1. Introduction

Visually impaired persons sometimes have the impression that the Braille generated by an electromechanical Braille display is more difficult to understand than the Braille embossed on paper. It is seemed that this phenomenon is because the protrusions generated by a Braille display are lower than those in Braille on paper. However, when comparing paper Braille with the Braille generated by the electromechanical display, we found that the protrusion heights are usually same and that the heights of the paper Braille is often lower. Protrusion height thus seems unlikely to be the major reason why some people feel that the electromechanical Braille is harder to understand than that of the paper. Observing the way for the visually impaired to read the paper Braille and the electromechanical Braille, we noticed that some of them wipe the reading finger occasionally with their clothes or handkerchief only when rubbing electromechanical Braille. From interviews to them, some visually impaired reported that they wiped the finger when it stumbled or slipped on the electromechanical Braille. Furthermore, they always felt that it was difficult to rub the Braille if the finger did not move smoothly. In our previous research, it turned out that some sighted persons were aware of sweat on the finger pad when they felt a kind of resistance while sliding their finger on the surface of an acrylic sheet.1)

We hypothesized that the sweat on the finger had some influences on smoothness while moving the finger on Braille and measured the friction between the fingers and the object. Adelman et al. demonstrated that in mammals with sweat glands, the maximum value of the coefficient of static friction between the skin and the object greatly changes.2) Smith et al. investigated how an antiperspirant minimizes the value of the coefficient of static friction between the skin and the object. From the results, they found that the subject held objects with a stronger force than usual because the amount of sweat had decreased.3) Although there are many researches on the friction between finger with moisture and objects, most of them are studies on the influence of perspiration using data indirectly measured or simulated as to the influence of sweat. Any experiment has not conducted to measure the frictional force between the finger and the object while measuring the sweat state of the finger in real-time or nearly in real-time.

In this paper, we report our experimental results confirm that the perspiration rate measured nearly in

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Abstract

Braille contents can be presented to the visually impaired not only by dot patterns on an embossed paper but also dynamically by a machinery display. Material quality of surface of these Braille displays that are touched by fingers has an effect on comfort in reading Braille. The effect seems to be due mainly to the friction change caused by perspiration. In this research, we experimentally examined how sweat affects the friction between a finger and an object. Comparing an acrylic sheet with a copy paper used for the displays, we found the influence of the sweat to be greater on the acrylic sheet than the copy paper and also found, even if the fingertip was sweat, any change is not observed in frictional force when rubbing objects covered with the copy paper.

Keywords: finger pad, perspiration, sweat, friction force, sweat absorption.

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Sweat Absorption Reduces the Frictional Force Between a Finger Pad and the Surface of a Flat Plate

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real-time on a person’s finger is not constant and that
the influence of sweat changes depending on the surface
structure of the object made of two representative
materials being touched.

2. Experiment

2.1 Measurement of perspiration

First we measured the perspiration rate on the finger
pad of each subject’s working forefinger with a
perspiration meter (SKN-2000, Nishizawa Electric
Meters Manufacturing Company, Ltd., Nagano, Japan)
(Fig. 1). The meter calculates the time rate of amount of
moisture transpired from the skin by comparing the
humidity between ambient air blown on the skin and the
returning air by the capsule. The effective area of the
skin surrounded by the capsule is 1 cm². At an operating
temperature of 23.5°C and a relative humidity of 60%,
perspiration rates between 0 and 1 mg/cm²-min were
measured with an accuracy of ±10%. In our experiments,
the value displayed by the SKN-2000 often exceeded 1
mg/mm and was recorded as a reference value because
the accuracy at that level was uncertain.

2.2 Measurement of frictional force

After perspiration rate measurement, we measured
the change in the frictional force between the subject’s
finger pad and the acrylic sheet. The subject moved
his/her finger to the surface of the acrylic sheet of the
friction force measuring system set 8 cm to the right of
the measuring terminal of the SKN-2000. Sweat on the
surface of the finger pad evaporates constantly even
when the finger is stationary relative to the air, and the
amount of evaporation increases as the finger moves in
the air. Therefore the amount of movement of the finger
should be as small as possible. In this experiment, the
moving distance of the finger was set to 8 cm for
convenience of machine layout. In a preliminary
experiment, we evaluated the perspiration rate before
moving the finger during moving the finger 8 cm, the
difference in the perspiration rate before and after
moving the finger was within ±3% for 8 subjects and was
within ±5% for 2 subjects. We judged that the influence
on the perspiration rate caused by the movement of
fingers was not large enough to affect the results.

A general friction measuring device using a
piezoelectric element is suitable for measuring a
frictional force of several newtons in a state where there
is a normal force of several newtons. In this study, we

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Fig. 1 Perspiration measurement equipment. A subject stuck his
index finger on the capsule of the perspiration meter.

Fig. 2 Frictional force measuring system.
made a device to measure the frictional force at normal forces of several hundred mN to several newtons, which is the range that visually impaired persons use when reading Braille.

The acrylic sheet was 200 mm long, 100 mm wide, and 10 mm thick, and it had a thermal conductivity of 0.19 W/(m·K) and a surface roughness $R_a < 0.05 \mu m$. The sheet rotated on an axis that balanced the subject's finger pad with a counterweight used to adjust normal force. The equipment overview is shown in Fig. 2. Both the center of the counterweight and the center of the finger were 8 cm to the side of the rotation axis, and the normal force applied to the finger changed by 1% of the counterweight when the acrylic sheet was moved ±5 degrees from the horizontal direction. Data were excluded if later observation of a video recording showed that the subject rotated the acrylic sheet ±5 degrees from the horizontal direction. As the counterweight used in this experiment was 100 g, the normal force given to the finger was approximately 0.98 N.

A visually recognizable cross marker was placed at a position 2 cm away from the left end of the acrylic sheet as seen from the subject and 8 cm away from the rotation axis. Subjects put center of the finger pad on the center of the cross marker. And make an effort to move the finger to the right direction parallel to the rotation axis from there while to use attention not to rotate the acrylic sheet as possible. The frictional force was generated when subjects moved the finger on the acrylic sheet to the right. And the force moved the box with the wheel to the right.

As the box moved to the right, the side of the box pressed the rotator which changed the direction of the frictional force and the bias force from horizontal to vertical so that it could be measured by an electronic balance (UW4200S, Shimadzu Corporation, Japan). However, if the lower part of the converter floated from the top plate of the electronic balance, the frictional force could not be measured accurately. A 0.5 N bias force in the right direction was applied to the box with a coil spring at all times to keep the converter pressed against the top plate of the electronic balance. And the transition error of the amount of the horizontal force to the amount of the vertical force was within ±1%. The measured value from the UW4200S was recorded about 12.5 Hz by another computer connected to the UW4200S with an RS-232C interface. The measured value began to rise when the subject started to move his/her finger. We regarded the maximum recorded value as the maximum static frictional force until the subject finished moving the finger or quitted trying to move it. The maximum value of the coefficient of static friction $\mu_{\text{max}}$ was calculated and used as an evaluation value. The UW4200S indicates the value at least 0.7 sec integration if the weight fluctuates in both directions of increase and decrease. We assumed that the vibration state in moving finger should be obtained shorter than 0.7 sec and we decided not to evaluate the value of kinematic friction.

After the trials with the acrylic sheet, similar experiments were conducted on each subject twenty times using copy paper as the surface. A piece of copy paper 200 mm long, 100 mm wide, and 90 µm thick was glued on the upper surface of the acrylic sheet, and the same experiment was repeated 20 times for each subject. There is no standard that defines the surface roughness of copy paper, but we used copy paper with the air permeance specified in Japanese Industrial Standard P8117, which is almost the same as that specified in ISO 5636-5. After finishing each trial, the experimenter checked to see if the surface of copy paper was dry and, if it was not, replaced the acrylic sheet with another one on which new copy paper was affixed.

### 2.3 Subject and Experiment condition

The subjects were five Japanese adult men and five Japanese adult women, all healthy, all right-handed, and all with normal sight and hearing. Based on their self-reported finger sweat, the subjects were able to be classified into three types: always dry (four subjects, Group 1), almost always dry but sometimes sweaty (four subjects, Group 2), and always sweaty (two subject, Group 3). Twenty trials were performed with each subject. After finishing a trial, the experimenter cleaned the surface of the acrylic sheet with absorbent cotton wet with alcohol. At the end of each trial, we asked each subject to report whether he or she was aware of sweating, not aware, or not sure. The trials were conducted in a conference room at 22–25°C and 55%–65% relative humidity.

This experiment was performed according to the principles of the Declaration of Helsinki and was approved by the Utsunomiya University ethics committee.

### 3. Results

Figure 3 shows a graph of changing with time of the perspiration rate of representative subjects in each group. To allow measurements to settle down, we used the rate as value reported after 1 min. The rates of all
four subjects in Group 1 were stable almost at zero, like Fig. 3. The rates of subjects in group 2 were varied from trial to trial, and it was sometimes unstable during 1 minute observation. The rates of subjects in Group 3 were never got close to 0 mg/cm²·min.

The relationship between the perspiration rate and the $\mu_{max}$ between the finger and the acrylic sheet is shown in Figure 4.

The $\mu_{max}$ of Group 1 were stable within the range of 0.67 to 0.71. All the subjects in Group 1 declared that they were able to smoothly move their fingers on all trials to rub to acrylic sheet.

In Group 2 the perspiration rate was not stable in every trial and could be divided into two discrete sets: one close to 0 mg/cm²·min and the other over 0.5 mg/cm²·min. These rates were stable in the range close to 0 mg/cm²·min but were unstable if they were over 0.5 mg/cm²·min. The perspiration rate did not increase or decrease in proportion to the number of times the twenty trials were repeated, and we could not predict when the perspiration rate would be varied. The $\mu_{max}$ was between 0.62 and 1.11 when the perspiration rate was close to 0 mg/cm²·min but was more than 1.5 when the perspiration rate was over 0.5 mg/cm²·min. Group 2 subjects claimed that they sometimes felt difficulty in moving their finger when they felt stumbling in moving the finger. And the $\mu_{max}$ were larger than 1.5 all cases when they felt difficulty.

The perspiration rates in Group 3 were unlike those in other groups, did not have a value close to 0 mg/cm²·min and were over 0.5 mg/cm²·min and as unstable as the values all subjects of Group 2 who felt difficulty in moving a finger. And the perspiration rate could not be predicted. The $\mu_{max}$ values were always over 1.8 and were unstable. Group 3 subjects claimed that they always felt stumbling in moving their fingers and difficulty in moving their fingers.

Figure 5 shows the different relations between $\mu_{max}$ and perspiration rate in the trials using the acrylic sheet and the trials using copy paper. In experiments using copy paper, the $\mu_{max}$ of all trials of all subjects was stable at around 0.7 in spite of perspiration rates occasionally over 0.5 mg/cm²·min in Group 2 and Group 3 subjects.

Table 1 shows the correlation coefficients $r$ of the perspiration rate and the $\mu_{max}$ in each subject. The correlation coefficient $r$ was calculated by the value of perspiration rate and $\mu_{max}$ in each twenty trials of individual subject and linear regression analysis was performed to study the relationship.

In Group 1 the correlation between perspiration rate and $\mu_{max}$ is weak or moderate. In all Group 2 subjects there was a very strong correlation between perspiration rate and $\mu_{max}$ with acrylic sheet. As for reference, it was found that there was a moderate correlation when using data with perspiration rate greater than 0.5 mg/cm²·min and using data with perspiration rate smaller than 0.5 mg/cm²·min. And there was moderate correlation between perspiration rate and $\mu_{max}$ with copy paper. In Group 3, there was moderate correlation between perspiration rate and the $\mu_{max}$ with acrylic sheet and no correlation between perspiration rate and the $\mu_{max}$ with copy paper.

4. Discussion

We measured the effects of perspiration when a finger rubbed an acrylic sheet or copy paper. The perspiration rate of the fingers differs greatly among individuals. People who did not sweat could move their fingers smoothly on both an acrylic sheet and copy paper. On the other hand, some people felt it was difficult to move their fingers on an acrylic sheet occasionally or always, according to the amount of the sweat on their finger pads. The maximum $\mu_{max}$ value obtained in any of the trials was 4.85, and it was for subject No. 9 rubbing an acrylic sheet. He had not been diagnosed with hyperhidrosis but thought that he had a tendency to sweat a lot on hands and fingers. Results of an experiment using artificial fingers suggested that the slip phenomenon occurs depending on the amount of moisture. If the same experiment were done using a alive human finger of subject No. 9 or No. 10, which perspire continuously, a slip phenomenon due to the
sweat might occur. But in this research each trial was completed in a few seconds and we assumed that the moisture of sweat was not accumulated on a specific position on acrylic sheet or copy paper. If moisture due to sweat is present between a finger and an object, the fictional force between the finger and the object decreases or increases, affecting the movement of the finger. In Group 2 and Group 3 subjects, correlation between perspiration and friction was smaller for copy paper than it was for acrylic sheets. This can be thought to mean that the copy paper reduced the influence of sweat. The big difference between copy paper and an acrylic sheet is in their surface structure. In these experiments we did not measure the amount of moisture.
absorption, but because the sweat was absorbed in the fiber of the copy paper its influence was weakened. It is also known that the friction state between the finger and the object varies depending on whether the surface is hydrophilic or hydrophobic\(^8\). That report suggests that the possibility to vary in friction state due to moisture even if it is not an absorb material. On the other hand, it is also known that the stratum corneum on the outermost side of the finger is softened by water\(^9\). Furthermore, not only the moisture between the finger and the object, but also the moisture exuded as sweat from the inside of the skin may change the softness of the stratum corneum before reaching the object surface, it is still difficult to predict the influence of sweat on friction. Overall, in order to elucidate the influence of perspiration on frictional condition, further study would be required for obtaining data from fingers of alive human.

In an information transmission device like an electromechanical Braille display, there is a possibility of sweat changing the transmission efficiency. There are people who feel that perspiration on their fingers makes this kind of device hard to operate. We cannot know how many people can feel the perspiration on their finger pads because statistics on sweat are not being done. But the relationship between sweat and friction should be considered when designing finger-operated devices to be as stressless as possible for as many people as possible.

5. Conclusion
We investigated the relationship between sweat and friction nearly in real-time. In our experiments, we confirmed that the sweat on the finger pad influences the frictional force between the fingertip and the surface of an object and also that the sweat influences the correlations between the amount of sweat and the size of $\mu_{\text{max}}$. Furthermore, it was found that the correlation obtained using copy paper is smaller than that obtained using an acrylic sheet. It was anticipated that the copy paper used as the Braille document suppressed the influence of friction due to user sweat more than the
acrylic sheet did. We conclude that the fibrous material like copy paper absorbs the sweat of the fingertips, allowing our subjects to move the finger moderately and smoothly on the surface and achieving the comfortable information transmission.

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