This article has been accepted for publication in IEEE Transactions on Haptics. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TOH.2023.3310662

Toward Designing Haptic Displays for Desired Touch Targets: A Study of User Expectation for Haptic Properties via Crowdsourcing

Yusuke Ujitoko, and Yuki Ban

***Abstract*—Things that people desire to touch in daily life are known to be limited to a number of specific targets (e.g., cats). The utilization of haptic displays to provide the experience of touching such desired targets is expected to enhance people's quality of life. However, it is currently unclear which haptic properties (e.g., hardness and weight) of desired targets should be rendered with haptic displays, and how they should be rendered. To address these issues, we conducted an experiment with 600 Japanese participants via crowdsourcing. Among the 600 participants, we identified potential users of haptic displays and analyzed their responses for each target. For each desired target, we identified the haptic properties in relation to which a "need for consistency" was felt by potential users between their expectations and actual impressions during touching. We also identified the haptic properties in relation to which a "biased impression" was held by potential users for each target. For example, potential users responded that cats were soft and that the actual impression of softness during touching needed to be consistent with their impression. Our results provide insights into the design of haptic displays for realizing desired touch experiences.**

***Index Terms*—Haptic property, Touch desire, Haptic display, Biased impression, Need for consistency, Potential user.**

I. Introduction

In our daily lives, we can consume application services which involve our senses whenever we desire, for example, by listening to music or watching movies [1]. However, currently, there are no compelling consumer applications that provide the experience of touching targets (e.g., animals or objects) that people commonly desire to touch. Our aim is to use haptic technology to provide this desired touch experience and improve people's quality of life.

To provide desired touch experiences, it is crucial to understand people's touch desire. Our previous study analyzed touch desire using Twitter [2]. Our findings indicated that people's touch desires are concentrated on a limited range of targets, even though there are an infinite number of possible targets for physical touch in the real world. Developing haptic technologies that can simulate the experience of touching these desired targets has the potential to satisfy people's touch desire.

Yusuke Ujitoko is with the NTT Communication Science Laboratories, Nippon Telegraph and Telephone Corporation, Atsugi, Japan. E-mail: yusuke.ujitoko@gmail.com

Yuki Ban is with the Graduate School of Frontier Sciences, the University of Tokyo, Chiba, Japan. E-mail: ban@edu.k.u-tokyo.ac.jp

Manuscript received XXXXX XX, 2021

Two important questions need to be addressed if we are to develop haptic technologies that provide touch experiences for desired targets. Firstly, it is crucial to determine which haptic properties (e.g., weight and hardness) of a target (e.g., a cat) should be rendered. People with touch desires may have specific impressions for certain haptic properties, although not all rendered properties need be consistent with these imagined impressions. Therefore, it is important to investigate the "need for consistency" for each property to identify which properties need to be aligned with user impressions in order to create a satisfying haptic experience. For instance, accurately controlling only the hardness and fine roughness properties of a virtual cushion may suffice if individuals who desire to touch cushions only need consistency regarding these two properties for an effective haptic experience.

Secondly, it is essential to clarify how haptic properties should be rendered with haptic displays. A "biased impression" refers to a preconceived notion or expectation that users have about the haptic properties of a specific target, which may not necessarily align with the actual properties of the target. If we know that people have a "biased impression" in relation to certain haptic properties of a specific target, we can control the presentation of the touch experience with haptic technology in a way that is consistent with the biased impression. For example, if users have an expectation that a cushion will be soft, we should present an experience of softness when they touch virtual cushions. While people generally prefer softer and smoother targets over hard and rough ones [3], and dislike and avoid moist targets [4], it is unclear whether these general rules can be applied to the properties of each of the most highly desired targets.

We conducted an online experiment with 600 Japanese participants recruited via crowdsourcing. 18 touch targets that are commonly touched in daily life were carefully selected for subjects to respond to in the experiment. We extracted the potential users of haptic displays from among the 600 participants and analyzed only their responses. We clarified the need for consistency and biased impressions for each desired touch target. Fig. 1(A) shows the scope of the present study. The study's findings provide valuable insights for haptic researchers and engineers as to which haptic properties of a target should be rendered and how to render them using haptic technology (see Fig. 1(B)).

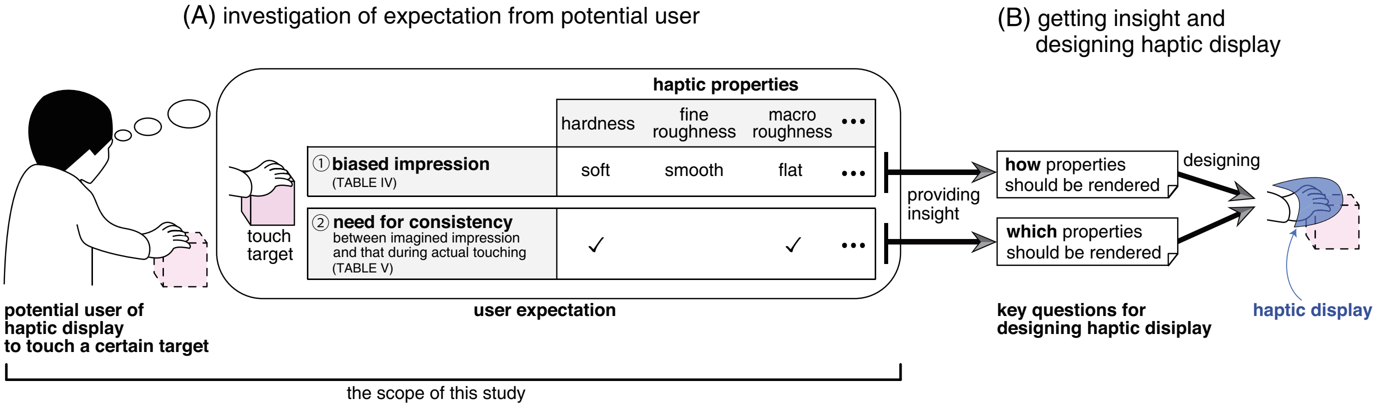

Fig. 1. (A) Investigation of user expectation among potential users of haptic displays, which is the principal focus of this study. We clarified the biased impressions and the need for consistency for each property and each desired touch target. (B) Getting insights into which haptic properties should be rendered, how they should be rendered, and designing haptic displays based on these insights.

II. Related Work

First, we introduce some previous studies investigating touch desire. Then, we introduce some previous studies that have developed haptic displays that can provide the experience of touching specific targets.

A. Investigation of Touch Desire

Touch desire in the context of purchasing has already been investigated. Touch is an important factor in increasing perceptions of quality and raising purchase likelihood [5], [6], [7], [8], but individuals differ in their need to touch products before purchasing [9], [10]. Peck and Childers created a scale that records individual preferences in terms of the need for touch (NFT), which consists of two subscales: instrumental NFT and autotelic NFT [9]. Our previous study [2] suggests that touch desire in daily life is usually dominated by the affective aspect of touch, which means that it is somewhat autotelic.

We have investigated people's desire to touch targets in daily life and found that animate targets, such as humans and animals, are more popular touch targets than inanimate objects [2]. After the COVID-19 outbreak, touch desire toward such animate targets became more intense in Japan [11]. Based on these previous studies, the present study focuses on how each haptic property should be presented when a haptic display aims to provide the experience of touching such highly desired targets.

Laboratory experiments have shown that certain haptic properties are generally important for activating people's touch desire [12], [3], [13], [14], [15], [16]. For example, Klatzky et al. found that abstract objects with smooth surfaces and simple shapes received higher "touch-ability" scores compared to those with rough surfaces or complex shapes [3]. Nagano et al. focused on textural properties and found that glossiness and surface shape affected the degree of haptic invitation [12]. Note that since their experiment was conducted focusing on certain experimentally-specific targets, their results cannot be directly extrapolated to other targets – such as the human body, animals, or other objects – that people commonly want to touch in daily life.

B. Providing Experience of Touching Specific Targets using Haptic Displays

There have been previous studies relating to the development of haptic displays that can provide users with the experience of touching specific targets [17], [18], [19]. For example, Lee et al. developed HairTouch, which allows users to feel the sensation of touching a hairy surface by actuating real brush hairs [20]. The display can control the perceived roughness and stiffness of the hair. Similarly, Takahashi and Kim used 3D-printed hairs to present the roughness and stiffness of fur [21]. Zhu et al. developed TapeTouch, a display that allows users to experience touching soft objects such as pillows and human ears [22]. The display is capable of providing users with multiple variations of shape and levels of softness. Zhang and Kajimoto developed a haptic display that can reproduce the roughness of human cheek skin [23]. They attempted to replicate the frictional force and roughness experienced when touching the skin using a DC motor and audio speakers. Culbertson and Kuchenbecker focused on hardness, slipperiness, and roughness properties in creating the feel of a surface, such as a blanket [24]. Punpongsanon et al. manipulated visual information relating to surface indentation and color to control the impression of the softness of fabric objects such as towels or cushions [25]. Lin et al. used an electrotactile display to control the roughness of cat fur experienced when users stroked it with their palm [26].

The targets presented in these previous studies were popular targets that people commonly desire to touch in daily life, as has been revealed by previous research [2]. However, the haptic properties presented in these studies may not necessarily align with the expectations of potential users. To avoid user dissatisfaction and ensure a more immersive and realistic experience, potential discrepancies between users' imagined expectations for certain haptic properties and their actual experiences should be considered and minimized [27]. For example, in addition to the hardness, slipperiness, and roughness properties which were presented by Culbertson and Kuchenbecker's system [24], certain other haptic properties (e.g., warmth and dryness) may also be important to control if we are to satisfy a person's desire to touch a blanket.

This article has been accepted for publication in IEEE Transactions on Haptics. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TOH.2023.3310662

To address this gap in our knowledge, we investigated user expectations for specific haptic properties of desired targets, with the aim of using this information to design and develop haptic technology that enhances user satisfaction.

III. Method

A. Participant

In total, 600 Japanese people participated in the experiment. Each age group (20s, 30s, 40s, 50s, 60s, and 70s) consisted of 50 male and 50 female participants. The participants were recruited online by a crowdsourcing research agent in Japan and were paid for their participation. Only people with access to their own smartphone or personal computer were recruited for participation, and they were unaware of the specific purpose of the experiment. Ethical approval for this study was obtained from the ethics committee at Nippon Telegraph and Telephone Corporation (Approval number: R02-009 by NTT Communication Science Laboratories Ethics Committee). The experiments were conducted according to principles that have their origin in the Helsinki Declaration. Written informed consent was obtained from all participants in this study. The investigation was performed in September 2022.

B. Selection of Touch Targets

To minimize the overall experiment duration, we limited our investigation in the main experiment to commonly desired targets that people frequently expressed a desire to touch. In order to identify such popular targets, we conducted a preliminary experiment.

As reported in our previous study [11], popular desired targets can be classified into three main categories: the human body parts, animals, and objects. Touch targets outside these categories (e.g., plants) were not found to be popular, as shown in Supplementary Figure 1, which displays the occurrence probability of the 50 most popular targets calculated from the data in our previous study. To determine which targets participants desired to touch in each category, we used the method described in Supplementary Note 1. We extracted the 10 most popular targets for each category, resulting in a total of 30 targets; Supplementary Figure 2 provides a detailed presentation of the top 10 targets for each category. Based on the following rationale, we selected 18 targets from the 30 ones as stimuli in the main experiment. Table I shows the 18 selected targets.

- In respect of human body targets, we included all body parts except for breasts and buttocks, as shown in Supplementary Figure 2(A). This decision was based on the concern that asking participants to respond to these targets could make some individuals uncomfortable and could even bias their responses for other targets.
- In respect of animal targets, we included only a dog and a cat because they received more than 80% of all responses, and other animals were found to be significantly less popular. Please refer to Supplementary Figure 2(B).
- In respect of other objects, we included all targets as shown in Supplementary Figure 2(C) except for smartphones and personal computers (PCs). We made this exception because, in Japanese, the phrase "want to touch smartphone/PC (smartphone/PC ni sawaritai)" can refer not only to physical contact with these devices but also to their normal use, and this ambiguity may lead to confusion in interpreting the results.

TABLE I
THE TOUCH TARGET IN THE MAIN EXPERIMENT. THESE 18 TARGETS WERE SELECTED BASED ON THE RESULTS OF THE PRELIMINARY EXPERIMENT.

human body	hand, cheek, hair, arm, face, muscle, ear, head
animal	dog, cat
object	cushion, blanket, slime, plush toy, futon, ball, towel, cloth

C. Haptic Object Properties

Referring to the taxonomy of haptic properties in previous studies [28], [29], [30], [31], [32], [3], we investigated the properties shown in the second column of Table II. We defined the texture-related properties according to the perceptual texture dimensions summarized by Okamoto et al. [28]. Then, we added weight, size, and shape properties, which are all sensed by exploratory procedures [29]. This categorization of haptic properties does not contradict those introduced in other papers [31], [32].

The tactile adjective pairs are shown in the third column of the Table. Note that we did not configure tactile adjectives for shape. There are many possible tactile adjective pairs for each aspect of shape (e.g., "round - angular", "complex - simple", or "symmetric - asymmetric"), and there was not enough time to allow participants to provide answers for all the possibly relevant tactile adjective pairs regarding shape. Thus, in the present experiment, we decided not to configure tactile adjectives for shape.

TABLE II
THE HAPTIC PROPERTIES USED IN OUR QUESTIONNAIRE.

	category of haptic property	**haptic property**	**tactile adjective**
1	texture	hardness	soft - hard
2	texture	fine roughness	smooth - rough
3	texture	macro roughness	flat - bumpy
4	texture	warmth	warm - cold
5	texture	moisture	dry - moist
6	texture	stickiness	slippery - sticky
7	weight	weight	light - heavy
8	size (volume)	size (volume)	small - large
9	shape	shape	

D. Questions

For each target, each participant was required to answer four types of questions. All questions and answers were conducted through Japanese text.

This article has been accepted for publication in IEEE Transactions on Haptics. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TOH.2023.3310662

1) Q1: Question on Touch Desire for Target: First, participants were asked to imagine a specific target. Then, they were asked to rate the degree of their touch desire for the target by selecting one option from the following: "do not want to touch", "neutral", and "do want to touch". There could be many variations in how participants might imagine each target. For example, when considering hands as touch targets, participants might imagine parents', children's, friends', or lovers' hands. Thus, we instructed them to imagine the one they would most like to touch.

2) Q2: Question on Desire to Own Haptic Display for Target: Participants were asked whether they would want to own a device that could provide an ideal feeling of touching a specific target whenever they wanted to experience it, if such a device existed. The options were: "would not want to own", "neutral", and "would want to own".

Since the participants were naive to haptic displays in general, we did not refer to the technology as a "haptic display" due to the probable unfamiliarity of this terminology. Instead, we referred to it as a "device".

3) Q3: Question on Impression of Haptic Object Property: Participants were asked to give ratings on a 5-point scale to describe their impression of each haptic property of the target. For example, for the haptic property of "hardness", participants chose one of the following ratings [-2:"soft", -1:"slightly soft", 0:"neutral", 1:"slightly hard", 2:"hard"] (see the right-most column in Table II). No question was given to participants about their impression of the haptic property of "shape".

4) Q4: Question on Need for Consistency between Actual Impression and Imagined One for Haptic Object Property: Participants were asked to rate the importance of the consistency between the actual impression of touch they would receive from the touch device and their imagined expectation on a 5-point scale from [-2:"not important at all", -1:" not terribly important", 0:"neutral", 1:"slightly important", 2:"very important"].

E. Procedure

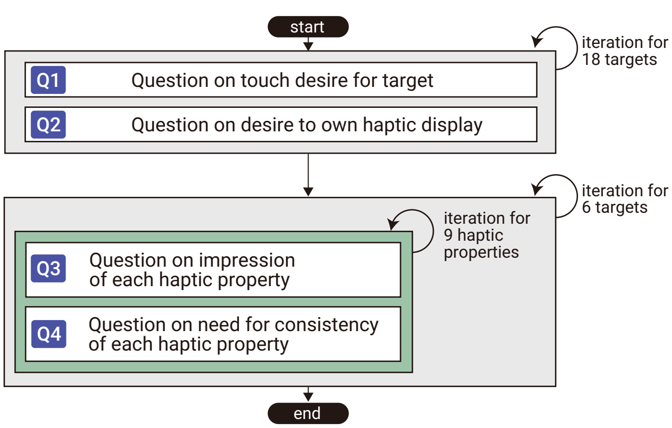

Fig. 2. The flow of questions.

Fig. 2 shows the flow of questions per participant. First, participants were asked to answer the questions on touch desire (Q1) and their desire (or lack of) to own a haptic display (Q2) for each of the 18 targets shown in Table I. The order of the 18 targets was randomized.

Next, participants were asked to answer impression questions (Q3) and need for consistency questions (Q4) for the haptic properties of six targets. The reason for limiting the number of targets to six was that there were 17 questions on haptic properties for each target (Q3 and Q4), and thus if we did not limit the targets, too much time would be needed to answer all the questions. The total number of questions per participant was 138 (= 18 for Q1 + 18 for Q2 + 6 targets × (17 questions for Q3 and Q4)).

These six targets were randomly selected from the group of targets which participants had indicated a desire to touch while also expressing a desire to own a haptic display that could simulate that touch experience, as assessed in questions Q1 and Q2, respectively. Since this study aimed to investigate the haptic properties of targets based on the responses from potential users of haptic displays (see detailed explanation in the next section), we prioritized the collection of responses about targets that participants indicated desire for in Q1 and Q2, as this would yield more relevant and useful data. If the number of such targets was fewer than six, additional targets were randomly selected from the remaining targets to make a total of six. This method of adding targets, even if the participant did not express a desire to touch them or a desire to own a haptic display, was employed to maintain consistent experimental time among participants. Note that the responses to the undesired targets were not used in our analyses.

IV. Results

A. Extraction of Answers from Potential Users (using Answers to Q1 and Q2)

Our objective is to acquire knowledge that can provide hints as to the optimal design of a haptic display that can satisfy a user's touch desire. To this end, we have decided to focus on analyzing responses solely from potential users of such a display. We regarded participants who express both touch desire and the desire to own a haptic display as potential users. Among the participants who report a desire to touch, some may not have a strong enough desire to justify owning a haptic display. We wanted to exclude responses from such participants, who we would not regard as potential users. We also wanted to exclude responses from participants who expressed a lack of desire to touch certain targets since they clearly would not be potential users of haptic displays satisfying touch desire for those targets. Thus, we narrowed down the responses using these two criteria (i.e., desire to touch and desire to own a haptic display).

The probabilities of the presence of both touch desire and the desire to own a haptic display are shown in Figs. 3(A)(B). Pearson's correlation coefficient was $r = 0.99$ ($p < 0.001$), showing their strong relationship. This indicates that the number of participants who reported that they desire to touch the target but do not desire to own a haptic display is small.

The number of potential users among participants is shown in Fig. 4. The subsequent analyses were conducted using only answers from this group. Although the sample size varied

This article has been accepted for publication in IEEE Transactions on Haptics. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TOH.2023.3310662

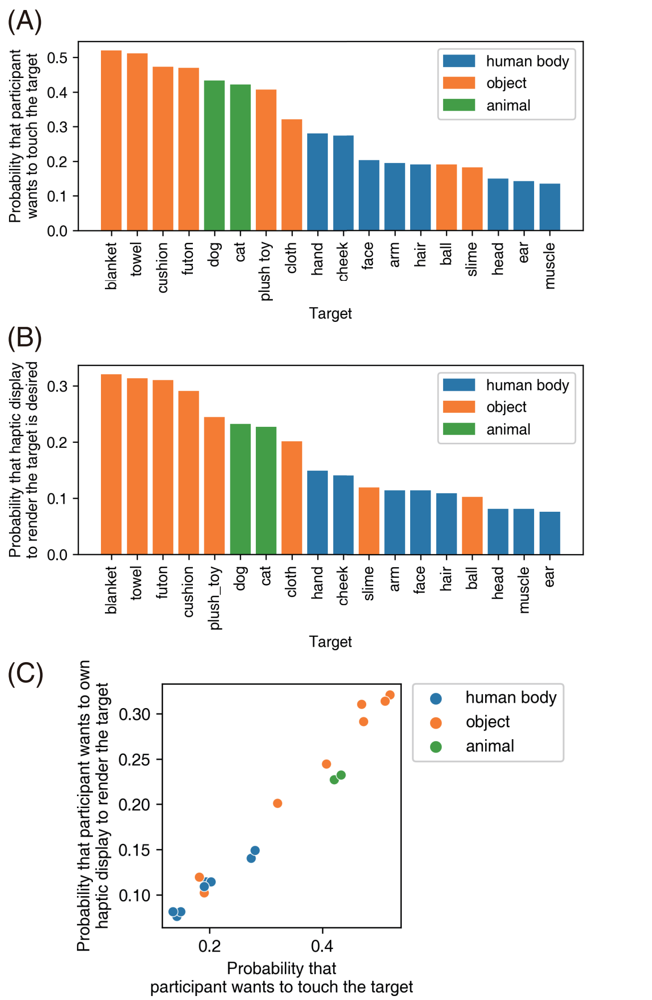

Fig. 3. (A) The probability that the participant wants to touch each target. This is based on answers to Q1. (B) The probability that the participant wants to own a haptic display rendering the target. This is based on answers to Q2. (C) The relationship between them.

target	num of potential users among participants
hand	65
cheek	63
hair	46
arm	46
face	49
muscle	28
ear	30
head	33

target	num of potential users among participants
dog	120
cat	115

target	num of potential users among participants
cushion	147
blanket	163
slime	50
plush toy	124
futon	155
ball	43
towel	155
cloth	96

Fig. 4. The number of potential users. These are participants who express both a desire to touch and a desire to own a haptic display capable of rendering the target.

depending on the target, there were always at least 28 samples, which we deemed sufficient for analysis. To obtain robust results even with relatively small sample sizes, we utilized the nonparametric bootstrapping method.

B. Analysis Results of Biased Impressions (using Answers to Q3)

Figs. 5(A)(B) and (C) show the mean rating scores for the imagined impressions in relation to combinations of each target and each haptic property. To identify whether there was a significantly biased impression, we calculated 10,000 mean scores from bootstrap samples [33] of the scores. If the Bonferroni-corrected 95% confidence interval (CI) did not overlap zero (i.e., the neutral point on the rating scale), we could conclude that the subjective rating for the haptic property was significantly biased. See Supplementary Note 2 and Supplementary Figure 3 for further explanation of the statistical analysis. When the rating was significantly biased, the characteristic adjective term has been provided in the relevant cell in Table IV. For example, in the case of the hand as a touch target, the rating scores regarding hardness were significantly less than zero (i.e., "neutral"), which means that potential users rated it soft to a significant degree. In addition to the hardness property, the rating scores for fine roughness, macro roughness, and warmth were also significantly biased. That is, they rated the hand as soft, smooth, flat, and warm.

The number of cells in Table III that were significant was 81, amounting to half of all cells ($162 = 18 \times 9$). The adjective terms in the cells generally showed consistency. For example, the adjective terms for hardness and fine roughness properties were always "soft" and "smooth".

The number of significant properties for each target is shown in the right-most columns. This shows that there were fewer significant properties for the human body than for animals and objects generally. The number of significant targets for each property is shown in the bottom row.

We conducted supplementary analyses for certain factors that do not strictly fall within the main scope of the present study. First, we thought it would be informative to show readers about the difference in imagined impressions between potential and non-potential users. We added these results in Supplementary Figure 4 and Supplementary Table 1. Second, since the sex or age of potential users influence their touch behavior [34], [35], it seemed plausible that touch desire, which may be the driving force behind a specific touch behavior, may also vary accordingly. However, we could not find a significant effect of sex or age on the impression.

C. Analysis Results of Need for Consistency (using Answers to Q4)

Figs. 6(A)(B) and (C) show the mean rating scores for the need for consistency between a haptic property's actual impression and a potential user's imagined expectation. To identify whether there was a significant need for consistency for each target and each property, we calculated 10,000 mean scores from bootstrap samples [33]. If the Bonferroni-corrected 95% CI were more than zero (i.e., "neutral"), we could conclude that the need for consistency was significant. The asterisks in Table IV indicate statistical significance. For example, in the case of the hand as a touch target, there were significant needs for consistency in respect of hardness and shape properties. If the potential users' impression of the

This article has been accepted for publication in IEEE Transactions on Haptics. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TOH.2023.3310662

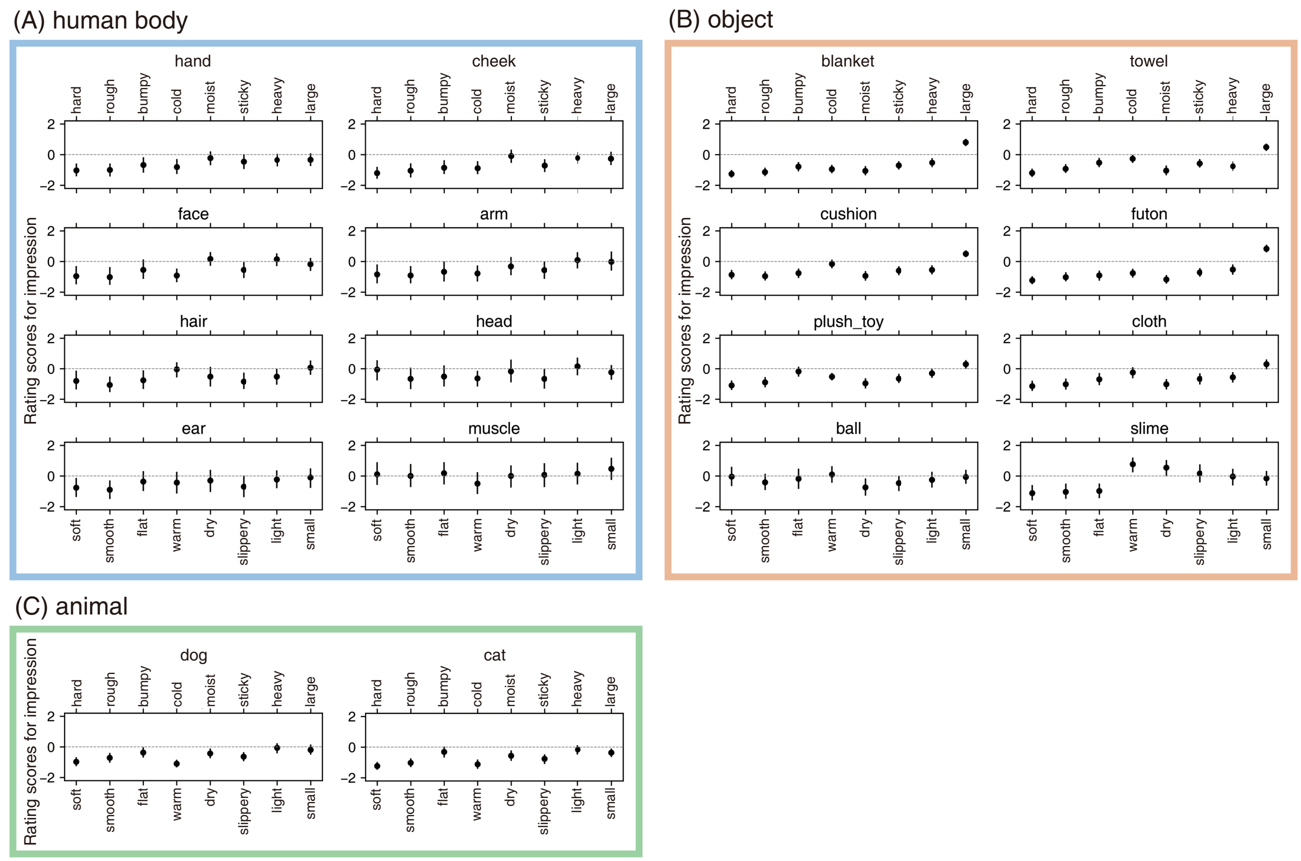

Fig. 5. (A-C) Mean scores for the impression of haptic property rated by potential users of haptic displays. (A) Mean rating scores for the human body. (B) Mean rating scores for objects. (C) Mean rating scores for animals. Error bar denotes Bonferroni-corrected 95% CI of the mean rating scores calculated by nonparametric bootstrapping.

TABLE III
THE RESULT OF THE STATISTICAL TEST TO DETERMINE WHETHER THE MEAN RATING SCORE FOR IMAGINED IMPRESSIONS IN RELATION TO A COMBINATION OF EACH HAPTIC PROPERTY AND EACH TARGET WAS SIGNIFICANTLY BIASED. THE TACTILE ADJECTIVE TEXT IN THE CELL INDICATES A BIASED IMPRESSION. CELLS WITH NO TACTILE ADJECTIVE TEXT INDICATE THAT THERE WAS NO SIGNIFICANT BIAS.

	hardness	fine roughness	macro roughness	warmth	moisture	stickiness	weight	size	number of significant properties for each target
hand	soft	smooth	flat	warm					4
cheek	soft	smooth	flat	warm		slippery			5
face	soft	smooth		warm		slippery			4
arm	soft	smooth		warm					3
hair	soft	smooth	flat			slippery			4
head				warm					1
ear	soft	smooth							2
muscle									0
dog	soft	smooth	flat	warm	dry	slippery			6
cat	soft	smooth		warm	dry	slippery		small	6
blanket	soft	smooth	flat	warm	dry	slippery	light	large	8
towel	soft	smooth	flat		dry	slippery	light	large	7
cushion	soft	smooth	flat		dry	slippery	light	large	7
futon	soft	smooth	flat	warm	dry	slippery	light	large	8
plush toy	soft	smooth		warm	dry	slippery			5
cloth	soft	smooth	flat		dry	slippery	light		6
ball					dry				1
slime	soft	smooth	flat	cold					4
number of significant targets for each property	15	15	10	11	9	11	5	5	

This article has been accepted for publication in IEEE Transactions on Haptics. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TOH.2023.3310662

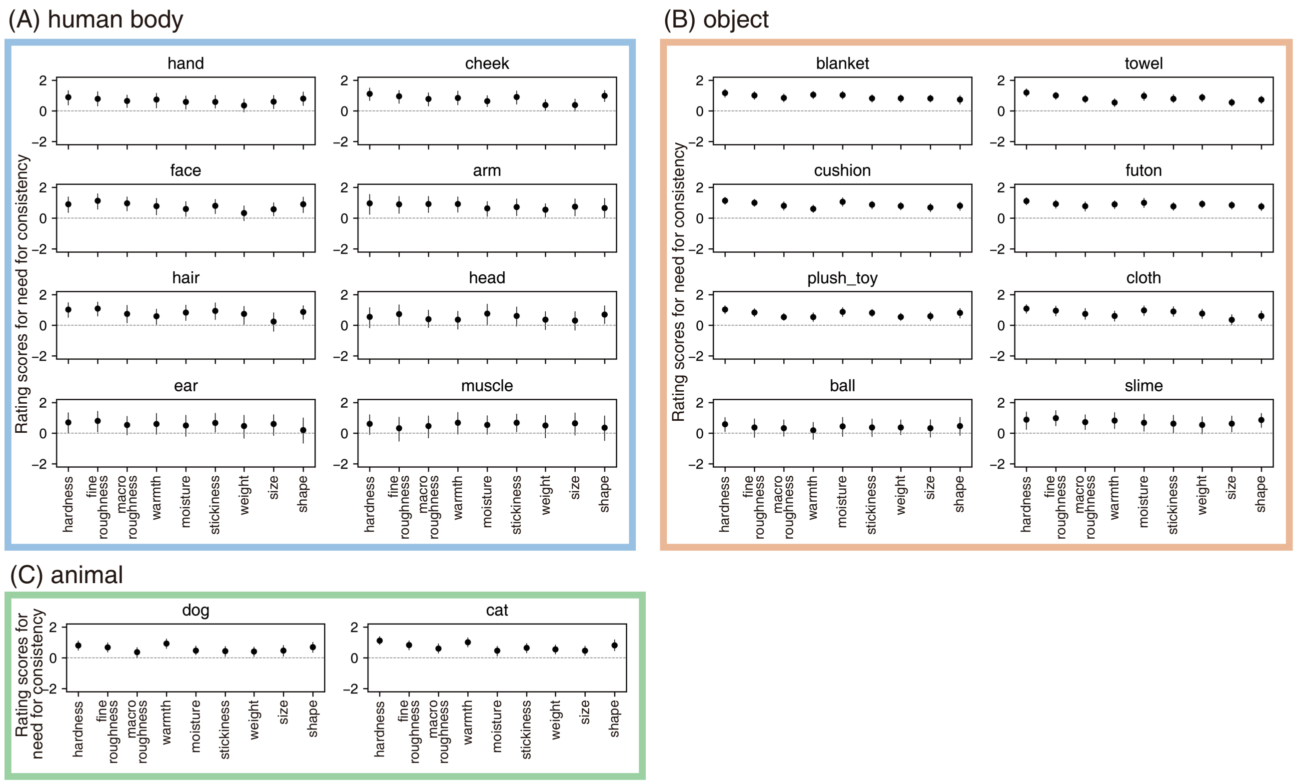

Fig. 6. (A-C) Mean scores for the need for consistency between a haptic property's actual impression and the participant's imagined expectation. (A) Mean rating scores for the human body parts. (B) Mean rating scores for objects. (C) Mean rating scores for animals. Error bar denotes Bonferroni-corrected 95% CI of the mean rating scores.

TABLE IV
THE RESULT OF A STATISTICAL TEST TO DETERMINE WHETHER THE MEAN RATING SCORE FOR THE NEED FOR CONSISTENCY BETWEEN A HAPTIC PROPERTY'S ACTUAL IMPRESSION AND A POTENTIAL USER'S IMAGINED EXPECTATION WAS SIGNIFICANTLY BIASED. WHEN THERE WAS A SIGNIFICANCE FOR THE COMBINATION OF TARGET AND PROPERTY, AN ASTERISK WAS PLACED IN THE CORRESPONDING CELL. IN ADDITION, THE BIASED IMPRESSION IS INDICATED IN BRACKETS IF THAT IS ALSO SIGNIFICANT.

	hardness	fine roughness	macro roughness	warmth	moisture	stickiness	weight	size	shape	number of significant properties for each target
hand	* (soft)	* (smooth)	* (flat)	* (warm)	*	*		*	*	8
cheek	* (soft)	* (smooth)	* (flat)	* (warm)	*	* (slippery)			*	7
face	* (soft)	* (smooth)	*	* (warm)	*	* (slippery)		*	*	8
arm	* (soft)	* (smooth)	*	* (warm)	*	*	*	*	*	9
hair	* (soft)	* (smooth)	* (flat)	*	*	* (slippery)	*		*	8
head		*			*					2
ear		* (smooth)				*				2
muscle						*				1
dog	* (soft)	* (smooth)	* (flat)	* (warm)	* (dry)	* (slippery)	*	*	*	9
cat	* (soft)	* (smooth)	*	* (warm)	* (dry)	* (slippery)	*	* (small)	*	9
blanket	* (soft)	* (smooth)	* (flat)	* (warm)	* (dry)	* (slippery)	* (light)	* (large)	*	9
towel	* (soft)	* (smooth)	* (flat)	*	* (dry)	* (slippery)	* (light)	* (large)	*	9
cushion	* (soft)	* (smooth)	* (flat)	*	* (dry)	* (slippery)	* (light)	* (large)	*	9
futon	* (soft)	* (smooth)	* (flat)	* (warm)	* (dry)	* (slippery)	* (light)	* (large)	*	9
plush toy	* (soft)	* (smooth)	*	* (warm)	* (dry)	* (slippery)	*	*	*	9
cloth	* (soft)	* (smooth)	* (flat)	*	* (dry)	* (slippery)	* (light)	*	*	9
ball	*									1
slime	* (soft)	* (smooth)	* (flat)	* (cold)	*	*		*	*	8
number of significant targets for each property	15	16	14	14	15	16	10	12	14	

property was significantly biased, as described in the previous section (see Table III), that biased impression is also indicated by text in brackets in the relevant cells.

The number of significant properties in terms of the need for consistency for each target is shown in the right-most columns. The number of significant targets for each property is shown in the bottom-most row.

While it does not fall within the main scope of the present study, we thought it would be informative to show readers about the difference in the need for consistency between potential and non-potential users. We added these results in Supplementary Figure 5 and Supplementary Table 2. In addition, we analyzed the effect of sex and age on the need for consistency, but could not find any significant effect.

V. Discussion

By utilizing crowdsourcing, we obtained the rating scores for biased impression and the need for consistency for each haptic property of the 18 highly desired targets.

A. Discussion of Need for Consistency

The findings of our study on the need for consistency in haptic properties, as presented in Table IV, provide researchers and engineers with insights into which properties they should prioritize to accurately control haptic impressions. For instance, our results demonstrate that potential users who desire to touch another person's head require haptic displays to render impressions that consistently match expectations of the fine roughness and moistness of the head.

It should be noted that a lack of significance for a specific combination of target and property does not necessarily mean that it is not necessary to render that haptic property for the target. It means only that we could not find a significant need for consistency for that combination. Therefore, it is possible that presenting such a property, even if not exactly as imagined, could improve the user experience.

The number of significant properties per target in terms of the need for consistency can be regarded as an indicator of the difficulty of designing the haptic display. Haptic displays for presenting the experience of touching targets such as arms, cats, or blankets are relatively difficult to design since the number of significant properties is relatively high. In contrast, haptic displays for presenting the experience of touching heads, ears, muscles, or balls, are relatively easy to design.

There were no significant properties for muscle as a target. This suggests the possibility that precise control of the impressions for haptic properties for muscle may not be needed, and that rough control of impressions might suffice for presentation to potential users. One point to note is that the variation in the rating scores was relatively large (as shown in Fig. 6). One of the causes of the large variation might be that the touch situation that participants imagined varied. By providing a more limited situational context in the instructions given to participants, this variation could be reduced. For example, while we did not specify whether the muscle target belonged to a male or female, adding this information to the instructions could help to limit the situational context and reduce variation in the need for consistency ratings, potentially leading to a more significant need for consistency. It is important to note that the situational context includes not only information about the person being touched but also other aspects such as the time, location, and manner of the touch.

The number of significant targets per property may indicate the importance of that property in terms of the need for consistency among properties. For example, the number of significant targets related to surface impressions, such as hardness, was higher than the number related to weight and size. This suggests that consistency in surface-related properties was generally more important for meeting users' expectations than consistency in weight and size properties.

B. Discussion of Biased Impression

Also, by referring to our results on biased impressions (specifically, Table III), researchers and engineers can gain insights into how to design the haptic stimuli. Where certain combinations of target and property are shown to be significant in terms of both the need for consistency and biased impression, it would be better to include the biased impression in the presentation provided by a haptic display. For example, we found that participants who wanted to touch a cat expected the cat's skin to feel soft when touched. In this case, when researchers and engineers develop a haptic display to present the feeling of touching a cat, the softness impression should be precisely controlled with the display.

In contrast, for specific combinations of targets and properties, there was a significant need for consistency, but no significant biased impressions were observed. For example, the macro roughness of a cat was important in respect of the need for consistency but was not significantly associated with a biased impression. This suggests that participants want to experience the macro roughness of a cat as they imagine it should feel, but the variation in the imagined impression of macro roughness might be considerable. This substantial variation could potentially stem from differences in the kind of touch imagined by the participant, such as which part of the cat's body they are imagining touching or how they are imagining touching it. It would be worth investigating whether limiting the situations that participants imagine, such as "which part to touch" or "how to touch" would reduce the variation in the impression of properties. If the variation of the impression could be reduced, it would become easier to present haptic sensations to users in a way that aligns with how they imagine those sensations should feel.

The biased impressions for each property were generally consistent. For example, the impressions for hardness and fine roughness properties were consistently rated as soft and smooth. This can be related to previous studies showing that people prefer softness [36] or smoothness [3]. On the other hand, there are differences depending on target categories.

Regarding human body parts (see rows colored in blue in Table III), potential users generally rated the targets as soft, smooth, and warm rather than hard, rough, and cold. Note that not all human body parts were significantly rated as soft, smooth, and warm. Some specific targets such as hand, cheek, and hair were rated as flat and slippery. Potential users did not rate body parts as significantly biased for moisture, weight, and size properties, potentially due to the inherent variability of these properties among different individuals.

As for animals (see rows colored in green in Table III), potential users rated the targets as dry in addition to soft, smooth, warm, and slippery. For animate targets such as the human body and animals, the impression of dryness was characteristic of animals. This might be attributed to the fact that most dogs' or cats' skin is covered with hair, making it less likely that humans would commonly be aware of skin moistness when touching dogs or cats. In contrast, human skin is relatively hairless, making moisture on human skin more easily recognizable. There was a significant difference between dogs and cats concerning properties of size, which are consistent with their size difference in the real world. Additionally, there was a significant difference between them in respect of properties of macro roughness, but the specific reason for this difference remains unclear.

Regarding objects (see rows colored in red in Table III), potential users generally rated the targets as soft, smooth, flat, warm, dry, and slippery, exhibiting similar biased properties as observed for animals as targets. In contrast, in respect of weight and size properties, participants rated several target objects as both light and large, qualities which were specific to certain objects used as stimuli but not characteristic in the case of the human body or animals. Also, attention should be paid to slime. Those who wanted to touch slime rated it as cold, which contrasted with other target objects.

C. Limitations

It should be noted that the findings in the present study do not guarantee that users would rate the impression of the target's property as important when using a haptic display. Also, the findings do not guarantee that users would be satisfied with the touch experience. This study investigated only imagined expectations, and the findings could serve as a guide for haptic display design. However, it is unclear how users would feel about the experience when it is rendered based on their expectations. Currently, there is no haptic display available that can simultaneously control specific haptic properties, making it difficult to conduct experiments with actual haptic displays. This is a limitation that we hope future research will address.

Next, our investigation into touch desire was limited in that we were unable to manipulate the reasons for touch desire or the situations in which it may arise. Thus, our findings provide a general understanding of touch desire without focusing on specific reasons or contexts. However, if we aim to comprehensively comprehend the application of touch experience to a particular target, investigating specific contexts or reasons for touch is going to be crucial. Building upon our results, future research should explore how the findings may vary depending on different contextual situations or reasons for touch.

In the case of humans as touch targets, we would expect the results to change due to the relationship between the toucher and the touched targets. For example, it is known that the frequency of touch events or allowance for touch is influenced by the relationship between those involved [37]. Our study did not manipulate the relationship between the toucher and the touched, which means our findings may not fully capture the influence of such relationships on touch desire and expectations. Based on our results, further study is needed to investigate this direction.

Finally, it should be also noted that our findings may be limited to the Japanese cultural context. The survey used in this study was conducted with Japanese participants, and it is possible that cultural biases may have influenced their responses. An earlier study reported that the role of touch could vary significantly across cultures, with different cultural norms and practices shaping how people perceive and engage in haptic interactions [38]; for example, in Italy, hugging and kissing on the cheeks are common forms of greeting, while in Japan, physical contact is generally avoided, and bowing is a more common greeting [39], [40]. Therefore, the results of this study may not be generalizable to other cultural contexts. Future studies are needed to better understand how cultural factors shape people's expectations regarding haptic experiences.

References

[1] I. Motion Picture Association of America, "Entertainment industry market statistics," http://www.mpaa.org/USEntertainmentIndustryMarketStats.pdf, (Accessed on 01/11/2021).

[2] Y. Ujitoko, Y. Ban, and T. Yokosaka, "Getting insights from twitter: What people want to touch in daily life," *IEEE Transactions on Haptics*, 2021, (in press).

[3] R. L. Klatzky and J. Peck, "Please touch: Object properties that invite touch," *IEEE Transactions on Haptics*, vol. 5, no. 2, pp. 139–147, 2012.

[4] K. Iwasa, T. Komatsu, A. Kitamura, and Y. Sakamoto, "Visual perception of moisture is a pathogen detection mechanism of the behavioral immune system," *Frontiers in psychology*, vol. 11, p. 170, 2020.

[5] B. Grohmann, E. R. Spangenberg, and D. E. Sprott, "The influence of tactile input on the evaluation of retail product offerings," *Journal of Retailing*, vol. 83, no. 2, pp. 237–245, 2007.

[6] D. B. McCabe and S. M. Nowlis, "The effect of examining actual products or product descriptions on consumer preference," *Journal of Consumer Psychology*, vol. 13, no. 4, pp. 431–439, 2003.

[7] A. Krishna and M. Morrin, "Does touch affect taste? the perceptual transfer of product container haptic cues," *Journal of Consumer Research*, vol. 34, no. 6, pp. 807–818, 2008.

[8] J. Peck and S. B. Shu, "The effect of mere touch on perceived ownership," *Journal of Consumer Research*, vol. 36, no. 3, pp. 434–447, 2009.

[9] J. Peck and T. L. Childers, "Individual differences in haptic information processing: The "need for touch" scale," *Journal of Consumer Research*, vol. 30, no. 3, pp. 430–442, 2003.

[10] A. V. Citrin, D. E. Stem Jr, E. R. Spangenberg, and M. J. Clark, "Consumer need for tactile input: An internet retailing challenge," *Journal of Business Research*, vol. 56, no. 11, pp. 915–922, 2003.

[11] Y. Ujitoko, T. Yokosaka, Y. Ban, and H.-N. Ho, "Tracking changes in touch desire and touch avoidance before and after the covid-19 outbreak," *Frontiers in Psychology*, vol. 13, 2022. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.1016909

[12] H. Nagano, S. Okamoto, and Y. Yamada, "Visual and sensory properties of textures that appeal to human touch," *In Proceedings of International Journal of Affective Engineering*, vol. 12, no. 3, pp. 375–384, 2013.

[13] ——, "Haptic invitation of textures: Perceptually prominent properties of materials determine human touch motions," *IEEE Transactions on Haptics*, vol. 7, no. 3, pp. 345–355, 2014.

[14] A. Metzger, M. Toscani, A. Akbarinia, M. Valsecchi, and K. Drewing, "Deep neural network model of haptic saliency," *Scientific reports*, vol. 11, no. 1, pp. 1–14, 2021.

[15] M. Lau, K. Dev, W. Shi, J. Dorsey, and H. Rushmeier, "Tactile mesh saliency," *ACM Transactions on Graphics*, vol. 35, no. 4, pp. 1–11, 2016.

[16] R. Etzi, C. Spence, and A. Gallace, "Textures that we like to touch: An experimental study of aesthetic preferences for tactile stimuli," *Consciousness and Cognition*, vol. 29, pp. 178–188, 2014.

[17] H. Culbertson, S. B. Schorr, and A. M. Okamura, "Haptics: The present and future of artificial touch sensation," *Annual Review of Control, Robotics, and Autonomous Systems*, vol. 1, no. 1, pp. 385–409, 2018.

[18] S. Choi and K. J. Kuchenbecker, "Vibrotactile display: Perception, technology, and applications," *Proceedings of the IEEE*, vol. 101, no. 9, pp. 2093–2104, 2012.

[19] C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, and D. Prattichizzo, "Wearable haptic systems for the fingertip and the hand: taxonomy, review, and perspectives," *IEEE transactions on haptics*, vol. 10, no. 4, pp. 580–600, 2017.

[20] C.-J. Lee, H.-R. Tsai, and B.-Y. Chen, "Hairtouch: Providing stiffness, roughness and surface height differences using reconfigurable brush hairs on a vr controller," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021, pp. 1–13.

[21] H. Takahashi and J. Kim, "Designing a hairy haptic display using 3d printed hairs and perforated plates," in *The Adjunct Publication of the 35th Annual ACM Symposium on User Interface Software and Technology*, 2022, pp. 1–3.

[22] L. Zhu, X. Jiang, J. Shen, H. Zhang, Y. Mo, and A. Song, "Tapetouch: A handheld shape-changing device for haptic display of soft objects," *IEEE Transactions on Visualization and Computer Graphics*, 2022.

[23] J. Zhang and H. Kajimoto, "Haptic reproduction of different human skin textures and comparison of rendering approaches," *Transactions of the Virtual Reality Society of Japan*, vol. 27, no. 3, pp. 231–234, 2022.

[24] H. Culbertson and K. J. Kuchenbecker, "Importance of matching physical friction, hardness, and texture in creating realistic haptic virtual surfaces," *IEEE transactions on haptics*, vol. 10, no. 1, pp. 63–74, 2016.

[25] P. Punpongsanon, D. Iwai, and K. Sato, "Softar: Visually manipulating haptic softness perception in spatial augmented reality," *IEEE transactions on visualization and computer graphics*, vol. 21, no. 11, pp. 1279–1288, 2015.

[26] W. Lin, D. Zhang, W. W. Lee, X. Li, Y. Hong, Q. Pan, R. Zhang, G. Peng, H. Z. Tan, Z. Zhang *et al.*, "Super-resolution wearable electrotactile rendering system," *Science advances*, vol. 8, no. 36, p. eabp8738, 2022.

[27] G. A. Churchill Jr and C. Surprenant, "An investigation into the determinants of customer satisfaction," *Journal of marketing research*, vol. 19, no. 4, pp. 491–504, 1982.

[28] 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.

[29] S. J. Lederman and R. L. Klatzky, "Extracting object properties through haptic exploration," *Acta psychologica*, vol. 84, no. 1, pp. 29–40, 1993.

[30] ——, "Hand movements: A window into haptic object recognition," *Cognitive Psychology*, vol. 19, no. 3, pp. 342–368, 1987.

[31] D. Wang, K. Ohnishi, and W. Xu, "Multimodal haptic display for virtual reality: A survey," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 1, pp. 610–623, 2019.

[32] L. M. Carey, Y. Y. Mak-Yuen, and T. A. Matyas, "The functional tactile object recognition test: A unidimensional measure with excellent internal consistency for haptic sensing of real objects after stroke," *Frontiers in neuroscience*, vol. 14, p. 542590, 2020.

[33] B. Efron and R. J. Tibshirani, *An introduction to the bootstrap*. CRC press, 1994.

[34] N. Henley, *Body politics: Power, sex, and nonverbal communication*. Prentice Hall, 1977.

[35] J. A. Hall and E. M. Veccia, "More" touching" observations: New insights on men, women, and interpersonal touch." *Journal of Personality and social Psychology*, vol. 59, no. 6, p. 1155, 1990.

[36] A. Pasqualotto, M. Ng, Z. Y. Tan, and R. Kitada, "Tactile perception of pleasantness in relation to perceived softness," *Scientific reports*, vol. 10, no. 1, pp. 1–10, 2020.

[37] J. T. Suvilehto, E. Glerean, R. I. Dunbar, R. Hari, and L. Nummenmaa, "Topography of social touching depends on emotional bonds between humans," *In Proceedings of the National Academy of Sciences*, vol. 112, no. 45, pp. 13 811–13 816, 2015.

[38] P. Duarte and S. C. e Silva, "Need-for-touch and online purchase propensity: A comparative study of portuguese and chinese consumers," *Journal of Retailing and Consumer Services*, vol. 55, p. 102122, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0969698919314389

[39] R. H. Finnegan, *Communicating: The multiple modes of human interconnection*. Psychology Press, 2002.

[40] E. McDaniel and P. A. Andersen, "International patterns of interpersonal tactile communication: A field study," *Journal of Nonverbal Behavior*, vol. 22, no. 1, pp. 59–75, 1998.

Yusuke Ujitoko has been a researcher at the NTT Communication Science Laboratories since 2020. He was a member of the R&D Group in Hitachi, Ltd. from 2016 to 2020. He received his PhD from the University of Electro-Communications, Japan, in 2020. He received his BE degree in Mechanical Engineering and MAE degree in Interdisciplinary Information Studies from the University of Tokyo, Japan, in 2014 and 2016, respectively. His research interests include applied haptic perception and interfaces.

Yuki Ban received his MS and PhD degrees in Information Science and Technology from the University of Tokyo, Japan, in 2013 and 2016, respectively. He was a researcher at Xcoo Inc. research from 2016 to 2017. He is currently a project lecturer at the Department of Frontier Sciences at the University of Tokyo. His current research interests include cross-modal interfaces and biological measurement.