the body-propagating vibrations, the signal strength increased in beginner subjects when the brush got caught. However, the signal strength did not increase or decrease in expert subjects. These findings indicate that the measurement system developed in this study may be able to quantitatively evaluate a hairdresser's brushing skills.

VI. CONCLUSION

In this paper, we aim to use the brush and body-propagating vibrations during brushing movements to evaluate hairdressers' skills. We measured and analyzed the body-propagating vibrations during brushing movements. Under two different conditions, we measured the body-propagating vibrations, the strain of the brush, the sEMG of the flexor digitorum superficialis and extensor digitorum communis muscles, and the amount of brush movement. We demonstrated that it is possible to measure the change in wrist joint stiffness caused by co-contraction of antagonistic muscles from the change in signal strength of the body-propagating vibrations. There was also a difference between expert and beginner participants in the increase in the signal strength of the vibration that was transmitted through the body when the brush got caught in the hair. So we showed the possibility of evaluating the difference in skills between expert and beginner people. However, it was thought that the approach to preventing the brush from getting caught in hair in expert users could not be measured. Therefore, when evaluating a hairdresser's skills, it is necessary to consider the location where the sensor should be attached.

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