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Individual differences of friction coefficient and normal force on friction perception

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***Abstract*—When we perceive an object by touching it, our motion is modulated according to our perception and objectives. Thus, tactile perception and motion are bidirectional. Clarifying the relationship between them can be important in the design of tactile interfaces, to improve their usability. In this paper, we focus on friction, which is one of the key factors in texture perception. The friction experienced by the fingertip depends not only on the explored surface, but also on skin characteristics and the user's motions. Therefore, the friction experienced by each individual is different, even if the object is the same. We investigated individual differences in the relationships between tactile sensitivity, friction coefficient, and normal force in active touch on an ultrasonic tactile display. The results of a psychophysical experiment showed a significant correlation between the discrimination sensitivity and the friction coefficient, indicating that humans with high friction coefficients have high sensitivity. The results also showed that participants with high sensitivity used similar small normal force with and without an exploratory objective. Some of the participants with low friction coefficients and low sensitivity changed the normal force when they had an exploratory objective, whereas the friction coefficients did not change much. These results indicated that tactile sensitivity to the friction coefficient is mostly affected by skin properties rather than normal force modulation.**

***Index Terms*—Haptic perception, Friction coefficient, Friction sensitivity, Normal force, Natural touch, Individual differences.**

I. Introduction

In tactile perception, the friction experienced by the skin is an important factor, as it is one of the physical dimensions that explains tactile texture perception, amongst a combination of several other physical factors [1]. When we perceive objects by touching them, factors such as normal force or velocity can be influenced by our perception. When touching objects, we get tactile sensations and, based on the tactile sensations we perceive, we can adjust our movements appropriately for different objects and purposes. For example, when people are gripping an object, they respond to changes in friction by adjusting their gripping force [2]. Motion is an essential component of friction, but friction varies not only with motion but also with finger or skin features (mechanical or chemical finger properties, as hydrolipid film) and environmental features such as temperature and humidity that can modify the finger characteristics [3]. Therefore, the friction obtained by each individual is different, even if the object is the same. Thus, clarifying individual differences in the perception of friction in relation to motion and skin properties will be of great benefit for the development of interfaces and product design.

Studies have shown that the coefficient of friction between skin and a glass plate decreases with increasing normal force [4]. It was demonstrated that a higher friction contrast is associated with a higher friction discrimination ability. This friction discrimination ability depends on individual finger characteristics and sliding velocity [5]. Many previous studies have confirmed that the coefficient of friction of the skin decreases with age and that this is partly due to a decrease in the humidity in the skin. For example, Mabuchi et al. [6] reported that the coefficient of friction when touching paper with a finger was 0.5 for participants in their 20s and 30s, but less than 0.25 for participants over 60 years of age. Moreover, they reported that the coefficient of friction also increased as the moisture content in the skin increased, even for participants in their 60s. Hence, moderate moisture increases the friction of the skin [7] [8]. Friction can decrease in wet skin conditions, as the film of water formed can act as a lubricant in mixed or hydrodynamic regimes [8] – [10].

There are individual differences in the relationship between friction and motion. Kurimoto et al. [11] showed that participants using small normal forces had high friction coefficients, whereas participants using relatively large normal forces had low friction coefficients and showed large individual differences in normal force. Hence, the normal force used by people varies considerably between individuals. The normal force also depends on the direction of tracing and the roughness touched [11] – [14].

By investigating how friction coefficients, forces and skin characteristics relate to friction sensitivity, it is possible to discuss how individual differences in motion and skin characteristics may affect the perception of friction.

The influence of friction between the finger and a surface on perceived friction has not received much attention in the literature. One probable reason is the difficulty to change friction without changing the surface roughness or the material [15] [16]. In [5], the authors studied the influence of friction on the detection threshold of a friction contrast. However, they did not consider discrimination of surfaces with different friction coefficient. In this study, we used a tactile stimulator to change the friction coefficient between a surface and the finger pad. This device called STIMTAC is able to instantaneously change the contact conditions between the finger and the plate by acting like a lubricant [17]. The lubrication effect is obtained by ultrasonic vibrations of the active plate of the stimulator at a well-chosen mechanical resonant frequency. This vibration frequency is not perceptible by human mechanoreceptors [18]. As a result, the friction coefficient can be modified, without changing the material or the finger's characteristics.

The aim of this paper is to clarify the relationships between the friction coefficient of the finger with a surface, the sensitivity to discriminating different friction coefficients, and the normal force used during tactile exploration, with an emphasis on individual differences. We also want to examine whether the exploratory strategy changes depending on whether the participant has to perform a discrimination task or not.

We tested two conditions: in one condition the participants had to just trace a surface of which the friction was varied systematically. In the other condition, participants had to touch two similar surfaces in a row and decide which of the two had the larger friction coefficient. In this way, we could study whether the touch parameters depend on task condition. During the tests, the normal and friction forces were measured. Before the experiment, the humidity of the users' fingers was assessed.

II. Method

A. Participants

Eighteen healthy adult individuals (12 male and 6 female, age range 21 – 46 years) participated in the experiment. Seventeen of them were strongly right-handed and one was strongly left-handed according to Coren's test [19]. The participants were instructed to use the index finger of their dominant hand during the experiment. All participants gave their written informed consent before participating in the experiment. This study was part of the research program multitouch that was approved by the University of Lille.

B. Experimental set-up

The setup for this experiment is shown in (Fig.1). It consists of an ultrasonic tactile stimulator, [20], made with an aluminum beam (18mm $\times$ 119mm $\times$ 2mm) covered with a hydrophobic surface. Four piezoelectric ceramics of dimensions ($14 \times 6 \times 0.5$ mm^3) were glued to the opposite surface of the beam to produce the ultrasonic vibration. One of them was used as a vibration amplitude sensor. The placement of the actuators and sensor is designed to be well coupled with the vibration mode, without changing the mode shape. A closed-loop control of the vibration amplitude of the beam was achieved thanks to the use of a Digital Signal Processor (STM32F4 from ST Microelectronics). The vibration control was achieved at 10 kHz. An external power amplifier (HSA 4051 from NF, Japan) amplified the controller's output up to 300 V peak-peak. The controller is implemented following the methodology described in [21].

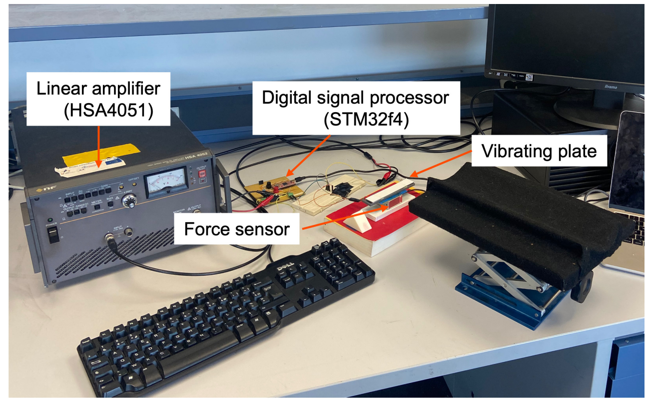

Fig. 1. General view of the experimental setup.

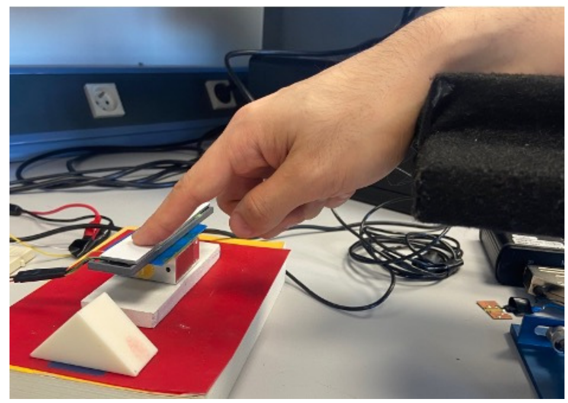

Fig. 2. A finger touching the surface of the stimulator.

The normal and lateral forces are measured by a three-axis load cell (model 3A60-20N, Interface Inc., Scottsdale, Arizona), onto which the tactile stimulator is affixed and which provides the components of the force exerted by the finger on the cell along three orthogonal axes (the vertical axis is denoted as z, the axes in the horizontal plane are named as x and y). The load cell is placed on the linear stage. To ensure a correct position of the finger relative to the sample and for the comfort of the participant, an adjustable gutter is designed to support the participant's arm. The participants were instructed to maintain an angle between the finger and the scanned surface of about $45°$. In addition, we recorded the duration for each trial.

Finally, a Matlab application was designed to conduct the experiments and display instructions to participants on a computer screen while a keyboard was used to transmit their responses to the application. The procedure followed by the application is described below.

C. Procedure

The participants washed and dried their hands before the experiment, and sat down in front of the experimental setup where the hydration level of their dominant index fingertip was measured using a Corneometer®(CM825, Courage + Khazaka). The hydration level of the skin surface was measured three times and the average value was adopted. Then, the participants practiced exploring the surface guiding their motion with the help of a metronome set to BPM = 83 corresponding to 100 mm/sec, to ensure an almost constant tracing velocity during the tests. However, the metronome was not used during the experiment. Two experiments were conducted with a 10-minute break in between. The stimuli consisted of a series of vibration amplitudes ranging from 0 μm to 2 μm, with a 11 level discretization. The reference stimulus was set in the middle of the discretization levels, leaving 10 test stimuli. The levels were adjusted based on the results of a pilot experiment with three participants. The same stimuli were used in Experiments 1 and 2. In the following section, the details of each experiment are presented.

a) Experiment 1: The purpose of this experiment was to measure the normal force and the friction coefficient when the participants were tracing in a natural way without performing a specific task. Since the objectives of a perceptual task might affect the exploratory movements, this experiment was used as a control task for comparison. Participants were instructed to trace at a replicated tracing velocity from the practice session, striking laterally from left to right, along the surface of the plate. All 10 test stimuli were presented five times in random order, with a different order for each participant, leading to a total of 50 trials (10 vibration levels * 5 times). During Experiment 1, the participants wore headphones so that they could not hear the sound emitted by the interaction of their finger and the device.

b) Experiment 2: This experiment was a sensitivity analysis. For each trial, we presented two stimuli, one after the other; the first stimulus was denoted “1” and the other “2”. The reference stimulus was randomly presented as the first or second one. First, the participant was asked to trace around three times his/her finger on the device, then to strike “1” on the keyboard to present the second stimulus. After around three swipes of the finger on the device with the second stimulus, the participant entered “2” on the keyboard. He or she was then asked to answer the question “which of the two stimuli gave the impression of a higher friction coefficient”, by pressing “1” or “2” on the keyboard. Following the answer, a new trial started.

Each stimulus was presented six times, randomly. As a result, the participants performed 60 trials in total, with a 2-minute break after every 20 trials. During the experiment, the participants wore headphones so that they could not hear the sound of stimuli. The data of one participant were lost during the analysis.

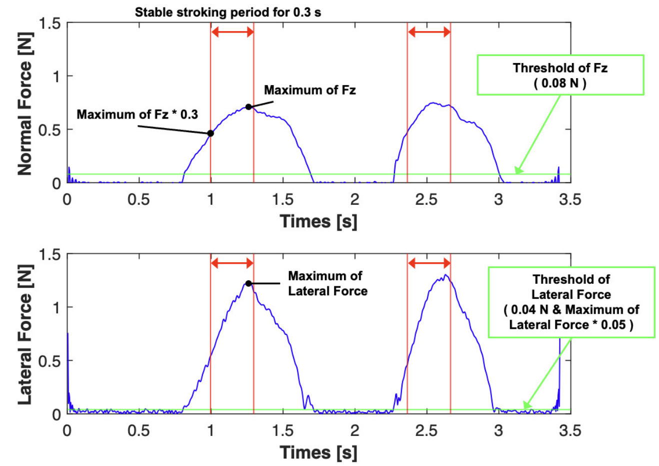

Fig. 3. Typical normal force and lateral force for two scanning periods.

D. Data Processing

The output of the force sensor is used to calculate the normal force and the frictional force during the trials. Fig. 3 shows the typical output of the 3-axis force sensor. A 37.5 Hz low-pass filter was applied for smoothing the curves of the normal force and the lateral force. To avoid sections where the finger was not in contact with the device, only the sections where F_z was above 0.08 N, the lateral force was above 1/20 th of the maximum value of the recorded data and above 0.04 N were extracted. During touch, stick and slip can lead to fast variations of the normal and lateral forces, which would result in incorrect friction coefficients. However, each stroke contained a sufficiently large duration of stable stroking. To remove stick and slip from our analysis, we extracted a section of 75 data points (300 ms at a sampling frequency of 250 Hz) where the F_z was larger than 30 % of the maximum F_z (see Fig. 3). The surface of the device was paper, not glass, so there was not a lot of stick and slip. However, one participant (No.1) had many occurrences of stick and slip; one of five trials did not have a sufficiently stable section of stroking; in this case, only four trials were used to calculate the mean normal and friction forces.

For each stable section, the friction coefficient f_{rc} was calculated by dividing the average friction force F_r that was calculated from the horizontal forces F_x and F_y ($F_r = \sqrt{{F_x}^2 + {F_y}^2}$) by the average of the normal force F_z ($f_{rc} = \bar{F_r}/\bar{F_z}$).

A psychophysical curve was obtained from the fraction of correct responses given by the participants. The average friction coefficient for each stimulus was used as the independent variable. For all participants, we calculated the

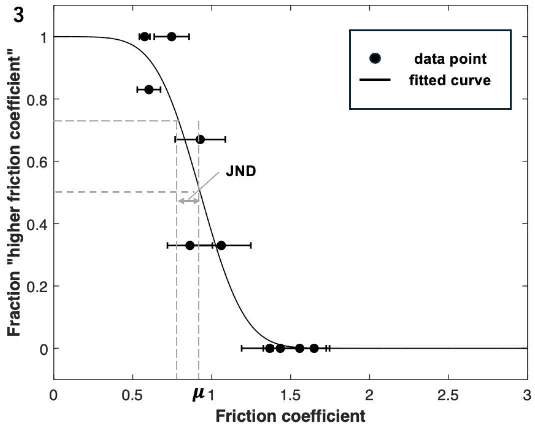

Fig. 4. One example of a psychometric function fitted to the data of a single participant (No.3). A data point shows the fraction that the friction coefficient of the test stimulus was chosen as higher. The JND is defined as the difference between μ and the 0.75 point of the curve. The error bars show standard deviations.

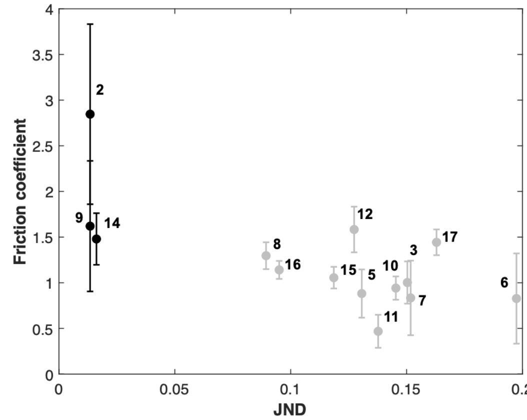

Fig. 5. Distribution representing the relationship between the mean friction coefficient on all trials of Experiment 2 and the JNDs for all participants. The number of each plot point represents the participant number. Participants with high friction coefficients and low JNDs are indicated with black marks, the other with gray marks. The error bars indicate the standard deviations.

fraction of responses indicating a higher friction coefficient for the test stimulus compared to the reference stimulus. The cumulative Gaussian distribution (f) as a function of the friction coefficient (x) for each stimulus was fitted to the data using the following equation:

$$f(x) = \frac{1}{2}(1 + erf(\frac{\mu - x}{\sigma\sqrt{2}})) \quad (1)$$

The friction coefficient for the stimulus varies from participant to participant, because the friction coefficient depends on motion and skin properties. Hence, the friction coefficient (x) in the psychometric curve is the average of the friction coefficient measured for each sample on each participant. μ is the point of subjective equality, and thus where the curve is 0.5. We calculated the difference between the point where the ratio is 75 percent and μ as a just noticeable difference (JND). An example of fitting is shown in Fig. 4. Fig. 4 shows a fit to the data of participant 3. As a characteristic of the device, the friction coefficient contains some variations, as indicated by the error bars. Mean of the error bars for all stimuli by all participants and its standard deviation was 0.20±0.0363. In three cases, it was not possible to fit a psychometric curve through the data of a participants, because the fraction correct was everywhere below 0.6. Therefore, data from these three participants were excluded.

Finally, we calculated the correlation coefficients between the friction coefficient and JND, the normal force and JND in Experiment 2 and the friction coefficient and humidity in Experiment 1. Also, we calculated correlation coefficients with JND. Statistical significance of the correlation coefficients (r) was assessed using a t-test based on Pearson's product-moment correlation. In this paper, the significance level was set at $p = 0.05$.

III. RESULTS

Fig. 5 shows the relationship between the mean friction coefficient and the JND for all participants. There was a significant correlation between the friction coefficient f_{rc} and the JNDs ($r = -0.69$, $p = 0.0058$), indicating that participants with high friction coefficient had high sensitivity. Participant 2 had an outstandingly high friction coefficient compared to the other participants, but even without participant 2, a significant correlation was found ($r = -0.60$, $p = 0.031$). On the other hand, there was no correlation between the standard deviation of the friction coefficient and the JND. On the basis of this figure, we divided the participants in two groups: a) Participants with high friction coefficients and low JNDs (black) and b) Others (gray).

Fig. 6 shows the relationship between the normal force and the JND obtained in Experiment 2 for all participants with the color corresponding to Fig. 5. This figure shows that there was no significant correlation between the normal force and the JND ($r = -0.039$, $p = 0.90$). There was no correlation between the standard deviation of the normal force and the JND.

Fig. 7 shows the averaged normal force and the friction coefficient for both experiments for all participants with the color corresponding to Fig. 5. This figure shows that the participants exhibited different friction coefficients and used different normal forces. Some of the participants with low friction coefficients used different normal forces in Experiments 1 and 2.

Fig.8 shows the relationship between the friction coefficient and the skin hydration averaged over all trials from Experiment 1 for all participants. The plots with back or gray correspond to Fig. 5 and the white circles denote the participants excluded from the analysis. Participants 4, 8, and 13 where the ones for whom no good psychometric curves were obtained and

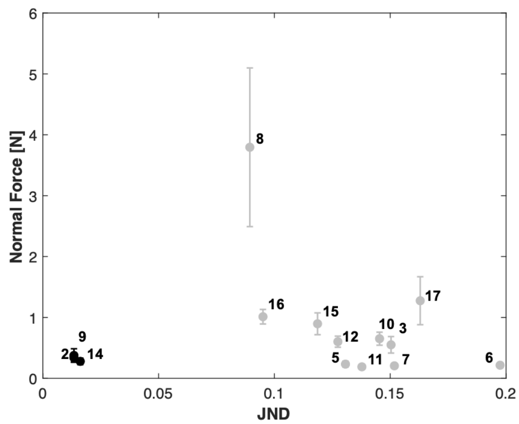

Fig. 6. Distribution representing the relationship between the average of normal forces on all trials obtained in Experiment 2 and the JNDs for all participants. The number of each plot point represents the participant number. Black marks indicate participants with high friction coefficients and low JNDs, gray marks all the others. The error bars indicate the standard deviations.

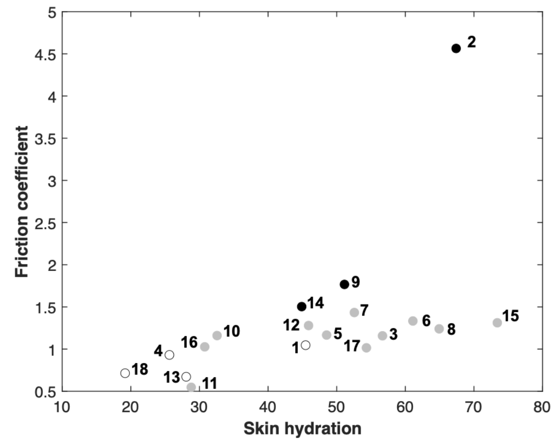

Fig. 8. Distribution representing the relationship between the average of friction coefficients on all trials obtained in Experiment 1 and skin hydration. White plots represent participants who were not included in the data analysis in Experiment 2.

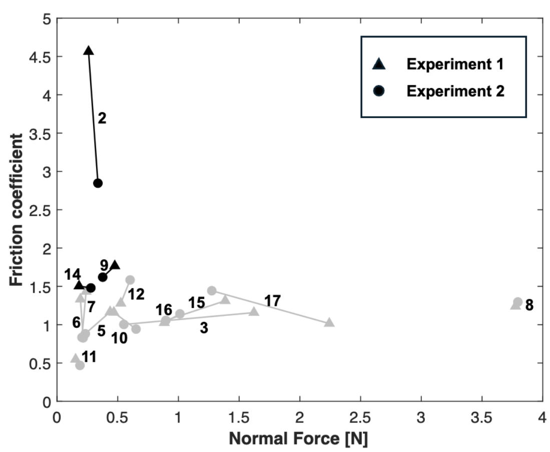

Fig. 7. Distribution of friction coefficients and normal forces for all participants obtained in Experiment 1 and Experiment 2. The number of each plot point represents the participant number.

the data of participant 1 were lost. Here, we used the friction coefficient of Experiment 1, traced without exploratory purpose, as a parameter during natural touch. There was a significant correlation between the friction coefficient and the skin hydration by all participants ($r = -0.53$, $p = 0.024$), indicating that low skin hydration trends to induce a low friction coefficient. Even without participant 2, a significant correlation was found ($r = 0.65$, $p = 0.0050$).

IV. Discussion

This study investigated the relationship between normal force, friction coefficient, and friction sensitivity during active touch. In Fig.5, we found a significant correlation between the JNDs and the friction coefficients, indicating that a higher friction coefficient induces a high sensitivity. However, participant 2 performed much better than the values reported in [22] [23]. One possible reason is that our experiment allowed participants to apply natural normal forces without any restrictions, unlike previous studies that adopted a constant force [22] [23]. Natural touch may contribute to improving the sensitivity. Fig.6 shows that there is no correlation between the normal force and the JNDs. This result suggests that people's friction sensitivity is more influenced by their skin properties than by active touch motion.

Fig.7 shows that participants with large friction coefficients (Group 1) used small normal forces whereas those with low friction coefficients (Group 2) used diverse forces. This tendency was observed in both Experiments 1 and 2 and is consistent with previous work [11], in which several glasses with different friction coefficients were used as samples and the participants traced the samples without a specific task.

We then focused on the changes in normal force in Experiment 1 (without exploratory objectives) and Experiment 2 (with exploratory objectives). Fig.7 shows that the participants in Group 1 used almost the same normal force in Experiments 1 and 2. This is probably because they could maintain high frictional sensitivity without any effort to change the normal force, resulting in high sensitivity for the discrimination of friction coefficient. On the other hand, some participants in Group 2 varied the normal force significantly. These participants may have tried to improve their performance by varying the normal force. However, their friction coefficients did not change much and their JNDs were not small. Unless the normal force is in a large range, the friction force is mostly proportional to the normal force, indicating that the friction coefficient is hardly affected by the normal force [20]. In this paper, the magnitude of the normal force was not imposed to the participants. They might exert normal forces expected in their daily lives. Therefore, although there was some variation in the magnitude of the normal force among individuals, it was within a limited range, and the friction coefficient did show large variations. However, participant 2 has a very large change in friction coefficient between experiments 1 and 2 compared to the other participants. In future experiments we will investigate whether this could be due to a change in skin hydration. Therefore, as discussed in Fig. 5 and Fig. 6, it suggests that skin properties have a significant influence on friction sensitivity. In this paper, we focused on one of them: skin hydration. In Fig. 8 there was a correlation between the friction coefficient and skin hydration. It appeared that the participants with low skin hydration (participant 11, 16 and 10) had low friction coefficients and high JNDs. The participants excluded from the analysis also had low skin hydration. Gueorguiev et al. [24] found the moisture level of the fingertips to be strongly correlated with individual performance. Our tendency supports this finding. However, there were participants with high skin hydration who did not have high friction coefficients and small JNDs. This shows that other factors besides skin hydration affected the friction perception. Monnoyer et al. [25] reported that individual differences in finger impedance affect friction perception. The skin hydration of Group 1 (black) also varied. This indicates that skin hydration is not enough to represent the friction coefficient, suggesting that other skin characteristics also affect the friction coefficient. Furthermore, André et al. [26] reported that skin hydration varies with normal force. In this experiment, the skin hydration was measured only once before experiments 1 and 2. Therefore, in future experiments, it will be useful to look at changes in moisture content and normal force.

Here, the actual contact area is an important factor to directly influence the friction coefficient. It has already been reported that the actual contact area has a significant effect on the friction coefficient [27] [28], and the contact area is derived from mechanical interaction between the finger pad and the object, involving skin properties, such as finger size, skin thickness, and skin softness [29] [30], and motion. Therefore, individual differences in the relationship between the normal force and the friction coefficient in natural touch may be more deeply understood by looking at the actual contact area.

V. Conclusion

In this paper, we investigated the relationship between normal force, friction coefficient, and sensitivity, focusing on natural touch. We found that participants with higher friction coefficients were better at discriminating friction. They used normal forces of almost the same magnitude, both when they were not given the exploratory task and when they were. These participants used smaller normal forces than the whole group of participants. The other participants who had smaller friction coefficients tended to use greater normal forces than the mentioned participants, but the normal forces varied from individual to individual. The results obtained are consistent with previous results [11]. We observed variations in the normal force both when the participants were given an exploratory task and when they were not. This seems to be a strategy used in order to improve their sensitivity. However, their friction coefficient did not change much when they changed the normal force. This is probably because the friction coefficient of a human finger is not determined solely by active motion, but is also highly dependent on other factors such as skin characteristics. In our experiments, we also observed that people with low finger moisture content also had a lower coefficient of friction. The overall sensitivity results then depended on the coefficient of friction. No correlation was found with normal force. We conclude that people's sensitivity is to a certain extent dominated by the friction coefficient characteristics they had even if they strategically adjust their motions on an individual level.

In this paper, the participants were not given a specific magnitude of normal force, and they performed the experiment at a fixed tracing speed. In future studies, we are interested in researching other factors related to exploratory tactile perception strategies, such as individual differences in exploration velocity when the normal force is imposed.

References

[1] S. Okamoto, H. Nagano, and Y. Yamada, "Psychophysical dimensions of tactile perception of textures," IEEE Transactions on Haptics," vol. 6, no. 1, pp. 81–93, 2012.

[2] L. Willemet, F. Roël, D. Abbink, I. Birznieks and M. Wiertlewski, "Grip force control under sudden change of friction," Computational physiology and modelling, vol. 603, no. 2, pp. 411–422, 2025.

[3] S.M. Pasumarty, S.A. Johnson, S.A. Watson and M.J. Adams, "Friction of the Human Finger Pad: Influence of Moisture, Occlusion and Velocity," Tribology Letters, vol. 44, no. 2, pp. 117–137, 2011.

[4] A. A. Koudine, M. Barquins, P.Anthoine, L. Aubert and J. L. Leveque, "Frictional properties of skin: proposal of a new approach," International Journal of Cosmetic Science, vol. 22, no. 1, pp. 11–20, 2000.

[5] W. B. Messaoud, M. Bueno and B. Lemaire-Semail, "Relation between human perceived friction and finger friction characteristics," Tribology International, vol. 98, pp. 261-269, 2016.

[6] K. Mabuchi, R. Sakai, K. Yoshida and M. Ujihira,"Effect of ageing on friction of human fingers," Biosurface and Biotribology, vol. 4, no. 4, pp. 117–121, 2018.

[7] C.P. Hendriks and S.E. Franklin, "Influence of surface roughness, material and climate conditions on the friction of human skin," Tribology Letters, vol. 37, no. 37 pp. 361–373, 2010.

[8] S.E. Tomlinson, R. Lewis, X. Liu, C. Texier and M. J. Carré, "Understanding the friction mechanisms between the human finger and flat contacting surfaces in moist conditions," Tribology Letters, vol. 41, no. 1, pp. 283–294, 2011.

[9] S. Derler, L.-C. Gerhardt, A. Lenz, E. Bertaux and M. Hadad, "Friction of human skin against smooth and rough glass as a function of the contact pressure," Tribology International, vol. 42, no. 11, pp. 1565–1574, 2009.

[10] S. Johnson, S. Watson, S. Adams and M. Adams, "Friction of the human finger pad: Influence of moisture occlusion and velocity," Tribology Letters, vol. 44, no. 2, pp. 117–137, 2011.

[11] K. Kurimoto, A. M. L. Kappers, and Y. Tanaka, "Anisotropy in Normal Force and Friction during Active Tracing," In: Proceedings of EuroHaptics 2024, pp. 162–167, France, 2025.

[12] M. Natsume, Y. Tanaka, W. M. Bergmann Tiest and A. M. L. Kappers, "Skin Vibration and Contact Force in Active Perception for Roughness Ratings," In: Proceedings of the 26th IEEE International Symposium on Robot and Human Interactive Communication, pp. 1479–1484, 2017.

[13] Y. Tanaka, W. M. Bergmann Tiest, A. M. L. Kappers and A. Sano, "Contact Force and Scanning Velocity during Active Roughness Perception," Plose One, vol. 9, no. 3, e93363, 2014.

[14] D. Katicilar and K. Drewing, "The Effects of Movement Direction and Glove on Spatial Frequency Discrimination in Oriented Textures," In: Proceedings of 2023 IEEE World Haptics Conference, pp. 313–318, Netherlands, 2023.

[15] M.G. Gee, P. Tomlins, A. Calver, R.H. Darling and M. RidesA, “A new friction measurement system for the frictional component of touch,” Wear, vol. 259, no. 7–12, pp. 1437–1442, 2005.

[16] M.J. Adams et al., “Finger pad friction and its role in grip and touch,” Journal of The Royal Society Interface, vol. 10, no. 80, pp. 1–19, 2013.

[17] M. Biet, F. Giraud and B. Lemaire-Semail, “Implementation of tactile feedback by modifying the perceived friction,” The European Physical Journal Applied Physics, vol. 43, no. 1, pp. 123–135, 2008.

[18] M. Biet, F. Giraud and B. Lemaire-Semail, “Squeeze film effect for the design of an ultrasonic tactile plate,” IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 54, no. 12, pp. 2678–88, 2007.

[19] S. Coren, he left-hander syndrome. Vintage Books, New York, 1993.

[20] D. A. Torres et al., “PCA Model of Fundamental Acoustic Finger Force for Out-of-Plane Ultrasonic Vibration and its Correlation with Friction Reduction,” IEEE Transactions on Haptics, vol. 14, no. 3, pp. 551 - 563, 2021.

[21] F. Giraud, T. Hara, C. Giraud-Audine, M. Amberg, B. Lemaire-Semail, and M. Takasaki, “Evaluation of a friction reduction based haptic surface at high frequency,” In: Processing of IEEE Haptics Symposium, San Francisco, California, pp. 210–215, 2018.

[22] D. Gueorguiev, E. Vezzoli, A. Mouraux, B. Lemaire-Semail, and J. Thonnard, “The tactile perception of transientchanges in friction,” The Royal Society, vol. 14, no. 137, 2017.

[23] M. Fehlberg, E. Monfort, S. Saikumar, K. Drewing and R. Bennewitz, “Perceptual Constancy in the Speed Dependence of Friction During Active Tactile Exploration,” IEEE Transactions on Haptics, vol. 17, no. 4, pp. 957–963, 2024.

[24] D. Gueorguiev, S. Bochereau, A. Mouraux and V. Hayward and J. Thonnard, “Touch uses frictional cues to discriminate flat materials,” Scientific Reports, vol. 6, no. 25553, 2016.

[25] J. Monnoyer, E. Diaz, C. Bourdin and M. Wiertlewski, “Optimal Skin Impedance Promotes Perception of Ultrasonic Switches,” 2017 IEEE World Haptics Conference, pp. 130-135, Germany, 2017.

[26] T. André, P. Lefèvre and J. L. Thonnard, “Fingertip moisture is optimally modulated during object manipulation,” Journal of Neurophysiology, vol. 103, no. 1, pp. 402–408, 2010.

[27] L. Willemet, K. Kanzari, J.Monnoyer, I. Birznieks and M. Wiertlewski, “Initial contact shapes the perception of friction,” Biophysics and Computational Biology, vol. 118, no. 49, e2109109118, 2021.

[28] X. Liu et al, “Measuring contact area in a sliding human finger-pad contact,” Skin Research and Technology, vol. 24, no. 1, pp. 31–44, 2018.

[29] A. Abdouni, G. Moreau, R. Vargiolu and H. Zahouani, “Static and active tactile perception and touch anisotropy: aging and gender effect,” Scientific Reports, vol. 8, no. 14240, 2018, doi: https://doi.org/10.1038/s41598-018-32724-4.

[30] A. Abdouni et al., “Biophysical properties of the human finger for touch comprehension: influences of ageing and gender,” Royal Society Open Science, vol. 4, no. 8, 2017, doi: https://doi.org/10.1098/rsos.170321.