User Experience of Conveying Emotions by Touch*

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***Abstract*— In the present study, 64 users were asked to convey eight distinct emotion to a humanoid Nao robot via touch, and were then asked to evaluate their experiences of performing that task. Large differences between emotions were revealed. Users perceived conveying of positive/pro-social emotions as significantly easier than negative emotions, with love and disgust as the two extremes. When asked whether they would act differently towards a human, compared to the robot, the users' replies varied. A content analysis of interviews revealed a generally positive user experience (UX) while interacting with the robot, but users also found the task challenging in several ways. Three major themes with impact on the UX emerged; responsiveness, robustness, and trickiness. The results are discussed in relation to a study of human-human affective tactile interaction, with implications for human-robot interaction (HRI) and design of social and affective robotics in particular.**

I. Introduction

Socially interactive robots are expected to have an increasing importance in everyday life for a growing number of people. It is therefore important to study how people want to interact with robots and what constitutes an intuitive and natural interaction between humans and robots. For social robots, like in all other interactive systems, products, and devices, positive user experience (UX) is necessary in order to achieve the intended benefits. The UX is not built in the product itself; instead, it is an outcome of the interaction that depends on the internal state of the user, the quality and attributes of the product, and the particular situation [1, 2]. Hence, positive UX is difficult to define but easy to identify [3]. The UX of social robots needs to be a central issue of concern, because positive UX underpins the proliferation of social robots in society [4]. Accordingly, negative UX can result in reluctance to interact with robots and challenge the acceptance of future robotic technologies [5]. However, a positive UX does not appear by itself. Instead, it has to be systematically, thoroughly, and consciously designed for, not least in the interaction *per se* between human and robot [1–3, 6].

Social robots, designed to interact with human beings, need to act in relation to social and emotional aspects of human life, and be able to sense and react to social cues. As interaction between humans and robots become more complex, there is an increased interest in developing robots with human-like features and qualities that enable interaction with humans in more intuitive and meaningful ways [7, 8]. Consequently, touch, as one of the most fundamental aspects of human social interaction [9], has started to receive interest in the field of human-robot interaction (HRI) [10, 11]. It has been argued that enabling robots to "feel", "understand", and respond to touch in accordance with expectations of the humans would enable a more intuitive interaction between humans and robots [11]. The fundamental role of touch for human bonding and social interaction emphasizes the likelihood that humans will seek to show affection by touching robots, particularly social robots meant to engage in social-human interaction. Hertenstein et al. [12] reported results from a study of affective tactile communication between humans, noting that tactile communication has similar information content as facial and vocal communication. We therefore see a growing need to consider touch as a natural part of the interaction between humans and social robots. However, in HRI, touch, and especially affective touch that communicates or evokes emotion, has received less attention than modalities such as vision and audio [11]. This stands in contrast to prior research showing that humans want to interact with robots through touch [13–15]. In order to create interaction possibilities that facilitate a positive UX, there is a need to understand how humans, as users of robots, experience interaction via touch and the conveyance of emotions to the robot. This is important in

Figure 1. Author demonstration of experimental situation. Nao robot standing on a high table, facing participant.

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order to enable a natural interaction that the robot can interpret and respond to in a correct manner.

This paper reports on a subset of work from an experimental study of affective tactile HRI. The study is an attempt to replicate the human-human interaction (HHI) study conducted by Hertenstein et al. [12]. One of the purposes of the study is to gain further scientific understanding of affective tactile interaction and to investigate whether it is possible to transfer theories and findings of emotional touch in HHI research to the field of HRI. The specific subset of work reported in this paper investigates how the users in the study experience interaction with the humanoid robot Nao [16] while conveying emotions to the robot via touch. This can be seen as an initial step before conducting more structured UX studies in this area of research.

II. Background

The recent and rapid development of autonomous technology emphasizes the importance of considering various aspects of human-robot interaction (HRI) from a human-centered perspective. HRI is a relatively new and growing research field that is concerned with the ways humans might work, play and interact with different kinds of robots. Socially interactive robots are expected to have an increasing importance in everyday life for a growing number of people [7]. It is therefore relevant that they display social intelligence, i.e. qualities that reflect human social expressions such as emotional appearance and perception, and advanced dialogue capabilities. It is also important that the robots are able to make use of gaze and gesture as part of communication [17]. When it comes to social interaction with robots, HRI research can be categorized into three different approaches: robot-centered HRI, robot cognition-centered HRI, and human-centered HRI [1]. While robot-centered HRI views the robot as an autonomous entity and the human as the robot's "caretaker" who should identify and respond to the needs of the robot, robot-cognition HRI views the robot as an intelligent system and the fundamental problem is to provide these robots with cognitive capacities. In human-centered HRI, the human perspective is emphasized and issues related to design of robot behavior that is comfortable for human users are included in this approach, and the UX perspective is thus emphasized. This involves acceptability and believability, as well as the users' expectations of, attitudes towards, and perceptions of robots [1]. In order to get robots to "inhabit our living environments", the three approaches need to be synthesized to enhance social interaction [1]. However, historically human-centered HRI has not received as much attention as the other two approaches [18–21]. Different aspects related to the quality of the interaction have been addressed in the HRI literature, including engagement, safety, intentions, acceptance, cooperation, emotional response, likeability, and animacy. However, UX has largely been omitted, and this is the topic to which we now turn.

A. *User Experience - UX*

It is becoming increasingly important to design interactive artifacts that are not only acceptable, safe, and easy to use, but also experienced as positive and fun to interact with. From the users' point of view, a product should be suitable for its purpose, easy to use, and fit into its intended context. These are just basic requirements of the technological artifact. Recently, the users have also started to postulate and demand a positive experience when interacting with technological artifacts [18–20]. Both practitioners and researchers have embraced the notion of UX because it offers a tentative alternative to the more traditional and instrumental human-computer interaction (HCI). While UX is hard to characterize, it can be viewed as: "the totality of the effect or effects felt by a user as a result of interaction with, and the usage context of, a system, device, or product, including the influence of usability, usefulness, and emotional impact during interaction and savoring memory after interaction" [1, p. 5].

Hassenzahl and Tractinsky [2] differentiated between *pragmatic* and *hedonic* aspects of interactive artifacts. Pragmatic aspects relate to the usability component of UX and have their roots in HCI. These aspects include effectiveness, efficiency, satisfaction, ease-of-use, and learnability. Hedonic aspects relate to component of UX beyond the instrumental aspects addressed in HCI. The hedonic aspects are usually portrayed as the emotional impact that emerges when the user interacts with the interactive artifact [1]. Negative UX can have its cause in poor interface design or a perceived lack of functionality, resulting in a negative emotional experience during interaction with the artifact. Accordingly, the positive expectations of a new, cool, high-tech system can quickly shift from amazement to annoyance if the usage of the interactive artifact fails. High-tech is thus not a causative factor of positive UX [1]. Accordingly, positive UX is not built into the interactive artifact itself.

Just as with all interactive systems, positive UX is necessary for robots to achieve the intended benefits. If the users experience the interaction with the robot as negative, the consequence might be reluctance to interact with robots, which in turn may inhibit the acceptance of future robotic technologies [5–20]. Therefore, the UX of social robots needs to be a central issue of concern when developing these kinds of robots.

B. *The Role and Relevance of Touch in Social HRI*

Several attempts have been made to develop robots with the modality of touch. Most notable are perhaps the small, animal shaped robotic companions with full-body sensing, designed to detect affective content of social interaction, for example, the robot seal Paro [22], Huggable [23], and the Haptic Creature [24]. These robots are small in size, which allow them to be picked up and held, and designed for HRI applications in companionship and therapeutic interventions. The Huggable has a "sensitive skin" that features four modalities of somatic information: pain, temperature, touch, and kinesthetic information [23]. The Haptic creature has touch sensors and accelerometer that allow the robot to sense when being touched and moved [24]. Yohanan and MacLean [24] examined how humans communicate emotional states through touch to the touch-centric social robot and their expectations of its responses. A user study was conducted where participants selected and performed touch gestures to use when conveying nine different emotions to the robot. The major findings are patterns of gesture use for emotional expression; physical properties of the likely gestures; expectations for the robot's response to mirror the emotion communicated; and analysis of the user's higher intent in communication. The findings also reveal five tentative themes of "intent" that overlap emotion states: protective, comforting, restful, affectionate, and playful. Their obtained results may support the future design of social robots by clarifying details in affective touch interactions between humans and robots [24].

When it comes to humanoid robots, the capability to recognize affective touch may be even more important due to the humanoid form which might elicit expectations of a high degree of social intelligence. Cooney et al. [25] studied user's affectionate behaviors toward a humanoid robot with capabilities of touch, vision, and sound. In this multimodal interaction, the users were free to interact with the robot in any way they liked and were asked to describe how much affection they communicated by their behavior. The results show that touch was considered significantly more important for conveying affection than distancing, body posture, and arm gestures. Thus, touch plays an important role in the communication of affection from a human being to a humanoid robot [25]. In another study, Cooney et al. [26] investigated how users touched a humanoid robot when conveying affection, i.e., positive feelings of love, gentleness, regard, and devotion. This was then used to build a recognition system that can recognize people's affectionate behaviors by combining touch- and vision-based approaches. In order to identify typical touches, participants were instructed to convey various intentions and emotions and for each touch, describe the degree of affection conveyed by the touch. Twenty typical touch gestures were identified, of which hugging, stroking, and pressing were the most affectionate, patting, checking, and controlling were neutral touch gestures, and hitting and distancing were unaffectionate. Thus, affective touch, as fundamental in human communication and crucial for human bonding is likely to take place also in the interaction between humans and social robots. It should therefore be considered important for the realization of a meaningful and intuitive interaction between human beings and robots.

This is in line with the findings presented by Lee et al. [13], which showed that physically embodied robots were evaluated as having a greater social presence than disembodied social robots (a screen character version of the robot). However, the physical embodiment alone did not cause the positive experience. In fact, when users were prohibited from touching the physically embodied robot, they evaluated the interaction and the robot's social presence more negatively than when they were allowed to interact with the robot via touch. This suggests that tactile communication is essential for a successful social interaction between humans and robots [13] and that the fundamental role of tactile interaction in interpersonal relationships goes beyond human-human interaction and extends to human-robot interactions.

III. Method

In an on-going study, we investigate how users convey emotions via touch to the humanoid robot Nao [16]. Here we report a subset of this work, focusing on the user's experience from interacting with the robot. The study takes inspiration from the human-human interaction research performed by Hertenstein et al. [12], where participants were asked to communicate eight different emotions to another person, via touch.

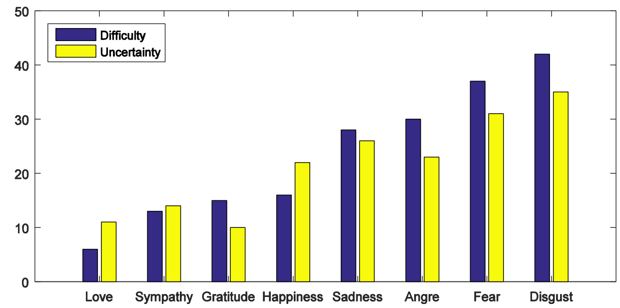

Figure 2. Number of users answering "difficult" or "very difficult" and "uncertain" or "very uncertain" over different emotions.

A. Participants

Sixty-four volunteers between 20 and 30 years of age participated in the experiment (32 men and 32 women). All were recruited via fliers and mailing lists at the University of Skövde in Sweden and received a movie ticket for their participation. The majority of participants were staff or students at the university. 47 participants were Swedish speakers and the remaining 33 were English speakers. No participant reported having previous experience of interacting with a Nao robot.

B. Procedure and Material

The study took place in the *Usability Lab* at the University of Skövde, which consists of a medium-sized testing room furnished as a small apartment and an adjacent control room. The testing room is outfitted with three video-cameras and a one-way observation glass. The adjacent control room allows researchers to unobtrusively observe participants during studies and is outfitted with video recording and editing equipment. The participants entered the testing room to find the Nao robot standing on a high table (see Figure 1).

Following Hertenstein et al. [12], eight different emotions were displayed in random order on individual slips of paper. These emotions consisted of five basic emotions: Anger, Disgust, Fear, Happiness, Sadness; and three pro-social emotions: Gratitude, Sympathy, Love. A built-in functionality, "Autonomous Life", was active on the Nao robot [16] during interventions. This comprised simulated breathing, head motions towards faces and change of eye color to give the impression of eye blinking. The robot was in other respects passive in a standing position during all interventions.

The participants were instructed to read each emotion from the paper slips, think about how he or she wanted to communicate the specific emotion, and then to make contact with the robot's body, using any form of touch he or she found to be appropriate to convey the emotion. To preclude the possibility to provide non-tactile clues to the emotion being communicated, the participants were advised not to talk or make any sounds. Participants were not time-limited as this might impose a constraint on the naturalness or creativity of the emotional interaction. Following the setting used by Hertenstein et al. [12], the study's purpose, background story, or context was not communicated to the participants.

One of the experimenters was present in the room with the participant at all times and another experimenter observed from the video control room. All interactions were video-recorded. (The outcome from this main study is work in progress, and will be reported in another paper).

In addition to the design used by Hertenstein et al. [12], a UX perspective was investigated using a questionnaire and an interview, which was conducted at the end of the experimental run. Quantitative data were collected by the questionnaire, which was administered to the participants and comprised of two questions relating to their experience from participating in the experiment. The participants' replies were reported on two different 5-point rating scales. Each question was answered eight times, once for each emotion. The questions were phrased as follows:

- Q1) How easy or difficult was it to convey the emotions via touch? 1: Very easy, 2: Easy, 3: Neither easy nor difficult, 4: Difficult, to 5: Very difficult.
- Q2) How certain are you of the way you chose to convey the emotions? 1: Very certain, 2: Certain, 3: Neither certain nor uncertain, 4: Uncertain, 5: Very uncertain.

In addition, qualitative data were collected from all participant with the use of two interview questions regarding the participant's subjective UX of interacting with the robot via touch. These questions were formulated as follows:

- Q3) Do you think you would have conveyed the emotions in the same way if it had been a human?
- Q4) How would you summarize your experience of interacting with the robot via touch?

The interviews were conducted by the first two authors, and all interviews were audio-recorded and then transcribed by the second author.

IV. Results

The collected data were analyzed in the following way. Questions 1 (Q1) and 2 (Q2) were statistically analyzed using χ^2 and Z-test of proportions. The interviews were analyzed via content analysis, searching for the core meanings in the collected data via a sense-making effort of qualitative data reduction to identify several patterns that develop into core themes [27]. Two of the authors initially performed the content analysis independently and thereafter compared and discussed their resulting themes. Only agreed upon results are reported here. Minor deviations existed and were disregarded in further analysis. The following iterations were performed collaboratively, and the findings emerged out of the reduced data in the shape of patterns representing certain aspects in the users' experience of conveying emotions to the robot. Three major themes emerged and these are labelled as: 1) *Responsiveness* of the humanoid robot, 2) *Robustness* of the humanoid robot, and 3) *Trickiness* of conveying emotions to the humanoid robot. Accordingly, the themes identified in the data analysis are presented by some representative quotes selected to show the users' experiences of conveying emotions to the robot by touch only.

A. Findings for difficulty and certainty

An $\chi2$ test of independence showed a significant ($\chi2 \approx 130$, $P < 0.001$) association between communicated emotion and difficulty (Q1). Similarly, $\chi2$ test of independence applied to Q2 showed a significant ($\chi2 \approx 89$, $P < 0.001$) association between communicated emotion and certainty. As visible in Fig. 2, users found it both easier, and were more certain, communicating positive emotions (happiness, love, gratitude, and sympathy) compared to anger, fear, sadness, and disgust.

A Z-test of proportions testing effect of gender revealed no significant differences between male and female users on the proportion of "difficult" or "very difficult" replies to Q1 ($Z \approx 0.84$, $P \approx 0.4$) and the proportion of "uncertain" or "very uncertain" replies to Q2 ($Z \approx 1.33$, $P \approx 0.18$).

C. Findings for perceived similarity to human interaction

Answers to Q3 (*Do you think you would have conveyed the emotions in the same way if it had been a human?*) were divided into three types of replies:

1. Yes – similar as if it would be a human
2. No – different than as if it would be a human
3. Indecisive

24 users (38%) answered positively to Q3. The majority of answers were short without motivations, but in a few cases the users provided some motivation for their answer:

- *Yes, to a fairly large extent. It felt as if it that was the idea, considering that it is a fairly humanlike robot to the looks and how it follows my face and so on…*
- *Yes, or that was how I imagined it. […] I see it as if it wouldn't be any point to express feelings if not somebody received it in some way.*

29 users (45%) replied negatively to Q3. These answers were more varied and revealed a number of different reasons for why they would act differently towards a human being:

- *No I do not think so. […] In a normal interaction, I would usually not be limited to only touch and this becomes a limitation so to speak. And people, I guess, would reply in some way. In this case, I was the only actor […].*

The remaining 11 participants (17%) answered indecisive, most commonly with a conditional answer depending on the conveyed emotion or relation to another human:

- *Yes, well, it depends on whom… with humans it is so much dependent on the relation one has with the other person, so I thought… for many of the [communicated emotions] I thought of it as a fairly good friend […]. The most difficult was not which emotions, but this. Which relation do we express and in which context does the social interplay take place.*

- *Not for all emotions. For sadness I think I would probably leaned towards the person for example. Otherwise, the positive emotions were a bit easier. […]*

To summarize, the users clearly viewed the similarity to human-human interaction differently. Some perceived the whole task very different compared to "natural" human-human tactile interaction. Other users described the interaction as similar to a human-human setting, because they tried to act as if the robot was a human. Thus, we consider these differences in answers as evidence that the users approached the situation differently, not necessarily indicating differences in their tactile interaction with the robot.

D. Findings for the perceived UX of interacting with the robot via touch

In their answers to Q4 (*How would you summarize your experience of interacting with the robot via touch?*), users typically described a positive UX when interacting with the robot, often using the terms interesting, exciting, nice, and fun. As a result of the content analysis, three themes, describing major aspects of the users' experiences, emerged:

- *Responsiveness* of the robot
- *Robustness* of the robot
- *Trickiness* of conveying emotions to the robot

Responsiveness is illustrated by the ways the robot is perceived by the users, based on whether the robot responded to the users' actions when conveying the different emotions to the robot.

On the one hand, some users perceived that the robot responded to their efforts to convey emotions as illustrated;

- *If felt very responsive in some way. As it… I don't know, but when I rocked it, it responded with a beeping sound. It felt a little exciting […] that it was smart somehow.*
- *It is definitely something different. It is fun because when I touched it, I had the feeling that, in some way it responded sometimes. Not always, but sometimes. I weren't really sure how strongly I should touch it but… yeah it was a nice experience. Just to try it.*

Another user expressed that the positive UX of interacting with the robot was accompanied by the robot's responses via some kind of intersubjectivity between them that was phrased as:

- *And… it was really interesting because he like… changed the color [Nao's eyes] and moved the face so it was like a kind of feedback. And it was really, really great… and… another thing is that when I took his hand, he was like holding mine so it was like… it was really great also. It was a really good experience for me. I liked it a lot.*

A similar issue, regarding the robot's responses of bodily movements, having a positive impact on the UX, was phrased as follows:

- *But it's a god experience because when I touched his head he already… he also reacted to me I think, I don't know. I think he realized that I touched his head.*

On the other hand, some users were disappointed that the robot seemed to lack an expected level of response capability to the users' efforts to convey emotions as expressed:

- *Then I experienced […] I would have wished that it should have been more interactive.*
- *It is so odd. That one doesn't receive any responses. Maybe that was the reason for the silly experience when you are asked to give full expression to your emotions but without any feedback. That was the oddest aspect.*

The lack of responses from the robot was also expressed as:

- *It feels that there is a need for more humaneness in it, to be experienced as natural. […] It's more like interacting with a stone wall.*
- *It was difficult when one didn't receive any feedback from the robot, one doesn't know whether it noticed what happened or not […].*

A similar negative UX was reported by another user:

- *It was nice but I was missing like a kind of feedback. Yeah like a response from the robot, I didn't get anything back and that is strange.*

Another user reflected on how the robot's hand was positioned and to what extend is was moveable, indicating a negative impact on the UX:

- *Yeah, trying to get the robot to move […]. The robot was equipped with movable body parts but its arms offered resistance. I can't move one of the hands upwards and grip it in a way that I want in order to symbolize or convey [an emotion]. So it's a difference between moving a down facing hand compared to lifting one hand upwards and gripping it. If I only could have aligned it […]. Then it had been another experience, I guess.*

The lack of bodily movements, negatively affecting the UX, was also perceived in this way:

- *One thing… when I tried to shake his hand, it was not flexible enough. I would like to be able to do a proper handshake.*

In sum, the users appreciated the situations when the robot responded to their actions which resulted in a positive impact on the UX, indicating a kind of "intersubjectivity" between them and the robot, whereas the lack of robot responses negatively affected the UX.

Robustness of the robot relates to the extent the robot is perceived by the users as being easily damaged and brittle when interacting with it. This aspect portrays various beliefs regarding uncertainty and hesitance when conveying the different emotions to the robot via touch. Some users expressed that:

- *When I begin to reflect, I'm very seldom touching others when conveying emotions. I don't' want to damage the* *robot, you know … when one is expressing anger for example.*

- *I was very insecure when I should push it, one think that it's a robot, it's a thing, being very brittle so to say […]. I was very worried that I should push it down because it stood on such a pedestal and there was not enough space around it. Otherwise, I could have been acting more powerful, but I didn't do that because I was anxious that I should knock it over and ruin everything.*

The anxiety and fear of damaging the robot is also illustrated by these lines:

- *People are bigger and somewhat easier to grab compared to that little figure. It is easier to hug [a person] or clap in the back or something… or sympathy could not… like clap in the back. Then it would fall over.*

Furthermore, another user expressed some hesitance to interact with the robot, because the robot was not perceived as being necessary robust as well as having some objection to the placement of the robot:

- *It felt as if… as if I would make it fall over all the time. I was afraid I would break the stuff when I wanted to express feelings. […] Grab it and so one could not do in the same way as one willingly would have done, only because I was afraid to break it. […] and the size of course.*

In sum, users refer to experimental conditions, such as the placement of the robot, but also to the task that they were asked to physically interact with an unknown, expensive, and possibly fragile, digital artifact. Several reasons for this perceived fragileness are expressed, e.g., robot size, placement, stiffness of joints, and conveyed emotion.

Trickiness is characterized by the users' own experiences of conveying emotions to the robot only via touch. The trickiness comprises several different aspects of UX, including the oddness of the task, the uncertainty and unfamiliarity of how to convey the emotions to the robot via touch, and the limitations of only using one modality.

Firstly, the oddness of the task is portrayed by some of the users as follows:

- *Very strange, actually. I would have liked to speak because it felt very strange... Even if I stood with a human it would be very strange to only do this, to convey emotions with touch.*

- *It was strange, it was really uncommon, is that the word. Odd, I've never done anything like this before.*

- *Surreal, […] this is strange. But that comes from interacting with something that does not really have any emotions.*

Secondly, the uncertainty and unfamiliarity of how to convey the emotions to the robot via touch is expressed in the following ways:

- *For some emotions, it was very uncertain since I would probably not communicate by touch in any of those cases.*

- *I'm not used to communicate emotions by touching others… well, since it is a robot it will be a slightly different emotion compared to if it would be a person.*

- *I do not have an easy time communicate emotions normally, and it was even more difficult now, with a robot.*

- *[…] it was a bit unpleasant since it is emotions that one tries to avoid in general, like disgust I thought was very difficult. […] To convey some emotions is rather private, like love and similar. To stroke its back, as I think I did for love, is a rather private thing. A little uncomfortable to show that to a small robot that also feels like a child.*

Thirdly, the limitations of only using touch for conveying emotions were expressed by several users. For example:

- *Disgust I thought was very difficult! I was forced to think about that one for a while […] to communicate that via touch is like a contradiction in itself.*

- *I noticed that I changed face expression and things like that to enhance my feelings so that it became interesting. Even though I knew that it did not matter what face I expressed towards the robot, I noticed how I sort of enhanced my feelings by changing face expression.*

Another example is phrased as follows:

- *It was very difficult to know how to express feelings in an understandable way by touch alone, without using words and without… the face really. Some emotions are easier to express without touch.*

Some users expressed it in this way:

- *I mean interact with the robot is not the thing that is confusing, it's the exercise to try to express emotion without talking and without getting any response […] I felt really lost trying to communicate in that way.*

- *[…] some of the emotions were hard because some of them, if it were a person I would maybe just make a face, like disgust. I wouldn't touch the person to show that I am feeling disgust.*

This experience is summarized in the following utterance:

- *[…] positive emotions, or what to say, kind emotions, they were easy while anger and disgust, aggressive emotions, were very difficult. Because that's the type of emotions where you actually… how to say it, you do not express them physically.*

Another user experienced the task to convey fear via touch in this way:

- *Fear is very difficult to communicate. Often one would rather flinch and avoid contact so then it becomes difficult to express by touch.*

Finally, a telling portrayal of the limitation of conveying emotions through touch on the robot is phrased as follows:

- *But if I should just show you that I am sad, I do not want to hug you. That must be shown in some other way, so I did a tear [pulling the finger over the cheek]. Difficult as hell.*

It should be noted that in the above quote, the user expressed the emotion via touch on his/her *own* body, instead of conveying the emotion on the robot's body, indicating that the robot was paying attention to the user in the human-robot interaction.

Thus, limitations of conveying emotions via one modality have generally a negative impact on the UX when interacting with the robot. In sum, several users express a strong difference between emotions, specifically highlighting disgust as a very difficult emotion to express via touch. These utterances match well with the questionnaire data presented in Sec. IV A.

The trickiness theme can also elaborate on the indecisive answers to Q3. Several users explicitly tied the oddness of the task to convey emotions to the Nao robot, arguing it would be easier if they would have interacted with a typical human being. Others expressed the trickiness in terms of the limitation to only use touch, explicitly saying that this issue was not related to the fact that they interacted with a robot.

V. Discussion

In general, the users perceived a positive UX of interacting with the robot. Although several users described the task as challenging and in some cases awkward, they still described the overall experience as positive. It should however be noted that the result may have been affected by a selection bias in this regard, since users with a positive attitude towards robots may be more inclined to accept an invitation to participate in the study. The obtained results have implications for tactile interaction in HRI in general, but also for the design of social robots in particular.

A. Implications for tactile communication in HRI

Users in the present study found it both easier and were more certain when communicating positive emotions (gratitude, happiness, love, and sympathy) compared to the negative emotions (anger, disgust, fear, and sadness). A strong effect was found with seven times as many users finding it difficult, or very difficult, to convey disgust, compared to love.

When users were asked whether they would act in the same way if the robot would have been a human, both positive and negative answers were received. Some users clearly executed the task as if the robot would have been a human being. Others gave a variety of reasons why they thought their actions would be different towards a human, but rarely referred to the fact that they communicated with a machine. Instead, users frequently referred to the lack of context and response from the robot. It may be worth noting that these observations could be made also in relation to previous research on human–human tactile communication. For example, Hertenstein et al. [12] used a similar setting, explicitly asking participants receiving the tactile communication to remain passive. The present work indicates that this experimental setup, using a passive agent receiving tactile communication, may change the tactile interaction itself.

Contrary to the above, several users explicitly described the robot as interactive. We believe this may be due to the "Autonomous Life" mode active on the robot, making it respond with head movements towards the user. Although these responses were quite limited, they clearly engage at least some users when executed at the right time. To what degree the perceived differences in interactivity were due to the functionality of the robot or different user expectations, is still unclear.

B. Implications for robot design

Few users directly expressed that they adjusted their interaction as a result of the receiver being a robot rather than a human, but several users reported other aspects, inherent from the robot design, affecting interaction. The perceived lack of robustness of the robot was clearly limiting the interaction, leading some users to reducing or even avoiding tactile communication they otherwise would have expressed.

In a similar direction, several users commented on the rigidness and stiffness as a constraining aspect of the tactile communication. While tactile interaction is often seen as a sender–receiver communication in the information transmission metaphor (see Lindblom [28] for a discussion about different metaphors on interaction), these results highlight the interactive aspect of touch, and the role of the receiver as providing a certain level of compliance and responses. This follows the dance metaphor of interaction [28]. These aspects apply in design of compliance control of rigid robots, but could also be relevant in relation to soft robots or robots covered by soft materials, for example textiles. In a continuation of the present work, we would find it interesting to look at different levels of robot compliance, for example in terms of reduced stiffness in the robot's joints. This is however a careful tradeoff since high compliance may affect the robot's stability and, in a more ecological setting, even prevent the robot from executing its tasks.

Despite the fact that Hertenstein et al. [12] reported high information content in affective tactile communication between humans, several users in this study expressed a desire to also use other modalities than touch, explicitly referring to facial and vocal communication. We believe this should be understood as an argument for an increased multi-modality in the interaction design of social robots.

Another aspect of the robot design frequently expressed by the users is the size of the robot. Nao is just above 57 cm high, which some users perceived as a limiting factor of interactions. Other users compared the robot to a child, possibly making tactile interaction being more intuitive. We therefore look forward to the opportunity to extend this work to other robot platforms, e.g., Pepper [16]. Pepper has a height of 120 cm and may be perceived quite differently regarding tactile interaction.

VI. Conclusions and future work

Future work includes addressing the embodied and situated aspects of interacting with humanoid robots, which have been implicitly mentioned in the users' experiences when interacting with the robot through touch. The work reported in this study presents a short-term perspective of how the users experience the interaction. However, it lacks a long-term perspective and it would be of interest to examine whether the UX would change if the HRI occurred during a prolonged timeframe, e.g., the perceived trickiness when conveying emotions to the robot through touch only.

In addition, more elaborated and structured UX studies have to be conducted in this area of HRI research where specific UX goals are identified and then assessed iteratively [1–3]. Highlighting the importance of evaluating the quality of the human-robot interaction is of major concern for a user-centred perspective of social robots in HRI. Many evaluation methods and techniques have been developed resulting in evaluations of different aspects including acceptance, usability, UX, learnability, safety, trust, and credibility. While some of the aspects are covered in depth some are just briefly touched upon in HRI research [18, 19]. Lindblom and Andreasson [20] stressed that there is a need for more theoretical as well as methodological knowledge about methods and techniques that are appropriate for evaluating UX in HRI, and there is a significant need for conducting valid usability and UX studies in order to exploit UX to its full effect and to improve positive UX of socially interactive robots.

To conclude, we would like to point out that the UX perspective is of major concern given that this type of interactive technology allows humans to become more socially situated in the world of artifacts. That means the real strength of humanoid robotics is its potential to facilitate more 'natural' human-machine interaction, allowing humans to interact with artifacts in the ways they are used to interact with each other. Furthermore, studying how humans interact with humanoid robots may provide significant insights concerning the fundamentals of human-human interaction, because it is in relation to something more familiar that the unknown becomes visible and makes sense. Thus, it is a win-win situation for both perspectives, addressing what it means to be a human being.

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