Effects of Tactile Textures on Preference in Visuo-Tactile Exploration

WANJOO PARK, MUHAMMAD HASSAN JAMIL, RUTH GHIDEY GEBREMEDHIN, and MOHAMAD EID, New York University Abu Dhabi

The use of haptic technologies has recently become immensely essential in Human-Computer Interaction to improve user experience and performance. With the introduction of tactile feedback on a touchscreen device, commonly known as surface haptics, several applications and interaction paradigms have become a reality. However, the effects of tactile feedback on the preference of 2D images in visuo-tactile exploration task on touchscreen devices remain largely unknown. In this study, we investigated differences of preference score (the tendency of participants to like/dislike a 2D image based on its visual and tactile properties), reach time, interaction time, and response time under four conditions of feedback: no tactile feedback, high-quality of tactile information (sharp tactile texture), low-quality of tactile information (blurred tactile texture), and incorrect tactile information (mismatch tactile texture). The tactile feedback is rendered in the form of roughness that is simulated by modulating the friction between the finger and the surface and is derived from the 2D image. Thirty-six participants completed visuo-tactile exploration tasks for a total of 36 trials (3 2D images × 4 tactile textures × 3 repetitions). Results showed that the presence of tactile feedback enhanced users' preference (tactile feedback conditions were rated significantly higher than the no tactile feedback condition for preference regardless of the quality/correctness of tactile feedback). This finding is also supported through results from self-reporting where 88.89% of participants preferred to experience the 2D image with tactile feedback. Additionally, the presence of tactile feedback resulted in significantly larger interaction time and response time compared to the no tactile feedback condition. Furthermore, the quality and correctness of tactile information significantly impacted the preference rating (sharp tactile textures were rated statistically higher than blurred tactile and mismatched tactile textures). All of these findings demonstrate that tactile feedback plays a crucial role in users' preference and thus motivates further the development of surface haptic technologies.

CCS Concepts: • **Human-centered computing** → *Empirical studies in interaction design*;

Additional Key Words and Phrases: Haptic texture, tactile perception, affective computing

ACM Reference format:
Wanjoo Park, Muhammad Hassan Jamil, Gebremedhin Ruth Ghidey, and Mohamad Eid. 2021. Effects of Tactile Textures on Preference in Visuo-Tactile Exploration. *ACM Trans. Appl. Percept.* 18, 2, Article 9 (May 2021), 13 pages.
https://doi.org/10.1145/3449065

9

1 INTRODUCTION

Touchscreen devices, such as tablets and smartphones, have become a commonplace technology in many of our daily lives. Touchscreen technologies are overwhelmingly based on audio-visual interaction. Relying on

Authors' address: W. Park, M. H. Jamil, R. G. Gebremedhin, and M. Eid, New York University Abu Dhabi, P.O. Box 129188, Saadiyat Island, Abu Dhabi, United Arab Emirates; emails: {wanjoo, hassan.jamil, ruth.gebremedhin, mohamad.eid}@nyu.edu.

1544-3558/2021/05-ART9 $15.00
https://doi.org/10.1145/3449065

audio-visual cues can be ineffective in mobile applications due to small screen size, ambient noise, social restrictions, the demand for other real-word tasks, and the need for novel applications [21]. With only audio-visual interaction, one important usability feature is lost: the tactile feedback [2]. For instance, it was found that the users' attention to audio-visual feedback is attenuated if no tactile feedback is associated with graphical controls such as buttons, switches, and knobs [7]. Furthermore, the performance also degrades in text entry tasks when tactile feedback is lost, such as when typing using a soft keyboard [6, 15].

An effective way to address the issue of lacking tactile feedback involves rendering artificial tactile feedback directly on the screen (preferably perceivable with a bare finger [9]), which has led to an emerging field of research called *surface haptics* [26]. Surface haptics technologies strive to control the interaction forces between the user's fingertip and the surface to simulate physical properties such as roughness and friction [4, 5, 10]. Most existing technologies are focused on modulating friction that encodes roughness when a user's fingertip slides on a surface to simulate haptic texture. The integration of tactile feedback into touchscreen devices will enable new applications in user interface design, ranging from online shopping to gaming and entertainment, education, and arts, in addition to supporting visually impaired users. A recent literature review of surface haptics technologies is found in the work of Basdogan et al. [3].

Preference is an important usability factor that influences the user experience and performance [22]. The sense of touch plays a prominent role in defining the preference value of a tangible object, as corroborated by several neurocognitive studies [19, 23, 29]. For instance, when buying furniture, people often change their perception of a couch's comfort after sitting on it and feeling its texture, causing people to associate their decision regarding the purchase with the tactile properties of the object [27].

Previous studies demonstrated that the physical properties of an object's surface significantly influence preference evaluation. For example, surfaces with high compliance are liked [8], whereas wet surfaces [28] or surfaces with large friction coefficient [18] are rated as disgusting or unpleasant. Furthermore, the user behavior such as average velocity, interaction time, and interaction forces are correlated with the perception of the physical properties and eventually the preference evaluation [35].

The relationship between tactile feedback on a touchscreen device and the preference evaluation remains unclear. The current study is primarily interested in examining the role of friction-based tactile feedback in preference evaluation of 2D images on touchscreen devices. We define preference as the tendency of participants to like or dislike a 2D image based on its visual and/or tactile properties. The following hypotheses are examined:

(1) Tactile feedback has an impact on the preference for 2D images rendered on a touchscreen device. Two conditions named the *no tactile* and *sharp tactile feedback* conditions (with and without tactile feedback) are developed to test this hypothesis.
(2) The quality of tactile information influences the preference of 2D images. Two conditions with sharp and blurred tactile information are included in the study to address this hypothesis.
(3) The accuracy of tactile information plays a role in the preference ratings of 2D images. To test this hypothesis, a condition of incorrect tactile information is included where mismatching visuo-tactile information is displayed on the touchscreen.

The remainder of the article is organized as follows. Section 2 presents the experimental method and material to examine the preference of tactile textures. In Section 3, the results of behavior data and exit survey are presented and thoroughly analyzed. Section 4 presents a general discussion about the results. Finally, Section 5 provides a summary of the findings of the study and perspectives for future work.

2 METHODS AND MATERIALS

Figure 1 shows the graphical user interface for the experimental application developed for this study. The application displays a 2D image along with an associated tactile texture on the touchscreen, depending on the tested

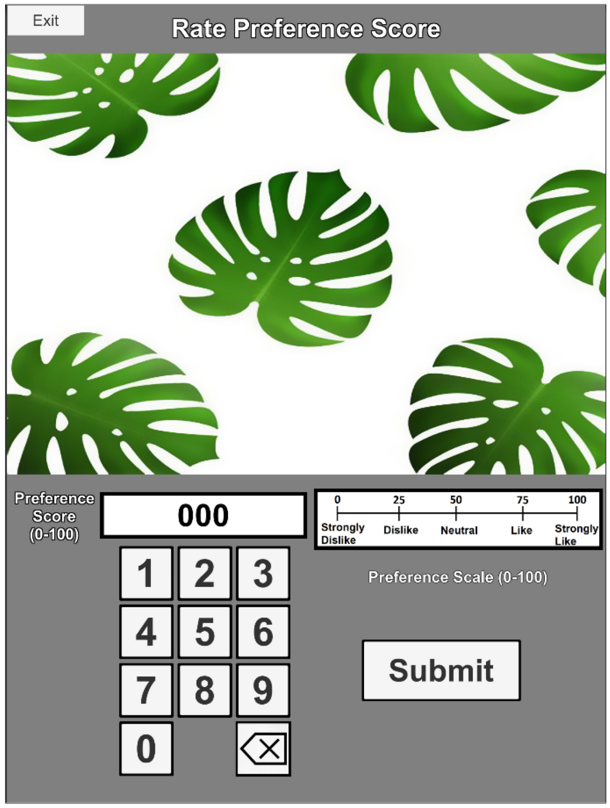


Fig. 1. Graphical user interface for the experimental application.

condition. The application displays the visuo-tactile information on the touchscreen device, prompts the users to experience the 2D image via touch using the index finger, and use a touchpad to rate their preference of the 2D image (how much they like/dislike it with visual or visuo-tactile feedback) on a scale of 0 (strongly dislike) to 100 (strongly like). Once the user submits his or her response, the application displays the next image. The application was developed with Unity3D[1] game engine using C# programming language.

The TanvasTouch device was used to provide tactile feedback along with the visual feedback. The device utilizes an electrostatic display that modulates the friction force between a fingertip and a physical display panel to simulate surface texture [24, 25]. As shown in Figure 2, the device is composed of a transparent electrode sheet placed onto a glass plate. The electrode sheet layer is coated with an insulator layer. When the electrode layer is excited with an electrical signal (Vs), an electrically induced attractive force named the electrostatic force (Fe) is developed between the finger and the underlying electrode along the normal direction of the touchscreen plane. As the finger slides along the surface, the electrostatic force (Fe) is controlled via the applied voltage (Vs) to modulate the friction force (Fr) and thus create a perceived texture. The amplitude and frequency of the friction force (Fr) are controlled by the amplitude and frequency of the applied voltage (Vs). A sinusoidal voltage of 140-V peak amplitude and 10-Hz frequency is applied, which produces a maximum friction force of around 0.1 N. The peak voltage is varied between 0 and 140 V to produce friction force between 0 and 0.1 N, depending on the corresponding pixel value of the tactile texture image (black corresponds to no friction, whereas white

[1]https://unity.com.

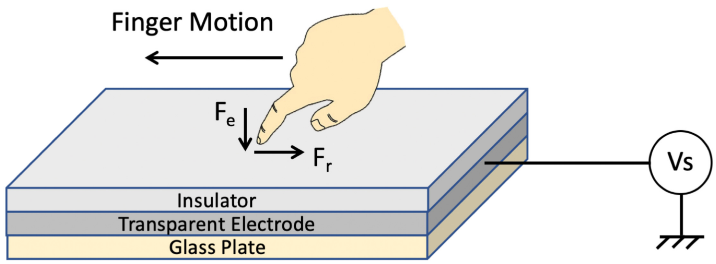


Fig. 2. Electrostatic tactile display. Fe and Fr indicate the electrostatic force and the dynamic friction force, respectively. Vs indicates the applied voltage.

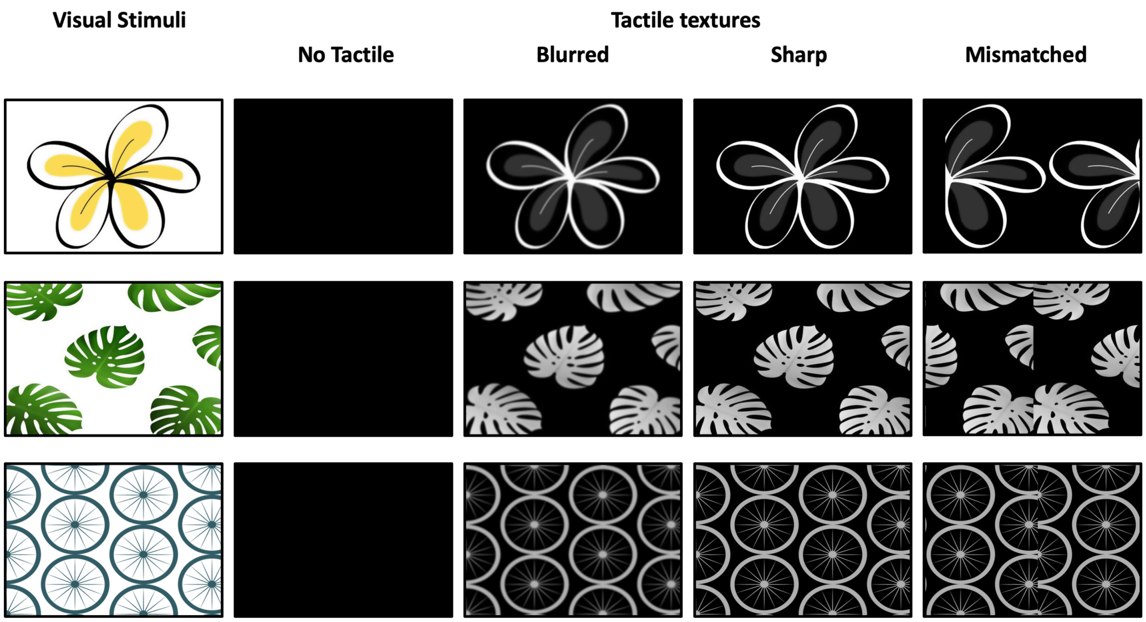
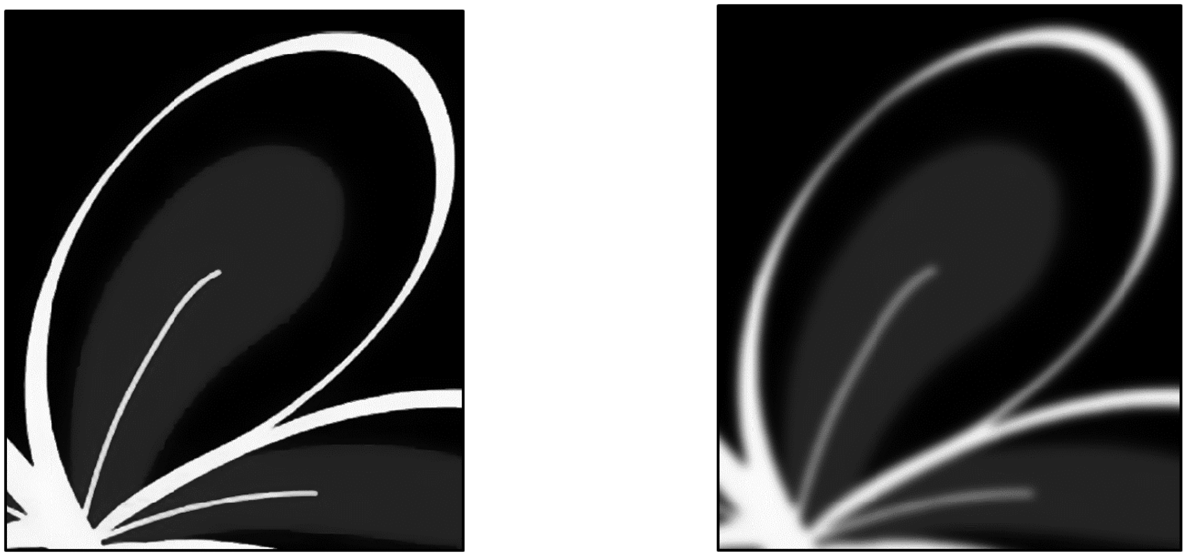


Fig. 3. Visual stimuli and tactile textures utilized in the study.

corresponds to maximum friction). There is no electric connection between the device and the user's hand. Note that the exact friction force varies depending on several factors such as the finger bio-mechanics and finger speed [24]. It is also worth noting that this device provides a single point of tactile interaction due to the fact that the electrostatic force is rendered uniformly through the entire screen surface. Another limitation of this technology is that the tactile stimulus is clearly perceptible when the surface is laterally scanned, but not when the finger is stationary.

2.1 Visual and Tactile Stimuli

The visual stimuli (2D images) for this experiment are selected based on color, shape, and two textural features, namely regularity and roughness [33]. Three 2D images are considered: a yellow flower, green leaves, and a bicycle-wheel pattern, as shown in Figure 3. The yellow flower image has a variation of colors, an object-centered shape that stands out prominently in the foreground (the flower object), and consists of round petals that are known to have a soft feel when touched. The green leaves image uses a different color, has split lines and sharp



(a) Sharp (b) Blurred

Fig. 4. Sharp and blurred tactile textures zoomed view.

parts for high roughness, and represents an irregular texture pattern. The bicycle-wheel image shows a regular pattern of circles and straight lines with the rough texture. A pilot study was conducted to confirm that the visual stimuli of these images did not affect the preference rating (no significant difference in preference score is found among the three images).

Tactile textures were generated (converted colored 2D images to 8-bit grayscale images) and manipulated in the graphics editing software[2] to create four different tactile texture variations. Visual and tactile textures used has a display resolution of 1536 × 1080 pixels. TanvasTouch device has a display resolution of 1536 × 2048 pixels with a density of 320 dots per inch. Tactile textures for the TanvasTouch device are grayscale images with pixel values being the intensity of the frictional tactile feedback. A pixel value of 0 yields no frictional variations while exploring the surface (the user experiences constant friction with the touchscreen surface), whereas a pixel value of 255 represents maximum frictional intensity on a tactile surface (a combination of the simulated friction and the constant friction with the surface). A plain black image was used to represent the no tactile feedback condition. The intensity of friction feedback is defined by the pixel value of the tactile texture that corresponds to the interaction point between the user's finger and the touchscreen. Visual and converted tactile textures had the same pixel resolution and scale. A sharp tactile texture was created by inverting the grayscale image obtained from the 2D image. To create the blurred tactile texture, a Gaussian blur filter (standard deviation of 5 pixels) was applied to the sharp tactile texture to soften the edges, hence smoothing the tactile feedback while exploring with a fingertip. It is worth mentioning that the blurred tactile texture is verified through pilot testing to be clearly perceivable; however, it is not clearly matching the respective visual texture. A mismatched tactile texture was created by splitting the sharp texture vertically and then swapping the two halves. The details regarding tactile textures to corresponding visual stimulation are highlighted in Figure 3. A close-up of the flower image is shown in Figure 4 to highlight the blurring effect.

[2]Adobe Photoshop CC 2018.

2.2 Participants

A group of 36 participants (18 females; mean and standard deviation of age is 21.75 ± 3.47) were enrolled in this study. Three of the participants were left-handed, whereas the rest were right-handed. All of the participants were students from New York University Abu Dhabi, recruited by an online call for participants. The inclusion criteria for participants were an age range of 18 to 55 years and normal (or corrected-to-normal) vision. The exclusion criterion was a person with orthopedic hand conditions. All participants were informed about the purpose of the experiment, and written informed consent was obtained prior to participation. The study was carried out with an approved protocol by the New York University Abu Dhabi Institutional Review Board (FWA: #024-2019).

2.3 Procedure and Evaluation Metrics

The experimental study involved examining three 2D images with four tactile texture configurations. The images were presented in a random sequence of a combined visual stimulus (three images) and corresponding tactile stimulus for that image (no tactile texture, sharp tactile texture, blurred tactile texture, and mismatched tactile texture) to minimize bias and learning effects.

The procedure for the study was as follows. After signing the consent form describing the purpose of the experiment and what participants are expected to do, participants were shortly briefed about the experimental setup. To provide tactile stimuli clearly, participants were asked to clean their index finger with an ethanol swab. We also cleaned the surface of the TanvasTouch device with another ethanol swab before the experiment. The experiment started by displaying a 2D image along with the elected tactile texture as shown in Figure 3. Participants were then asked to explore the tactile texture with the index finger for a minimum of 3 seconds. Each combination of visual/tactile stimuli appeared three times, and therefore participants were asked to respond to a total of 36 trials (3 2D images $\times$ 4 tactile textures $\times$ 3 repetitions). The trials were provided by randomized order in each repetition. After each trial, participants were asked to rate their preference of the stimuli on a scale from 0 to 100 (strongly dislike to strongly like). The participants took about 15 minutes to complete the entire experiment. Upon completion, the participants were given an exit survey (Appendix A, Table 2) to evaluate their quality of experience. The experiment data is publicly available,[3] along with documentation describing all parameters recorded during the experiment.

To evaluate participants' behavior, the software was able to collect the preference score, the reach time (the time it takes the user to move his or her hand after seeing the image/tactile texture to touch the screen in order to examine the tactile feedback), the interaction time (time spent by the user touching the screen), and the response time (time from removing the finger from the touchscreen until providing a preference score). The reach time is utilized to capture how quickly the user moves to examine the tactile properties associated with the visual stimulus displayed on the touchscreen device. The reach time is an indication of the user's preference based on the visual properties of the three images, which if significantly different would influence the preferences associated with the tactile feedback properties. A longer interaction time with the touchscreen device implied that participants were interested in learning more about the tactile properties of the texture. Interaction time would also be interesting to capture how participants responded to mismatch tactile information by spending even more time to resolve media conflicts (visuo-tactile mismatch). The response time indicates how confident participants were about their response.

An exit survey was designed to evaluate the subjective experience of the participants, as shown in Appendix A. Participants were asked if they could feel the presence and absence of tactile feedback, if they experienced more than one tactile textures for the same image, and the number of different tactile textures experienced for the same image. In addition to that, participants were asked if they preferred the interaction with or without

[3] https://osf.io/sygt4/.

Table 1. Means and Standard Errors of Evaluation Metrics for All Participants

Tactile Texture	Preference Score (%)	Reach Time (s)	Interaction Time (s)	Response Time (s)
No tactile	32.56 ± 3.67	1.58 ± 0.16	6.41 ± 0.40	3.90 ± 0.27
Blurred	59.84 ± 2.86	1.41 ± 0.06	9.44 ± 0.70	5.45 ± 0.39
Sharp	68.70 ± 2.64	1.56 ± 0.07	9.52 ± 0.74	5.46 ± 0.35
Mismatched	59.77 ± 2.91	1.63 ± 0.13	9.98 ± 0.78	5.29 ± 0.41

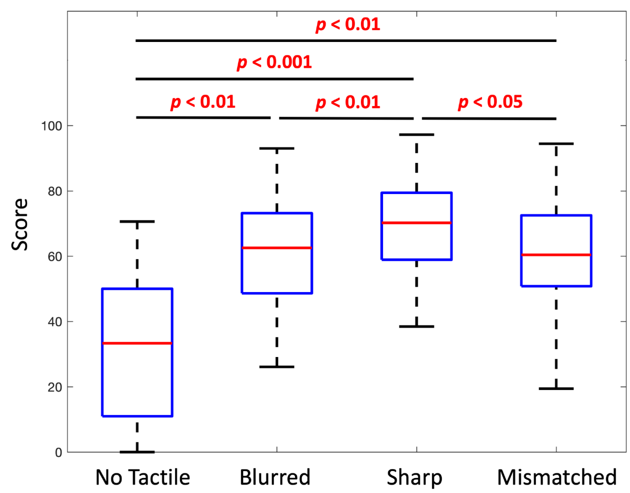


Fig. 5. Preference scores using Tukey's boxplot [20]. p-Values from the Friedman test, Bonferroni correction. This boxplot is made up of five components: red lines in the box for the median, two edges of the box for the upper (Q3) and lower (Q1) quartiles, and two whiskers extend to a maximum of $1.5 \times$ IQR beyond the box. IQR = Q3 − Q1.

tactile feedback. Participants were also asked if they recognized the mismatched tactile texture compared to the 2D image and the approximate percentage occurrence of the mismatched tactile experience. Finally, participants had an opportunity to provide any additional comments regarding the tactile experience.

We obtained data from 36 participants. Participants experienced three times all of the conditions with the visual and tactile stimuli combination; the average over these three repetitions is used in the data analysis. Therefore, 12 data points for preference score, reach time, interaction time, and response time were analyzed for each participant. Since the data were not normally distributed (Jarque-Bera normality test), non-parametric methods were utilized for statistical analysis. The Friedman test was considered to investigate differences in preference and behavior data for the four conditions, and the multiple comparison issue was corrected by Bonferroni correction. In addition, the exit survey served to cross validate performance using subjective feedback.

3 RESULTS

3.1 Quantitative Performance Evaluation

A summary of the means and standard errors of the performance metrics used to assess the experience of the participants is presented in Table 1.

3.1.1 Preference Score. The distribution of preference scores for all participants under the four testing conditions (no tactile, sharp tactile, blurred tactile, and mismatch tactile) are calculated and presented in Figure 5.

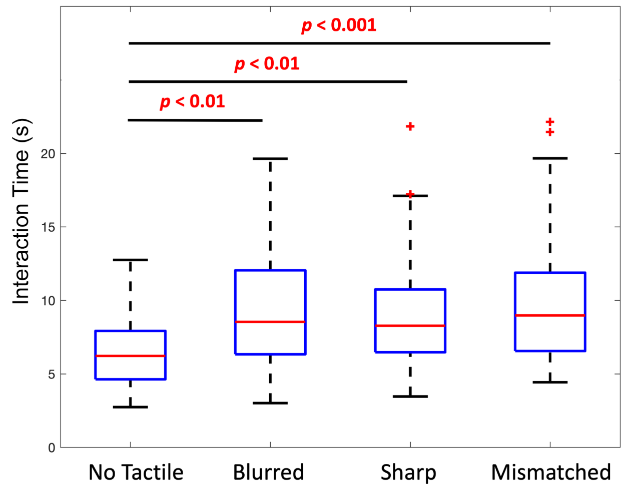


Fig. 6. Interaction time (in seconds) using Tukey's boxplot. p-Values from the Friedman test, Bonferroni correction. This boxplot is made up of six components: red lines in the box for the median, two edges of the box for the upper (Q3) and lower (Q1) quartiles, and two whiskers extend to a maximum of 1.5 × IQR beyond the box. IQR = Q3 − Q1, and individual points for outliers beyond the whisker.

Participants gave images with no tactile feedback their lowest preference rating compared to the other three conditions, whereas images with sharp tactile feedback received the highest preference scores. The differences between the no tactile condition and the other three conditions with tactile feedback were statistically significant (Friedman test, Bonferroni correction, $p < 0.01$). This finding demonstrates that participants preferred tactile feedback regardless of the quality/correctness of tactile information.

Examining the three conditions involving tactile feedback, there was a statistically significant difference between sharp tactile and blurred tactile conditions, where the sharp tactile condition was rated significantly higher (Friedman test, Bonferroni correction, $p < 0.01$). The same is found between the sharp tactile and the mismatch tactile conditions (Friedman test, Bonferroni correction, $p < 0.05$). These results show that accurate tactile information (the sharp tactile feedback condition) plays a crucial role in influencing the preference for 2D images after a visuo-tactile exploration task.

3.1.2 Reach, Interaction, and Response Time. The means and standard errors of the reach time for all participants under the four conditions are calculated and presented in Table 1. There were no statistically significant differences in reach time for the four conditions. Given the fact that reach time is associated with the visual properties of the image, these results demonstrate that there are no statistical differences in preference between the images based on their visual properties. Therefore, any significant differences in preference in interaction time or response time are mostly associated with the tactile experience.

Comparing the four conditions, there were statistically significant differences in interaction time among the three conditions with tactile feedback (sharp, blurred, and mismatch) compared to the no tactile feedback condition, with the tactile feedback conditions having larger interaction time, as shown in Figure 6 (Friedman test, Bonferroni correction, $p < 0.01$). However, there were no statistically significant differences between the three tactile feedback conditions. Users spent more time touching the screen when tactile information was available, regardless of the quality or the correctness of the tactile information. Users were actively seeking more information about the texture by exploring its tactile properties.

Similarly, the means and standard errors of the response time were calculated for the four conditions and are shown in Table 1. Comparing the four conditions, there were statistically significant differences between sharp

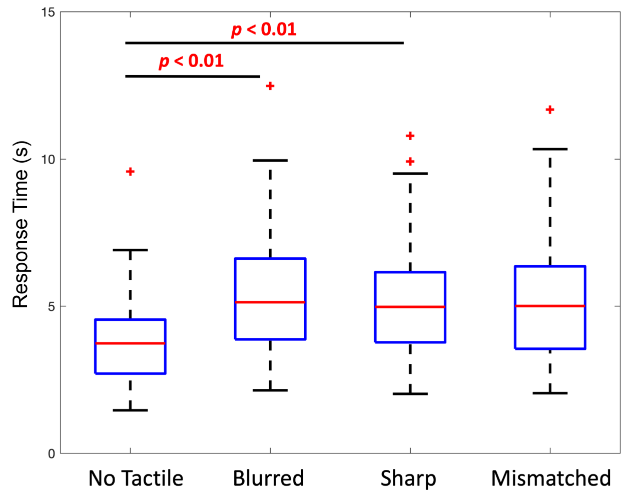


Fig. 7. Response time (in seconds) using Tukey's boxplot. p-Values from the Friedman test, Bonferroni correction. This boxplot is made up of six components: red lines in the box for the median, two edges of the box for the upper (Q3) and lower (Q1) quartiles, and two whiskers extend to a maximum of 1.5 × IQR beyond the box. IQR = Q3 − Q1, and individual points for outliers beyond the whisker.

and blurred tactile feedback conditions compared to the no tactile feedback condition, with the sharp/blurred tactile feedback conditions having larger response time, as shown in Figure 7 (Friedman test, Bonferroni correction, $p < 0.01$). However, there was no statistical difference between the mismatch tactile feedback condition and the no tactile feedback condition. Users took more time to provide their preference score when correct multi-modal data was available (visual and tactile) compared to when only visual information was available.

3.2 Exit Survey

All participants were able to recognize the presence/absence of tactile feedback during the interaction. Furthermore, 88.89% of participants (32 out of 36) preferred experiencing the visual stimuli with tactile feedback, whereas only four participants preferred no tactile feedback. This was also cross validated with the average preference scores for these four participants where the average preference scores are very similar with or without tactile feedback (means and standard errors: 60.16 ± 4.21, 60.39 ± 8.01, 56.42 ± 8.25, and 58.11 ± 8.60 for no tactile, blurred tactile, sharp tactile, and mismatched tactile conditions, respectively).

Participants were also asked if they could recognize more than one condition of tactile feedback and how many they recognized. A total of 91.67% of participants (33 out of 36) recognized that there was more than one condition of tactile feedback. Of these, 48.48% of participants (16 out of 33) correctly identified the three tactile conditions. A total of 15.15% (5 out of 33) responded that they could feel two tactile conditions, and 27.27% (9 out of 33) suggested that they could feel more than three conditions (four or five). A total of 9% gave a range of conditions (2 out of 33 gave the range of 3 to 4 and 1 out of 33 gave the range of 2 to 3).

Participants were also asked whether they could recognize any mismatch between the visual tactile textures of the 2D image. They were also asked about the percentage of times when mismatched visual/tactile information is presented. A total of 77.78% of participants (28 out of 36) recognized that the visual and tactile stimuli were sometimes mismatched. The perceived rate of the percentage of time mismatched stimuli was presented is shown in Figure 8, where 30.5% of participants (or 11 out of 36) recognized when the tactile feedback did not match the visual texture, which is well above the chance level.

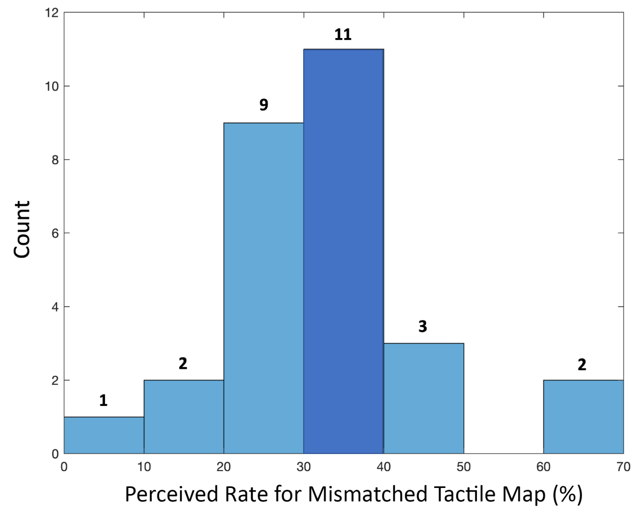


Fig. 8. In the exit survey, the perceived percentage of mismatched tactile texture (excluding the no tactile feedback condition). The dark blue color indicates the correct answer.

Participants were given the chance to provide any further feedback. Some participants commented that tactile feedback made the content more engaging. Others commented on the need for simulating edges since that makes surface textures significantly more realistic (the TanvasTouch device cannot support that due to technology limitations). Finally, some of the novice users described the tactile texture sensation as electric shock kind of feedback. That was particularly true for the four participants who preferred the no tactile feedback condition.

4 DISCUSSION

All but 4 of the 36 participants said they preferred tactile feedback. Figure 5 shows that participants rated preference significantly higher when tactile feedback was available on the touchscreen device regardless of the tactile condition (blurred, sharp, or mismatch). Thus, the first hypothesis, about whether the presence of tactile information influences preference, is accepted and shows that tactile feedback has a positive effect on preference. This finding is in line with previous research that surface haptics improves the quality of user experience [11]. In addition, in the response time of Table 1, no tactile feedback resulted in significantly shorter response time than tactile feedback conditions. It is interpreted that participants gave a low preference score to no tactile feedback with high confidence and certainty [31].

The second hypothesis is that the quality of tactile information influences preference. Results showed significant differences in preference score between the cases of blurred and sharp tactile feedback (Figure 5). Sharp tactile stimulation is a high quality of tactile information and thus is clearly perceivable. However, the blurred tactile texture provides a low quality of tactile information and thus is perceptually unclear. Therefore, the second hypothesis is accepted. In fact, it was expected that more interaction time would be required to confirm accurate information for tactile feedback of blurred texture. Despite providing false tactile information called *mismatched tactile feedback*, interaction time did not show a significant difference in three conditions of tactile feedback. This is consistent with previous findings that when people experience visuo-tactile stimulation, they rely more on vision than on touch [13].

The results of this study do not provide any evidence about the third hypothesis that incorrect tactile information (the mismatch tactile feedback condition) affects a user's preference. This is because there was a significant difference in preference score between the cases of sharp and mismatched tactile feedback; however, there was no significant difference between the cases of blurred and mismatched tactile feedback. Furthermore, mismatch tactile feedback is not significantly different from that of blurred and sharp tactile feedback in the interaction and response time. This supports the findings that the visuo-tactile stimulation is more dependent on vision than touch. More interestingly, in the exit survey, 91.67% of participants felt different tactile feedback in one visual stimulation and 77.78% of participants recognized unexpected tactile feedback. However, the rate of mismatched tactile feedback they thought was very different and only 11 participants (30.56 %) had the correct rate. Therefore, mismatched tactile feedback awareness may have a weak effect on the preference score, but it is not obvious because there was no significant difference in preference between blurred and mismatched tactile feedback.

Gender effects in quantitative evaluation (preference score, reach time, interaction time, and response time) and subjective feedback were examined. Even though previous studies linked gender to how people perceive and respond to tactile sensation [1, 12]—for instance, that women usually have a more acute sense of touch than men [14]—no statistically significant differences were found between the male and female groups. Therefore, the current study does not provide any evidence on gender effects on preference in visuo-tactile exploration on touchscreen devices. This could be due to the cultural diversity of the participants (highly diversified student body) and the relatively small number of participants per group.

Recently, various tactile displays have been developed in both academia and industry [16, 30] and with the driving force of Tactile Internet [32, 34], it is crucial to guide the design of surface haptic technologies to provide convincing tactile experiences at the lowest cost/hardware complexity. Low-resolution tactile feedback will have a great impact on users' preference because the perceptual differences are not great (between sharp, blurred, and mismatch). Nevertheless, creating a suitable tactile sensation according to the characteristics of the target group is obviously an important factor that can influence user preference [17].

Finally, it was interesting to observe that there were no statistically significant differences between the blurred tactile and mismatch tactile conditions. It seems that a blurred tactile texture is not as clearly recognizable and it became confused with incorrect tactile textures. This may also be attributed to the suggestibility effect where participants might have thought that they were encouraged to rate stimuli with tactile feedback more favorably.

Although there are clear results in this study, some limitations should be noted. We used Gaussian blurring to simulate the low quality of tactile information, and other techniques may produce slightly different results depending on how the tactile information is processed. A particular method for creating incorrect tactile information is utilized (split the image vertically in two halves and swapping). Other methods of creating incorrect tactile information may lead to different results. Furthermore, the current study utilized the TanvasTouch device that creates texture perception using electrostatic forces. Conducting the same experiment with other devices utilizing different technologies such as ultrasound or electrovibration may result in slightly different findings. Finally, the study utilized a limited number of visual stimuli (three 2D images), and having a wider variety of visual stimuli, including natural or synthetic, humans or objects, and familiar and non-familiar contents, could largely influence these results. This indeed makes an interesting perspective for future work.

5 CONCLUSION

In this study, we examined how tactile feedback, provided on a touchscreen device, influences users' preference of 2D images in a visuo-tactile exploration task. Participants preferred images that they could feel. The high-quality of tactile information (sharp tactile feedback) was the most preferred in comparison with the low-quality tactile feedback (blurred tactile feedback) or incorrect tactile information (the mismatched tactile feedback condition). However, there was no difference in preference between the low quality of tactile information and incorrect tactile information conditions. We conclude that the quality of tactile feedback and the accuracy of tactile information in visuo-tactile stimulation plays a crucial role in influencing the user's preference. However, we also conclude that the high-quality tactile display may not be required in the presence of a high-resolution visual display.

Future work includes developing a perceptual model to define thresholds for the quality of tactile textures necessary to have a satisfactory tactile experience. Further experiments would be conducted to verify the proposed model. It also would be interesting to extend the current study to examine the relationship between tactile textures and other affective values such as arousal, valence, or dominance. Finally, the relationship between the content of the 2D image and the effectiveness of tactile feedback is worth examining.

APPENDIX

A EXIT SURVEY

Table 2. Exit Survey

No.	Question
1.	Do you think that you could NOT feel the tactile feedback sometimes during the experiment?
2.	If yes, which one is more aesthetically pleasing, one with tactile feedback or the one without tactile feedback?
3.	Did you feel more than one tactile feedback for the same image?
4.	If yes, how many tactile feedback do you feel for the same image? (exclude no tactile feedback)
5.	Did you feel something strange (or wrong / mismatched) haptic feedback?
6.	If yes, can you guess the rate (%) of this strange tactile feedback for the same image? (exclude no tactile feedback)
7.	If you have any other comments

REFERENCES

[1] Abdenaceur Abdouni, Gilles Moreau, Roberto Vargiolu, and Hassan Zahouani. 2018. Static and active tactile perception and touch anisotropy: Aging and gender effect. *Scientific Reports* 8, 1 (2018), 14240.

[2] Bruce Banter. 2010. Touch screens and touch surfaces are enriched by haptic force-feedback. *Information Display* 26, 3 (2010), 26–30.

[3] Cagatay Basdogan, Frédéric Giraud, Vincent Levesque, and Seungmoon Choi. 2020. A review of surface haptics: Enabling tactile effects on touch surfaces. *IEEE Transactions on Haptics* 13, 3 (2020), 450–470.

[4] Olivier Bau, Ivan Poupyrev, Ali Israr, and Chris Harrison. 2010. TeslaTouch: Electrovibration for touch surfaces. In *Proceedings of the 23nd Annual ACM Symposium on User Interface Software and Technology*. 283–292.

[5] Séréna Bochereau, Stephen Sinclair, and Vincent Hayward. 2018. Perceptual constancy in the reproduction of virtual tactile textures with surface displays. *ACM Transactions on Applied Perception* 15, 2 (2018), 10.

[6] Stephen Brewster, Faraz Chohan, and Lorna Brown. 2007. Tactile feedback for mobile interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 159–162.

[7] William Buxton, Ralph Hill, and Peter Rowley. 1985. Issues and techniques in touch-sensitive tablet input. In *Proceedings of the 12th Annual Conference on Computer Graphics and Interactive Techniques*. 215–224.

[8] Xiaojuan Chen, Fei Shao, C. J. Barnes, Tom Childs, and Brian Henson. 2009. Exploring relationships between touch perception and surface physical properties. *International Journal of Design* 3, 2 (2009), 67–76.

[9] Erik C. Chubb, J. Edward Colgate, and Michael A. Peshkin. 2010. Shiverpad: A glass haptic surface that produces shear force on a bare finger. *IEEE Transactions on Haptics* 3, 3 (2010), 189–198.

[10] Frédéric Giraud, Tomohiro Hara, Christophe Giraud-Audine, Michel Amberg, Betty Lemaire-Semail, and Masaya Takasaki. 2018. Evaluation of a friction reduction based haptic surface at high frequency. In *Proceedings of the 2018 IEEE Haptics Symposium (HAPTICS'18)*. IEEE, Los Alamitos, CA, 210–215.

[11] Abdelwahab Hamam, Mohamad Eid, and Abdulmotaleb El Saddik. 2013. Effect of kinesthetic and tactile haptic feedback on the quality of experience of edutainment applications. *Multimedia Tools and Applications* 67, 2 (2013), 455–472.

[12] Mikel L. Hartman and Harve E. Rawson. 1992. Differences in and correlates of sensation seeking in male and female athletes and nonathletes. *Personality and Individual Differences* 13, 7 (1992), 805–812.

[13] David Hecht and Miriam Reiner. 2009. Sensory dominance in combinations of audio, visual and haptic stimuli. *Experimental Brain Research* 193, 2 (2009), 307–314.

[14] Rachel S. Herz and Elizabeth D. Cahill. 1997. Differential use of sensory information in sexual behavior as a function of gender. *Human Nature* 8, 3 (1997), 275–286.

[15] Eve Hoggan, Stephen A. Brewster, and Jody Johnston. 2008. Investigating the effectiveness of tactile feedback for mobile touchscreens. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1573–1582.

[16] Jeonggoo Kang, Heewon Kim, Seungmoon Choi, Ki-Duk Kim, and Jeha Ryu. 2016. Investigation on low voltage operation of electrovibration display. *IEEE Transactions on Haptics* 10, 3 (2016), 371–381.

[17] Dong-Ryul Kim, Ki-Hwan Jang, Won-Shik Chu, Dahyun Choi, Woo Il Lee, Caroline Sunyong Lee, and Sung-Hoon Ahn. 2019. Preference for case materials in smart devices: A comparative study in Korea, USA, and Tanzania. *International Journal of Precision Engineering and Manufacturing* 20, 5 (2019), 749–767.

[18] Anne Klöcker, Calogero Maria Oddo, Domenico Camboni, Massimo Penta, and Jean-Louis Thonnard. 2014. Physical factors influencing pleasant touch during passive fingertip stimulation. *PLoS ONE* 9, 7 (2014), e101361.

[19] Anne Klöcker, Michael Wiertlewski, Vincent Théate, Vincent Hayward, and Jean-Louis Thonnard. 2013. Physical factors influencing pleasant touch during tactile exploration. *PLoS ONE* 8, 11 (2013), e79085.

[20] Martin Krzywinski and Naomi Altman. 2014. Visualizing samples with box plots. *Nature Methods* 11 (2014), 119–120.

[21] Joseph Luk, Jerome Pasquero, Shannon Little, Karon MacLean, Vincent Levesque, and Vincent Hayward. 2006. A role for haptics in mobile interaction: Initial design using a handheld tactile display prototype. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 171–180.

[22] Emanuela Maggioni, Erika Agostinelli, and Marianna Obrist. 2017. Measuring the added value of haptic feedback. In *Proceedings of the 2017 9th International Conference on Quality of Multimedia Experience (QoMEX'17)*. IEEE, Los Alamitos, CA, 1–6.

[23] Francis McGlone, Johan Wessberg, and Håkan Olausson. 2014. Discriminative and affective touch: Sensing and feeling. *Neuron* 82, 4 (2014), 737–755.

[24] David J. Meyer, Michael A. Peshkin, and J. Edward Colgate. 2013. Fingertip friction modulation due to electrostatic attraction. In *Proceedings of the 2013 World Haptics Conference (WHC'13)*. IEEE, Los Alamitos, CA, 43–48.

[25] David J. Meyer, Michaël Wiertlewski, Michael A. Peshkin, and J. Edward Colgate. 2014. Dynamics of ultrasonic and electrostatic friction modulation for rendering texture on haptic surfaces. In *Proceedings of the 2014 IEEE Haptics Symposium (HAPTICS'14)*. IEEE, Los Alamitos, CA, 63–67.

[26] Joe Mullenbach, Craig Shultz, A. Marie Piper, Michael Peshkin, and J. Edward Colgate. 2013. TPad Fire: Surface haptic tablet. In *Proceedings of the Conference on Haptic and Audio Interaction Design (HAID'13)*.

[27] Richard L. Oliver and Gerald Linda. 1981. Effect of satisfaction and its antecedents on consumer preference and intention. In *NA—Advances in Consumer Research Volume 08,* K. B. Monroe (Ed.). Association for Consumer Research, Ann Arbor, MI, 88–93.

[28] Robert E. Oum, Debra Lieberman, and Alison Aylward. 2011. A feel for disgust: Tactile cues to pathogen presence. *Cognition and Emotion* 25, 4 (2011), 717–725.

[29] Wanjoo Park, Da-Hye Kim, Sung-Phil Kim, Jong-Hwan Lee, and Laehyun Kim. 2018. Gamma EEG correlates of haptic preferences for a dial interface. *IEEE Access* 6 (2018), 22324–22331.

[30] Craig D. Shultz, Michael A. Peshkin, and J. Edward Colgate. 2015. Surface haptics via electroadhesion: Expanding electrovibration with Johnsen and Rahbek. In *Proceedings of the 2015 IEEE World Haptics Conference (WHC'15)*. IEEE, Los Alamitos, CA, 57–62.

[31] Siegfried L. Sporer. 1993. Eyewitness identification accuracy, confidence, and decision times in simultaneous and sequential line-ups.*Journal of Applied Psychology* 78, 1 (1993), 22.

[32] Eckehard Steinbach, Matti Strese, Mohamad Eid, Xun Liu, Amit Bhardwaj, Qian Liu, Mohammad Al-Ja'afreh, et al. 2018. Haptic codecs for the Tactile Internet. *Proceedings of the IEEE* 107, 2 (2018), 447–470.

[33] Hideyuki Tamura, Shunji Mori, and Takashi Yamawaki. 1978. Textural features corresponding to visual perception. *IEEE Transactions on Systems, Man, and Cybernetics* 8, 6 (1978), 460–473.

[34] Martin Wollschlaeger, Thilo Sauter, and Juergen Jasperneite. 2017. The future of industrial communication: Automation networks in the era of the Internet of Things and Industry 4.0. *IEEE Industrial Electronics Magazine* 11, 1 (2017), 17–27.

[35] Takumi Yokosaka, Scinob Kuroki, Junji Watanabe, and Shin'ya Nishida. 2017. Estimating tactile perception by observing explorative hand motion of others. *IEEE Transactions on Haptics* 11, 2 (2017), 192–203.

Received January 2020; revised January 2021; accepted January 2021