Understanding and Designing Expressive Robotic Touch

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1 MEANING MAKING THROUGH EMOTIONAL TOUCH

Touch, the very first sense to develop in the womb [16], is the primary channel for humans to explore the physical world and plays a vital role in interpersonal communication. The meaning-making through touch was previously defined as the process of how people make sense of touch in communicative contexts [65]. In researching meaningful touch, we need to understand which and how contextual, relational, and personal factors may affect the perception and interpretation of a touch [82]. This section discusses the theoretical background of meaning-making in affective touch, existing approaches, and findings in related and our past works. Based on the insights, I propose a plan for future experiments to further investigate meaning-making through expressive robotic touch.

1.1 Background

1.1.1 Interpersonal Emotional Touch. Social touch is regarded as an affiliative behavior that serves a communicative function in interpersonal interaction [53]. Previous research in psychology demonstrates human capability to interpret emotional messages embedded in touch. Foundational psychology research by Hertenstein et al. indicated that beyond the hedonic tone and the intensity of emotions [45], a pair of strangers could convey distinct emotions (i.e., Anger, Fear, Disgust, Love, Gratitude, and Sympathy) to one another solely by touching on their forearm [36]. Their subsequent full-body study showed that Happiness and "Sadness" could also be decoded [35]. They also considered gender differences in this study, and the results revealed no significant differences in decoding accuracy. Still, the genders certainly used different actions to communicate various emotions [35]. Later studies by Thompon et al. suggested that romantic couples can even convey self-focused emotions such as Envy and Pride through direct touch [77]. These studies also identified the commonly used touch gestures when communicating each emotion based on visual observation [35, 36, 77]. Recent works demonstrate measuring and quantifying emotional touch with automated techniques, such as infrared video [34, 58], electromagnetic tracking [34, 58], or depth camera [85]. They specified essential attributes of the touch between a toucher's hand and a receiver's forearm, which provided a more precise understanding of emotional interpersonal touch.

1.1.2 Haptic Communication with Stereotypical Emotions. Taking interpersonal touch findings as a theoretical basis, researchers started to explore conveying specific emotions through haptic technologies, especially by replicating social touch gestures. Prior studies explored various technologies and found certain patterns in

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emotional artificial touch [40, 48, 91]. Closely followed the study design in the interpersonal research [36], these studies mainly prompted the participants with stereotypical emotion concepts. Kim et al. [48], for example, explored swarm robots to provide social haptic cues and analyzed the robot's behaviors for expressing 6 primary emotions [22] designed by 12 participants. Huisman et al. [41] introduced TassT, a haptic sleeve that has a force sensor input layer and a vibrotactile output layer 16 participants used TassT [41] to design mediated touch for conveying 8 emotions [40], whose resulting emotion-gesture associations matched fairly well with earlier psychology research [36]. Our first experiment [90] built servo-driven interfaces with pre-defined haptic patterns to convey 6 primary emotions and found 5 of them were decodable. Later we refined the device and invited 11 designers to create the haptic cues for 8 emotions [91]. All these results indicate the promise of communicating affects from artificial tactile cues. However, the above research also revealed the interpretation of touch could be contextual and subjective [48, 91], which is difficult to define one-to-one mappings for emotional communication. One possible explanation is that contextual factors (e.g., where, when, how, and by whom) have not sufficiently been considered in these outside-of-context experiments.

1.1.3 How is Affective Touch Interpreted? Touch is our first sense to develop [9, 31] and the skin with the receptors therein, "constitute both the oldest and the largest of our sense organs" [24, 27, 29, 59]. While many theories have been introduced to explain observations and beliefs about the "power of touch [57]," such as Field [24] points out touch is ten times stronger than verbal channel and Jones et al. [46] believe physical contact can convey vitality and immediacy at times more powerful than language, the investigation on the understanding of human interpretation in affective and meaningful touch is still at an early stage. Historically, researchers have viewed the senses of touch as generally subserving a primarily discriminative role [61] and largely concentrated on describing the sensory and perceptual consequences of stimulation of low-threshold mechanoreceptors found in the skin and joints [57]. In recent decades, researchers found a system of unmyelinated, mechanosensitive C-tactile (CT) nerve afferents under the human's hairy skin, which represents "the neurobiological substrate for the affective and rewarding properties of touch [57, 80]". It responded most vigorously at intermediate brushing velocities (1-10 cm s-1), which were perceived by subjects as being the most pleasant [54]. It was also found to be able to add specificity to social and emotional communication [49].

Moreover, research in bio-behavioral development [8] indicated that an individual's history of touch interactions from early on in life influence how they experience touch in later life. On the other hand, cognitive neuroscience findings have highlighted that the brain differentiates between the more affective aspects of touch and affectively-neutral tactile sensations [29, 56, 63, 67]. It suggested that the insular cortex might be an important component of a system responsible for our emotional, hormonal, and affiliative responses to tactile stimulation [29, 64]. Another potential factor for sense-making of touch might be haptic memory, while the research so far has mainly constrained to shape, texture recognition, object manipulation, or the memory of another person's body or face [28, 30]. Given those scientific explanations in human perception, many haptic researchers believed that a sole focus on the nervous system and the physicality of the tactile experience do not provide convincing answers about the social messages embedded in touch [20, 21, 66].

1.2 Meaning Making and Context in Haptic Research

Previous studies (section 1.1.1, 1.1.2) have focused on the existence of stereotypical emotional tactile patterns that can be interpreted outside of context, which could be a reasonable starting point of the experiment. However, to foster the exploration of the more meaningful touch experience, Jewitt et al. [44] suggest that haptic design need to be responsive to the individual and context, while Price et al. [66] also argues that "how we make sense of touch, how we receive, interpret and respond to touch are intimately connected to and shaped by the social, cultural and historical aspects of our touch experiences."

Existing experiments on haptic contexts mainly lie in two directions: (1) Focus on the cultural context and social norm which studied where, when, how, and by whom the touch is allowed and means what [7, 65]; (2) Narrow down to application scenarios with specific meaningful messages.

1.2.1 Cultural Context and Social Norm. Studies in this category usually set up the gender or relationship between the touch receiver and sender. While they also studied emotional concepts separately, each emotion was prompted by a specific scenario. Early work from Smith and Maclean [73] investigated how the relationship between sender and receiver (romantic couples or strangers) affected mediated touch experience, while they found couples did appear to be more successful at communicating emotions and strangers were less comfortable in using HandStroke metaphor. Foo et al. developed an SMA garment [25] and investigated user expectations and mental models in using "warm touch" to convey emotions through crowdsourcing online surveys [26]. To ensure all scenarios were emotions that the sender is experiencing, they provide text-based prompts and set the receiver in the role of friend. From the study, they collected the features of touch design (e.g., body location, intensity) for each emotion and identified five major mental models. Askari et al. [42] previously studied mediated touch repeatedly applied by either the male partner or male confederate to female participants. Their results indicated that touch sent by one's partner was perceived as softer and more comforting than stranger touch. Recent studies conducted by Price et al. [65] built a research-informed haptic I/O system that could provide temperature, pressure, and vibration feedback on the hand to explore mediated touch communication in contextually-related emotional scenarios within a variety of simulated social contexts, which include friends, family, romantic or work relationship. In their study, a pair of participants received contextual prompts and used the haptic device to communicate that message. Each participant is sender and then receiver. Their results revealed that participants found interpreting (and sending) affective support through touch to be subtle and highly ambiguous. However, as they acknowledged the context before receiving the touch, they could anticipate the messages and make sense of the tactile stimulation. Moreover, they suggested the relationship context was critical to generating and interpreting touch messages, as the touch design was shaped by the norms of contexts. They also illustrated different strategies of touch behaviors when conveying emotions between various social relationships.

1.2.2 Meaningful Haptics for Specific Scenarios. Past works have demonstrated how expressive haptic cues can be applied to specific application scenarios to enrich user experiences. Feel Effects [43] presents a library of vibrotactile special effects to enhance storytelling, which provides explicit pairing between a meaningful linguistic phrase and a rendered haptic pattern. Their subsequent project FeelSleeve [86] integrated such tactile pattern design into example storylines and studied its effects in enhancing early reading with a mobile haptic device.

Our latest work, TactorBots, is a design toolkit for exploring emotional robotic touch [92]. To let our participants have first-hand experiences of perceiving and designing haptic cues engagingly, we also provide a text-based narrative as a prompt. The fictional story for the design task had two main protagonists: a game player (receiver) and an elf (toucher). We used "elf" because it was an abstract and ambiguous concept compared to an existing being or object. The plots of the narrative were created based on the 8 emotions studied in many previous works [35, 91]. Within the story, some highlighted blocks informed an expressive haptic cue needed to be designed. They complete the task at their own pace. Here we take Fear as an example: *"When starting the adventure, you are in a dark space without any light. You can only hear some creepy sounds from a distance. The elf in the bracelet is scared (**please design a haptic sensation that enables the elf to express FEAR through the bracelet and save the sensation by naming it 'Fear_1'**)..."* Our out-of-lab design exploration with 13 participants revealed the qualities of our toolkit on how they could foster rapid prototyping, reflective perception, alternative interpretations, and creative imaginations.

Another main purpose of expressive haptic design is to complement the interaction in other channels to create more immersive multisensory experiences. Ablart et al. [1] previously created and integrated mid-air haptic stimuli into short movie experiences, which was found to enhance the viewer's experiences and provide positive effects in immediate and long-term movie viewing. Similarly, Mazzoni et al. [55] explored enhancing mood music in film by using a custom glove embedded with vibration motors. We have also integrated the touch patterns designed in EmotiTactor [90] into a VR game scenarios [93]. We transformed the robot [91] into a forearm-mounted model that performs complementary touches in conjunction with the behavior of a companion agent in virtual reality.

1.3 Discussion

1.3.1 Why Started from Studying Stereotypical Emotions? One of the key reasons for researchers, including me, to start our expressive haptic experiments from stereotypical emotions is to pursue a generalizable result or finding. Those studies mainly focused on the primary emotions, which are defined as innate emotions that are evoked for short periods of time and appear rapidly, usually as a reaction to an outside stimulus, and are experienced similarly across cultures [22]. I believe taking such an approach as a starting point could indeed provide a more impactful contribution to inspire the community. However, since human touch and emotion are both complex systems, a more generalizable research finding also means it is less adaptable to be integrated into any specific use cases. Many emotional haptic researchers have realized such problems, so they usually chose to sell their research findings with subsequent projects that demonstrated their touch design in a specific application scenario (e.g., Huisman et al. [40, 41, 47].

1.3.2 Cultural Context in Mediated Social Touch and Robot-initiated Touch. The cultural context was shown to be essential, especially for genders and relationships [42, 65, 73]. However, most existing works discussing these contexts are on mediated social touch. This means both the touch sender and receiver need to be human. HRI research has also discussed a lot on the gender settings of the robot, especially for humanoid robots [5] or conversational robots [13]. But if we investigate a non-humanoid robot who initiates the performance of the touch, how should we consider the cultural context?

In our latest design exploration with TactorBots [92], we utilized a text-based fictional story as the design prompt. The toucher in the narrative was set as an elf locked in a cursed bracelet that talked to the haunted house visitor as it guided them through the house. While not consciously defined, the elf's pronoun was set to "he." In our post-study interview, only one participant with a psychology background pointed it out. He mentioned that when designing the touch patterns, he took gender into consideration, as he believed the elf's behavior would be different when set to a different gender, similar to different cartoon characters. While no other participants mentioned the factor of gender in their design, we found it might be interesting to investigate whether those non-humanoid robots or metaphors need to have gender and how it might affect human perception.

Another core context is the social norm. Many artificial emotional touch researchers [39, 48, 89] and our works [90, 91] took the forearm area as the studied location because it is considered socially acceptable [75]. While TactorBots [92] also set the forearm as the default location, many participants tried to place the small-scale modules on different body parts, including the sensitive neck and ankle. They commented that the aesthetic quality, transparent enclosure, and simple mechanism helped them build trust. We believe it was also because of the "otherness" feature created by its machine-like appearance and texture that made the robotic touch more acceptable to humans compared to interpersonal social touch. In this case, whether or to what extent we should consider the social norm in designing expressive robotic touch could also be an intriguing topic to explore.

Besides those cultural contexts in real life, the form of the metaphor is a unique context for robotic haptics. Previous works have explored programming commercial robot arms [18, 76, 88] or humanoid robots to touch humans [83], while our work focuses more on developing on-body interfaces that could render expressive haptic cues. We believe such an approach could be more portable and provide broader design possibilities. This means our haptic device usually performs as "an organ" to externalize the toucher's (e.g., human, animal, robot, agent, or more abstract metaphor) feeling or intention, which we call them "tactor" because it is not always considered in the form of a "hand." When being touched by a human, even if you close your eyes, you can easily imagine there is an entire body that the tactor (hand) belongs to [91]. However, when being touched by a small-scale on-body machine, the metaphor of the toucher pictured in the receiver's mind is ambiguous. In the design task of expressive storytelling [92], we had participant imagine the "elf" as small as our wearable module so that it could hide inside the bracelet, while another participant pictured a spirit similar to Genie in Aladdin, which can become huge, floating in the air. Various forms of the metaphor obviously will lead to different design decisions.

1.3.3 Generative Context in Elicitation Study. While providing a specific context or scenario for designing the emotional haptic cues could make the interpretation less ambiguous and the touch design more situated, it might also restrict the participant's imagination. Based on the experience in EmotiTactor [91], I would consider the open context in elicitation study as a context generation process since our participants could always provide a specific context they pictured in their mind when explaining their design decisions.

In our research [91], we brought designers into the exploration of emotional robotic touch. We developed an integrated robotic tactor interface with basswood together with a software design tool. Using the platform, we conducted an elicitation study [40, 48]. Eleven designers were invited and asked to program robotic touch sensations that enable the robot to express assigned emotions (such as happiness, fear, anger, etc.) to a person. They tested these tactile cues on their own forearm. To explore how textures may affect the perception of touch, we made three alternative skins with different materials (i.e., silicone, plastic, fake fur) that were commonly used in making affective robots [2, 87].

As the interpretation of touch and emotion can be contextual, the open context in our study allowed designers to employ a variety of metaphors based on their intuitive decisions: Some designers replicated ***interpersonal interaction*** according to their imaginations and memories. For instance, one designer remembered his buddy that used to pat his shoulder to express gratitude. ***Animal metaphor*** was also mentioned and was usually connected to the fake fur texture. Intriguingly, some participants associated the emotions with ***inanimate metaphors*** and tried to mimic the behavior of an object or an abstract feeling that the metaphor represented. As for love, some designers used gentle shaking. They said it felt like a warm cradle. Another designer used shake to convey disgust. They said they tried to tactilize the feeling of seasickness on a rocking boat.

In our study with TactorBots [92], we further identified three types of design rationales on metaphors which include: emerging metaphors for primary emotions, intentional metaphors by imagination and association, and provoking metaphors from touch perception. Those emerging metaphors and contexts could always exceed our assumptions on sense-making of touch, which brings novel inspirations and introduce new design opportunities into our community.

2 OTHERNESS IN ROBOTIC TOUCH

2.1 Introduction of Otherness Concept

2.1.1 Familiarity in Designing Social Robot. The term "robot" was first proposed in Karel Capek's play R.U.R (Rossum's Universal Robots) in 1920 [17], which was used to describe the creation of humanlike replacements for people at work. Similar to many early fictions [6, 72], the traditional strategy of designing social robots is mimicking humans or animals. This decision is based on the assumption that familiar appearance and modes of communication are the best way to support easy, effective, and accurate human-robot interactions [14, 15, 71]. Also, as a young interdisciplinary research field, HRI is still facing the challenges of establishing shared research methods and developing theories based on existing evidence. Findings in interpersonal communication, therefore, are commonly set as the theoretical basis when designing a novel interaction system [33, 37].

2.1.2 Otherness in Human-Robot Interaction. While humanlike robots are designed to reduce uncertainty and misunderstanding in the interaction, which might be helpful over the short term, some other HRI researchers suggest that leaving a machinelike robot's form and behavior open to alternative interpretations [3, 4, 33] may offer increased opportunities for a long-term relationship to develop [71]. On the other hand, the concept of "uncanny valley" proposed by Masahiro Mori et al. [60] suggests that if a robot's form and behavior are too similar to a human, but that it simultaneously is still clearly a robot, it will evoke a feeling of creepiness. Even perfect replicas of humans might be problematic because too much similarity blurs category boundaries that undermine human uniqueness [23]. Thus, HRI researchers start to argue the value of tempered anthropomorphism and zoomorphism as it allows a machinelike robot to be considered familiar enough in its behavior to be meaningfully interpreted while also ensuring a sense of the "otherness" of the machine and respect for its non-human abilities is retained [71].

2.1.3 Designerly Framing Related to Otherness. Otherness is defined as "an aesthetic category broadly used to describe robotic forms that are neither anthropomorphic nor zoomorphic in their outward form [10, 71]." This concept is not only used a lot in HRI, but also introduced in the design and art fields [11, 51]. Encountering otherness means encountering differences between the familiar and the unfamiliar [11], which could resonate to the "ambiguity" raised in design research and "estrangement [81]" and "defamiliarisation [52]" strategies employed in soma design [74]. We choose "otherness" here, as it is more specific for our robotic touch context and can be communicated well between HRI and design communities. Other relevant framings that are less commonly used in academic language can be "alterity," "alienness," or "outsider," while "alieness" could be even more exclusionary and "outsider" is connected more to human metaphor.

2.2 Otherness in Context of Robotic Touch

In the context of robotic touch, while replicating natural affective touch for mediated social touch is a conventional direction [39], researchers are starting to reconsider people's willingness and need to replace interpersonal physical contact [70], and constantly pursuing realistic social touch may even fall into the uncanny valley [60]. On the other hand, prior research also revealed that the meaning-making of artificial touch could be contextual and subjective, which is challenging to arrive at a generalizable haptic language [26, 48].

Therefore, in our current work [92], we propose treating the emotional robotic touch as a "design canvas" that can open up space for alternative opportunities inspired by the novel and deeper interpretations of the tactile stimulus. We argue the importance of embracing ambiguity in emotional haptic design and leveraging the balance between *familiarity* of distinguishable social gestures and the *otherness* of robotic haptic cues. More specifically, similar to the strategy mentioned in 2.1.2, our design of interaction *content* of robotic touch is inspired by the interpersonal touch gestures, while we keep the otherness feature when designing the machinelike robot *form*, which includes appearance and texture.

The results in our studies [91, 92] indicated that the sensations rendered by our robots were novel and expressive. While the tactors could render distinguishable gestures as their names informed, participants also mentioned their alternative interpretations of the tactors based on their true perceptions. During their design process, the otherness feature of the tactile sensations also evoked metaphors beyond the dominant anthropomorphic and zoomorphic paradigms, which broadens the design possibilities of emotional robotic touch and may enable tactilization of information that is not usually communicated through touch.

2.3 Novelty Effect, Cortical Plasticity, and Otherness

To narrow down the feature of otherness in designing expressive robotic touch, we need to clarify it with two other phenomenons in related fields: "Novelty Effect" emphasized in HCI [50] and "Cortical Plasticity" discussed in embodiment for VR and human augmentation [32, 78, 84].

2.3.1 Novelty Effect. Novelty Effect, "in the context of human performance, is the tendency for performance to initially improve when new technology is instituted, not because of any actual improvement in learning or achievement, but in response to increased interest in the new technology [1]." More relevantly, Rutten et al. [69] previously conducted a long-term study to investigate the user experience and emotional reactions of mid-air haptics after repeated use. Their results indicated that the value of valence added by the haptic feedback was only significantly elevated during initial use, showing a waning novelty effect. So, does the otherness of robotic touch also caused by the novelty effect? Will it wane off over time?

2.3.2 Cortical Plasticity. Cortical plasticity [68] is the hypothesized explanation of phantom limb pain [62] and rubber hand illusion [78], indicating the human capability to remap the body's motor control to a different, non-anthropomorphic body [84]. Accordingly, Won and Lanier et al. [84] proposed the concept of "homuncular flexibility," which means users can learn to control bodies different from their own by changing the relationship between tracked and rendered motion, which is employed in studying embodiment. In this case, Will a human always perceive it as a 'robotic other,' and will they get used to it? Will humans consider the on-body haptic device a part of their body in the end? Then how would "otherness" mean here?

2.3.3 What Does Otherness Mean Now? Apparently, more in-depth studies will be needed to answer those questions. Here I will discuss it with some hypotheses and speculation based on my personal research experience.

(1) The otherness feature mainly targets meaning-making rather than gaining interest or excitement.

In our studies, because we designed the robotic tactors in a machinelike form in appearance and texture, the sensation it rendered was novel to the receiver. Thus, the perception of such stimuli will not instantly recall any existing touch memory of the receiver. When making sense of the touch, the receiver needs to associate it with some cues they have experienced or metaphors they could picture. As there is no straightforward mapping (e.g., human touch could be easy to recognize), the meaning-making process could evoke personal interpretations and unique meaning mapping due to individual differences. We hypothesize that, in a long-term interaction, the meaning-making process will be shortened after repeatedly encountering similar cues and transferred to a novel touch memory. Thus, instead of waning off, we believe long-term interaction will reinforce the sense-making of meaningful robotic touch.

Moreover, our current study experiences indicated that the sense-making process of the meaningful touch is slow. Unlike many novel haptic effects that are aimed at bringing engaging and exciting experiences, our research needs the participants to calm down and take time to engage their bodily sensory experiences with subtle and nuanced tactile stimulations for reflective thinking. Thus, instead of waning off due to the novelty effect, we believe long-term interaction will actually reinforce the meaning-making of expressive robotic touch.

(2) A constant acknowledgment of the machine feature is important.

It seems that human understandings of robots, even machinelike robots, inevitably draw on anthropomorphic or zoomorphic responses [71]. For instance, many Roomba users give it a name or consider it a family member [3]. Rather than being a problem for otherness, HRI researchers consider it a valuable response [71]. Regarding those robots as "living" individuals could help build trust and relationships between them. As the robot is not designed in an explicit form familiar to humans, the relationship they built could be personal and unique. However, also because of its machinelike feature, people could always retain a clear acknowledgment of the otherness of the robot so that they would also be understood as machines that can be switched off and discarded.

In our TactorBots study, we indeed have one participant who mentioned that instead of thinking about any external toucher, she regarded the TactorBots as a part of her body and tried to design haptic cues to simulate the interoceptions of the body when experiencing different emotions. While such strategy is usually applied to

[1]https://en.wikipedia.org/wiki/Novelty_effect

breathing regulation with synthetic heartbeats [19] and might be related to the cortical plasticity concept, I am not very clear how it actually works in our context.

3 FUTURE EXPERIMENTS

3.1 Understanding the Making of Meanings

3.1.1 Bring in First-person Perspectives. As the fundamental to soma design [38], first-person perspectives is defined as: "one needs to understand first connections between sensations, emotions, and felt somatic experiences with digital and physical materials, through experiencing them themselves, before aiming to design such connections for others [74]." Although I always considered myself the No. 0 audience when designing my robots and studies, I have never consciously taken it as a concrete element in my design and research process. Thus, for future experiments, I will bring in the first-person perspectives. I will start with understanding how the sense-making and meaning-making processes of various robotic tactile cues happen on my own body. Then I will utilize such reflections to design better haptic robots, study settings, and interview prompts, which will have the potential to support me have a deeper understanding of the interpretations from other participants.

3.1.2 Cultural Probes for Capturing Nuanced Interactions. As section 1.2 has discussed the importance of context in emotional haptic design, we should definitely explore how context settings may impact the meaning-making of robotic touch. For instance, running a comparison study which has two very different settings:

(1) Open context with few given conditions, which includes no descriptions of the studied expressive concepts (if we want to go beyond primary emotions), and no restriction on the time and environment (out-of-lab study).

(2) Specific context with an explicit application scenario and a carefully designed immersive environment matched the given scenario.

Another important part of investigating the meaning-making process through user study is how to prompt the users to explain their experience in detail and how we can capture those nuanced mindset shifting and behavior changes during their design process. As we received a lot of insightful results from our out-of-lab study with TactorBots, I will continue using this strategy as it allows flexibility in time and space and enables our participants to design in a trustworthy environment for exploring the body's boundaries.

To better understand their design experience in the wild, I plan to prepare a set of new probes to capture their design environment and document the process. For instance, we can build custom cameras similar to TaskCam [12] and ask users to take photos of their surroundings before doing the design. Those who will not feel anxious under the camera can also use the camera to film their entire design journey. In our past study, some participants were more comfortable talking to themselves when thinking. Thus, they may want a custom recorder they can talk to in the study. Similar to the booklet we made for TactorBots, instead of designing for co-speculation, it can also be used for taking notes or writing diaries after being carefully curated.

For running the study, we will prepare a set of culture probes with various documentation methods, and the participants can decide to use one or multiple tools to accompany their study in a comfortable way. After that, we will prepare specific prompts in the semistructured interview based on their documentation. I believe this approach will help us have a more holistic and in-depth understanding of the participant's design rationale.

3.2 Exploring the Feature of Otherness

A unique design process emerged in our TactorBots out-of-lab experiment, Metaphor Elicitation, which could be a good approach for us to further explore the otherness feature of our robotic touch. Our participant Patrícia Alves-Oliveira mentioned that when receiving TactorBots "I first wanted to discover the personality of each tactor. When I tested them, I thought the touch was too abstract to remember. So I decided to draw comparisons with metaphors on things that would remind me of the tactor when I do the experiment. I put the tactors on my body, closed my eyes, and tried to think what is the most similar sensation I had to this type of touch."

Patricia explained that finding metaphors could be straightforward for some tactors, such as Rub and Stroke. She associated Rub with "feathers" because the sensation was soft. Stroke was surprisingly wild and reminded her of the "spice of rose." Shake, however, was hard for her to find a comparison. She felt the movement was very contained, which reminded her of the "tension of the rope." However, during our conversation, she came up with another metaphor, "turtle," as the Shake Tactor's concavity shape looked like a turtle's back. Its motion was similar to the turtle's walking style. She believed those metaphors helped her to memorize the features of each tactor and greatly supported her decision-making in the design task.

Following Patricia's strategy, we can conduct a metaphor elicitation study to collect more metaphors purely evoked by tactile perception and analyze the relationship and reasoning behind those inspirations.

3.3 Investigating the Waning of Novelty

Our approach to better understanding the waning of novelty and how it may affect the otherness feature will be conducting a long-term study. This time, we will provide multi-stage design tasks with regular check-in, similar to the setting in Wakkary's co-speculation [79]. In this study, we will investigate how our participants actively interact with our platform, learn more about how they live with the robots, and how the emotional haptic system might be integrated into their everyday life.

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A PRELIMINARY EXAM

A.1 Committee Members

Daniel Leithinger (Chair), Laura Devendorf, Harpreet Sareen, Wendy Ju, Madeline Balaam

A.2 Prompts for Writing Exam

Meaning Making: Interpretation of emotional touch depends on the context it occurs in, and prior experiences of the person being touched. How would you design a one-year study to help you understand meaning-making in your robotic touch research? What are the specific factors that should be considered to better understand a person's emotional reaction to touch? What methods have you employed in the past and which ones would you use in the future to investigate context and account for it? Ground your response in related work and describe it based on examples from your own research.

Otherness of Robotic Touch: The field of human augmentation demonstrates supernumerary limbs but grounds them in scientific studies of neuroplasticity. What are the scientific theories and phenomena that ground such 'otherness' in robotic touch? - Based on these scientific theories, how can you test these as it relates to your robots? What are designerly theories to frame 'otherness' alternatively and less exclusionary? Show reasons for choosing one framing over the other.

Novelty Effect: The HRI Community has previously mentioned that the novelty/otherness effect of robotic touch may wane off with time. Find prior robot interaction works that investigate effects like 'otherness' and related concepts like the 'uncanny valley' effect and compare/contrast them to your own. What study would you perform to investigate whether such gradual waning may happen in your wearable robots?