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Modeling Robot Hand Touch Behaviors to Express Emotions

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SEPTEMBER 2022

Modeling Robot Hand Touch Behaviors to Express Emotions

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Abstract

This thesis presents a series of works of design methodologies for a robot to use hand touch proactively to naturally convey various emotions. For the robot to express emotions in human-robot interactions (HRI), current social robots generally rely on four expression modalities: facial expression, speech, gesture, and tactile stimulation. Among these four modalities, the tactile approach is the least explored. Especially, past tactile research mainly focused on touch interactions from human to robot, and almost none explored hand touch from robot to human. As social robots are expected to provide human-like social utilities, and human social touch not only can intensify the conveyed emotions, but also play a critical role in human's psychological development, it is important to make social robots capable of performing social touch proactively. Therefore, the goal of this thesis is to explore how to design a robot's hand touch behaviors to physically touch people and express various emotions more strongly and naturally than using its facial expression, speech, and gesture.

The first study explored how to emulate the fine movements of the human hand and replicate the social touch in an robot. This help to set the design approach for creating social touch for robots. By reviewing the work on human social touch, I focus on hand-to-hand touch behaviors as it is a general approach to expressing emotions. I decomposed human's hand touch behaviors and select three most impactful hand touch characteristics, *length*, *type*, and *part*. Then I selected commonly used emotions in social HRI, i.e., happiness, and its counterpart emotion, i.e., sadness borrowing Ekman's definitions, as the goal for the robot to express through touch. I designed two behavior variants for each characteristic and map them to the two emotions from the arousal/valence perspective. I experimented and the results showed that the touch *length* and its *type* are useful to change the perceived strengths and the naturalness of the expressed emotions based on the arousal/valence perspective, while the*part* did not fit such perspective

assumptions. Finally, our results suggest that a brief "pat" and a longer "contact" by using the robot's fingers are better combinations to express happy and sad emotions with our robot respectively.

The second study extended the idea that social touch is to intensify emotional communication by exploring how to convey intimacy through touch. By referencing how humans use touch to how intimacy, I introduced a new touch characteristic *place*, i.e. where the robot should touch. Combining with most impactful touch characteristics *type* from the first study, I verified their effects on the perceived intimacy by expressing the common emotion, i.e. happiness. Our results showed that the touch *type* is useful to change the perceived intimacy, although the touch *place* did not show significant effects. I then investigated the perceived intimacy of the other two touch characteristics, *length* and *part*. The results showed that the touch *part* is useful to change the perceived intimacy while the touch *length* did not show significant effects. Finally, our results suggested that patting by fingers is a better combination to express intimacy with the robot.

The third study tackled the hand touch design from a different angle, i.e., selecting appropriate touching timing in context with interaction scenarios. While I have laid down the foundation of combing characteristics to design various hand touches, the goal of this thesis is to help robots express emotions through touch. And without the context and scenario, no emotion can be properly expressed. Therefore, I took a novel approach by using probability modeling. Firstly, I chose heartwarming and horror video clips as emotional stimuli and designed a video-watching scenario to make the robot touch participants at the appropriate time. I conducted a data collection experiment with participants identifying appropriate touch timing and duration relative to a video's climax. From the collected data, I modeled touch timing and duration by fitting them to probabilistic models. Results indicated that participants preferred a touch timing before and after a climax for horror and heartwarming videos respectively. Then, I implemented the best-fitted models to decide on touch timings and conducted a verification experiment. The results showed that touch timing before the climax received better evaluation than touch timing after it for both horror and heartwarming videos. This study demonstrated that appropriate touch timing could help emotional expression and provide new approaches to designing robot hand touch behaviors.

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Chapter 1

Introduction

Due to the advance in daily environments of socially intelligent robots that perform such services as physical and mental health support [1, 2, 3], education [4, 5, 6], and companionship [7, 8, 9], representing the emotions of robots is critical for achieving more natural and acceptable interactions with ordinary people. Although robots do not process the biological mechanism for generating emotions, at least from the organic beings' perspective, it is possible to emulate human-like behaviors that allow robot users to perceive emotions from them.

Humans express emotions through various communication modalities, linguistic, visual, aural, etc. [10], which can be used to design emotional communication methods for social robots. These modalities are consolidated into four major channels: facial expression, speech, gesture, and tactile stimulation. The first three communication channels have received much attention in the research community over the past 20 years. However, while emotional tactile stimulation is intrinsically unique compared to the other three modalities, it received much less attention.

1.1 Emotional tactile communication is both unique and important

In social robotics, facial expression can be considered the earliest research area. The famous Kismet robot [11] has proven how simple, yet effective

Figure 1.1: Robot COZMO, its flat LED screen can display rich facial expressions. But users can quickly become used to its exaggerated expressions. (Image downloaded from https://bit.ly/3MLEmeT)

facial expression could be for robots to convey various emotions. Following that, many of the robotic products later developed in research and industry communities demonstrate repeatedly that even a simple LED screen could become an effective channel to display various facial expressions, like that of the COZMO robot (fig. 1.1). However, while simple and direct, facial expressions can only convey a limited emotional intensity and more exaggerated facial expressions often lead to uncanny effects [12]. That is, if the robot wants to convey stronger emotions, facial expressions are not enough.

As the speech synthesizer and speech-to-text technology matured from the 1990s [13], designers were able to make speech available for social robots. This is a powerful channel to exchange information but generally falls short in emotional expression. Only until perhaps the early 2000s did research on emotional expression through speech start to gain attention [14]. One of the technical difficulties in emotional speech is that it is hard to simulate human-like vocal prosody, e.g., pitches, tones, etc. [15]. Another method to embed emotion is through the context of the speech [16], but heavily relies on scenario design. And if language is not the concern, it is possible to use non-linguistic utterances to convey basic emotions [17]. However, synthesized speech is less effective to convey emotions not only due to technical limitations, but also suffer the vagueness of expressing the intended emotions by itself [15, 17]. It works better as a supplement to facial expression.

Gesture is another method to display emotions. For virtual agents, it is much easier to design complex and subtle postures. While for physical robots, the available postures are limited by both the robot's physical structure and its controlling mechanism [18]. Posture has the same problem as speech and should also be considered as a supplement to facial expression.

Lastly, tactile stimulation is unique compared to the other three modalities. Firstly, it requires physical contact and thus the robot must be physically presented in the same space as its users. Secondly, it could provide psychological benefits like reducing stress or lowering heart rate [19, 20], which can rarely be achieved by other modalities. Thirdly, it is a more universal and accessible communication channel [21]. In fact, looking back from a biological and psychological perspective, tactile sensory is the earliest sensation developed in birds and mammals [22]. Inadequate touch stimuli in human infants and early years of childhood can lead to impaired growth and cognitive development [23]. On the other hand, proactive touch stimuli have proved to be very effective in psychotherapy [24] and can provide various health benefits like treating hypersensitivity, pain and other mechanosensory disorders [25].

1.2 Robot social touch

When referring to touch behaviors to express emotions in human-human interactions, the word "affective touch" is used. affective touch can be defined as tactile processing with a hedonistic or emotional component [26] and CT fibers are likely to convey this component [27, 28]. In comparison to the "non-affective" touch, affective touch can evoke different brain responses and is an effective way to communicate emotions and create social bonds [29].

The concept of "affective touch" has been used in social robotic research to enrich human-robot interactions [30, 31]. In these researches, most touch behaviors focused on hugging or contact with the robot acting as the receiving end of the touch [32]. In other works, researchers use the word "social touch" [33, 34, 35, 36], to describe the touch behaviors performed from robots to humans. According to Sawabe [36], the definition of social touch is occurring between individuals and used to ease interpersonal communication and express personal feelings for other people. If used in social HRI, we can say that social touch from robot to human is to ease human-robot communication and help express robot feelings toward other people.

1.3 Design robot hand touch to convey emotions

In human-human touch interactions, one of the most common channels is hand-touch [37]. Hand touches, i.e. caress, stroke, etc., can provide unique social utilities like intensifying emotional display for showing social bonds between couples [38] or provide positive psychological effects like reducing feelings of social exclusion [39].

Despite the importance of touch as a communication modality, only until recent years that robotics researchers started to pay attention to human-robot touch interactions [40, 41, 32, 42, 19]. However, even though these studies identified the positive effects of a robot's touch, appropriate hand touch design remains unknown. More importantly, past studies generally focused on human-robot touch interaction from humans to robots, but overlooked touches from robots to people. As a result, we lack the knowledge to design and implement appropriate hand touch behaviors to express emotions.

Given the lack of research regarding the methodology for designing hand touch behaviors for robots, the goal of this thesis is to explore how we can design a robot's hand touch behaviors to express emotions. Working towards the goal, it can be summarized into three research objectives:

- 1. To decompose human hand touch behaviors and identify touch characteristics that can be used to design robot hand touch.
- 2. To evaluate the effectiveness of designed robot hand touch to convey emotions.
- 3. To verify the feasibility of implementing the hand touch behaviors in the context of emotional scenarios.

Therefore, I layout three research questions that are covered sequentially in three studies:

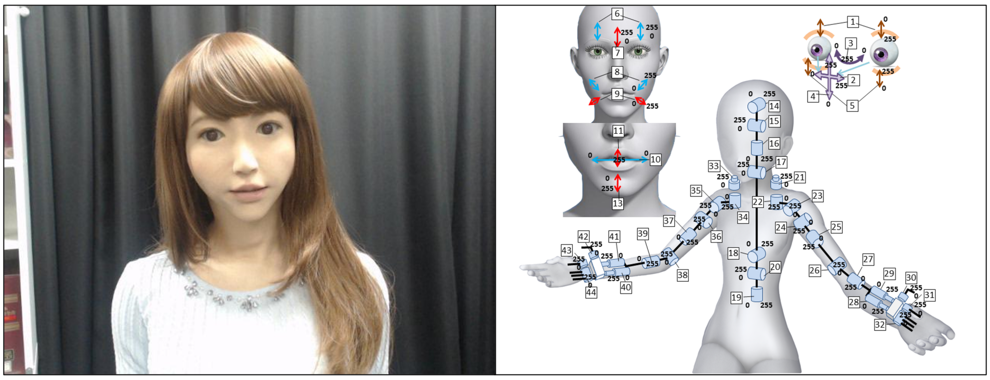

Figure 1.2: Overview of android ERICA

- 1. How to design human-like hand touch behaviors for a robot to express basic emotions?
- 2. Could the robot hand touch behaviors intensify the expressed emotions, i.e., make people feel intimacy?
- 3. How to implement the touch behaviors to express different emotions in the context of a scenario?

1.4 General approach

This thesis used Android ERICA [43] to develop touch behaviors. ERICA is an advanced android with a feminine appearance and sophisticated mechanical structures that are capable of human-like movements (fig. 1.2). She can seamlessly perform human-like facial expressions and gestures, and has a speech synthesizer to speak in both Japanese or English with feminine human-like voices. She has silicon skin that is soft and somewhat feels like human skin if ignoring the fact that her skin is cold.

All studies in this thesis started by referring to corresponding human touch behaviors or human-human interaction norms. Because of this, it is advantageous to use an android as a research platform. The android made it straightforward to emulate human touch behaviors because we could directly apply the touch characteristics to design her touch behaviors. Her ability to use all four modalities made it easier to evaluate the naturalness and strength of her touch behaviors in comparison to her facial expressions, speech, or gestures. Her arm is flexible enough and her movement torque is small so that it is safe for her to directly make physical contact with experiment participants without worrying about causing injuries.

To convey emotions through touch, we took the psychological constructionism approach [44] by combining basic elements, i.e., touch characteristics, to construct touch behaviors that are effective for different emotions. We took the widely used Russell's circumplex model [45] in social HRI research as the base psychological model for decomposing behavior variants for each touch characteristic.

1.5 Organization of chapters

The remainder of this thesis is structured as follows:

Chapter 2 presents the first study, in which three touch characteristics, i.e., *type*, *part*, and *length*, of using the android's hand to proactively touch human participants are explored. These touch characteristics are combined to design different touch behaviors and are evaluated in their strength and naturalness in expressing the two most commonly used emotions in social HRI, i.e., happy and sad. Finally, the data are analyzed to show if the touch behaviors can intensify the expressed emotions and which combinations of touch characteristics are appropriate to express what emotions.

Chapter 3 presents the second study, in which we continue using the touch characteristics designed in the first study to explore how can the android express intimacy through hand touch. We investigated a new touch characteristic, i.e., *place*, and explores the effects of these four touch characteristics on perceived intimacy from participants touched by our android with an intention to convey happy emotion. The data are analyzed to find out which touch characteristics are effective to express intimacy in hand touch interactions.

Chapter 4 presents the third study, in which video-watching interaction scenarios are constructed to verify implementation methods under a more realistic situation. With carefully selected and edited commercial video clips acting as emotional stimuli, participants are given the chance to watch the video clips with our android while the android proactively touches the participants. This study consists of two parts. In the first part, participants' expectations regarding the appropriate touch timing are collected. The data is used to build probability models which are used to decide touch timing in reacting to different emotional stimuli. Then in the second part, these models are implemented to help the android decides touch timing when the android proactively touches the participants in video-watching scenarios. The result is analyzed to verify the feasibility of using these behavior models and the appropriateness of touch timing in conveying different emotions.

Chapter 5 presents the two possible scenarios to apply robot hand touch behaviors. Then this chapter presents the limitation, followed by the discussion and my reflections on the work of this thesis.

Finally, Chapter 6 concludes this thesis in relation to the research objectives, and directions for future research.

Chapter 2

Design Hand Touch to Express Basic Emotions

2.1 Introduction

Touch is an essential factor in emotional communication for human beings in conjunction with facial expressions and language. Various human science literature has revealed how touch interactions are used between people [46, 47, 48] and how touch shapes emotions [49, 50, 51]. The positive and negative effects of touch interactions have also been broadly investigated, for instance, its importance for human well-being [20, 52, 53]. To understand the relationship between touch and conveyed emotions, Hertenstein et al. conducted a data collection with touch-type and touched-part and different emotions (Ekman's emotions [54, 55] and prosocial emotions [56]) and proposed a touch-emotional map [57]. CT afferent research perspectives focused on mechanisms for processing affective touch and effects of them, e.g., researchers investigated the brain regions involved in the perceptions of CT-supported affective touch [58, 59].

However, even if these studies identified the positive effects of a robot's touch, appropriate touch design remains unknown for expressing a robot's emotions toward people. In other words, past studies generally focused on human-robot touch interaction from people to robots and overlooked touches from robots to people in emotional interaction contexts [60, 61, 30]. Other work described a tactile-emotional map in human-human interaction [57] as well as human-robot interaction in the context of touching from people to robots [31, 62, 63] and reported that the touch situation contexts (e.g., emotions) complicate appropriate touch styles. Although several past studies focused on touch-speed characteristics, i.e. CT-optimal touch (around 3 5 cm/s) [64, 65, 66], they did not report any detailed effects of such major touch characteristics as length and concentrated less on the design guidelines for a robot's touch interaction scheme.

One critical question remains: what kinds of touch characteristics of robots effectively match a robot's emotional expressions? When we touch another person, depending on the emotions we hope to convey, we often implicitly use different characteristics: a short/long touch, contacting/patting, and/or touching by fingers/hand. For instance, a caregiver may use touch behaviors to express emotions and/or empathy when he is interacting with seniors. If social robots are used in such situations, they must choose appropriate touch characteristics to match the emotions they are going to express.

This study serves as a first step to understanding the relationships between touch characteristics and emotions in human-robot touch interactions. I investigated the relationship among three kinds of touch characteristics (length, type, and part) from an arousal/valence perspective and two emotions (happiness and sadness, which is a typical emotion pair in human-robot interaction contexts to express positive and negative responses) based on the definitions of Ekman's six basic emotions [55]. I experimented with an android named ERICA who has a feminine, human-like appearance in Fig. 2.1. Our study answers the following question:

- What combinations among touch characteristics are appropriate to express happy/sad emotions?

2.2 Robot setup

To investigate the relationships between the expressed emotions and touch characteristics, I need a robot that can express emotion by its voice and facial expressions. It also needs enough degree of freedoms (DOFs) in its arms to touch people with different touch characteristics. Based on these requirements, I chose a robot with a human-like appearance to express emotions by facial expressions and its voice as well as its arms to touch people in various ways. For the rest of this thesis, I will always use ERICA as the robot for experiments.

Figure 2.1: ERICA's touch interaction and happy/sad facial expressions.

The android ERICA [43] has a feminine appearance and the capability to express human-like facial expressions. She has three DOFs in her torso and ten in each of her arms. With the two DOFs on each of her wrists and the three on her palms, she can touch people with several touch characteristics. She uses an open-loop movement control system and can update each of her actuator target positions every 50 milliseconds. Even though her silicon-based skin appears very human-like, unfortunately, her touch feels different from human skin. I put gloves on her hands to avoid mismatched impressions between her appearance and the feeling of her touch. Figure 1 shows ERICA's facial expressions for happy and sad emotions. I also prepared corresponding fillers and sentences to express her emotions. For instance, when she expresses a happy emotion, she laughs and says (in Japanese) "I'm really happy." Voice cues are critical for the cognitive representations of the facial expressions of emotions in adults [67]. The facial expressions and voice cues are synchronized with the start timing of the touch behaviors. For the speech synthesis function, I used HOYA text-to-speech software (http://voicetext.jp/) that provides her with rich, human-like Japanese speech.

2.3 Emotions: happiness and sadness

Emotional expression is an essential factor for social robots to build friendly relationships with interacting people. In fact, several past studies investigated the positive effects of a robot's emotional expressions, including facial expressions, body gestures, and/or speech [68, 69, 70, 71, 72, 73]. In this context, showing positive emotions (typically happiness) is one basic interaction strategy for such robots in daily environments for friendly interactions. For example, past studies designed robots that expressed happiness to build relationships with people in long-term interaction settings [74, 75]. Based on these reasons, I focused on the relationships among touch characteristics with which robots more strongly and naturally express happy emotions.

I simultaneously focused on sad emotions because happy and sad emotions are considered a pair of bipolar emotions based on Russell's circumplex model of affect [45]. In other words, these two emotions have opposite arouse/valence aspects (happy: high arousal and valence, sad: low arousal and valence). From the perspective of HRI design, sad emotions are typically used as negative emotions [71, 72, 73]. In fact, expressing sadness has richer application scenarios such as showing empathy [76].

I focused on just two (instead of all six) of Ekman's basic emotions for two reasons: 1) comparing all six emotions combined with all the permutations of touch characteristics would greatly complicate our analysis, and 2) happiness and sadness are the most typical emotions used in designing human-robot interactions, and the scenarios that use the remaining four are situational and less frequent. For example, anger is another candidate emotion to replace sadness based on Russell's model; however, in the context of current HRI applications, anger is probably less common than sadness. Based on these reasons, I focused on happy and sad emotion pairs in our study.

2.4 Touch design

In human-human interaction, people can touch another person to express emotions. A past study investigated the relationship-specific maps of body regions where social touch is allowed and reported that touching the hands of another person is acceptable regardless of their relationship [76]. Another study investigated the body locations touched by participants to convey different emotions and concluded that they touched the hands/forearms to express happiness and the hand/shoulders to express sadness [57]. From a different perspective, another study concluded that participants mainly touched hands/forearms for both happy/sad emotions with robots [31, 62]. These differences remain unclear. Since all studies suggested that touching the hand commonly expresses happy/sad emotions and that the hand is an appropriate location for social touching, I chose a participant's hand as a robot's touch target.

To guarantee that all the participants experienced the same interactions with identical touch behaviors, I positioned them next to the robot as shown in Fig.2.1, allowing them to easily observe its facial expressions as well as its touching behaviors. I placed markers on a table to indicate where the participants should put their palms and forearms. I asked them to keep their right hands and arms on those markers when ERICA did her touch behaviors.

To change the perceived strength and naturalness of the emotions expressed by a robot, I focused on touch characteristics that can show different levels of arousal/valence. For example, a touch that expresses a high arousal/valence impression is more natural for expressing a happy emotion with a stronger impression. Although many other touch characteristics resemble the reasons for selecting emotions (i.e. difficulties in comparing large numbers), I investigated three kinds of related touch characteristics: length, type, and part (Fig. 2.2). All three items show different arousal/valence aspects.

2.4.1 Length

A past study reported that participants perceived a longer touch as a significantly negative valence perspective [34]. On the other hand, to the best of our knowledge, no past studies in touch interaction directly investigated the effects of touch characteristics on arousal. One past study on emotional expressions for a social robot did report that a gesture's speed influences its perceived arousal, e.g., a fast behavior can express higher arousal than a slow behavior [77]. Another paper [30] reported that the touch duration with high-arousal situations is relatively longer than low-arousal situations, even though the touching target is not a human being. Therefore, based on these considerations, I prepared short and long touches that express high/low arousal/valence feelings from the length perspective. Due to a lack of published references, I conducted a small pilot study within our laboratory and heuristically decided the actual lengths for short and long touches that enable people to feel the differences between them. I used 0.5- and 2-second contact durations for the short and long touches as shown in Fig. 2.3.

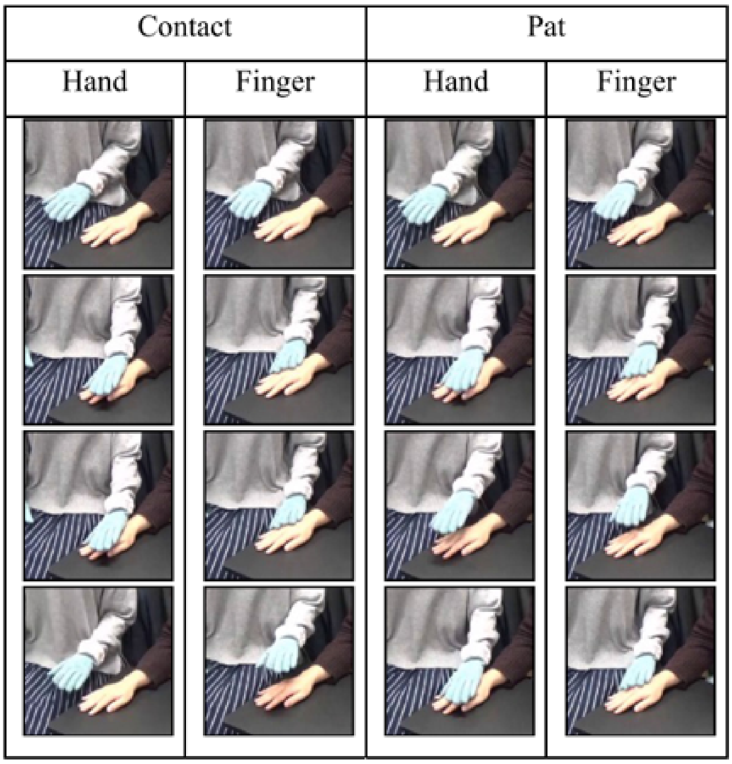

Figure 2.2: ERICA's touch behaviors.

2.4.2 Type

Type of touch: A past study reported that participants felt high arousal and valence with more pulses in the touch stimuli [76]. Another work reported that a patting gesture showed more aroused emotion than contact without movement [30]. I assumed that a simple contact (Fig. 2.3) is a single-pulse type, and a pat-like touch (Fig. 2.4) is a multi-pulse type. Therefore, I prepared contact and pat touches that express high/low arousal/valence feelings in the type perspective. I also heuristically determined a 50-millisecond stay time for short-pat touches and a 250-millisecond stay time for long-pat touches (Fig. 2.4).

2.4.3 Part

Part of touch: Although people use different body parts to make contact and express meaning [56, 78], e.g., hands, elbows, upper torso, etc., they are less focused on comparing arousal/valence perspectives. However, a previous study focused on the intensity of the touch stimuli [76] and reported that a high intensity showed a greater arousal than a low intensity without any valence significance. Another past study reported that the intensity of the aroused pats is stronger than relaxed pats [30]. In this study, I changed the size of area and the total touch pressure to show different touch intensities, i.e., using hand and finger (Fig. 2.2).

2.5 Experiment

2.5.1 Hypotheses and Predictions

People can select appropriate touch characteristics that match their own emotions with which they convey their feelings more strongly and naturally and achieve smooth interaction with others. In human-robot interaction, expressing such typical emotions as happiness and sadness are also important to build smooth interactions and relationships with people. If a robot's touch behaviors match the emotions being expressed (as designed from an arousal/valence perspective), their perceived strength and naturalness (i.e. happy and sad) from people will increase. Based on these considerations, I

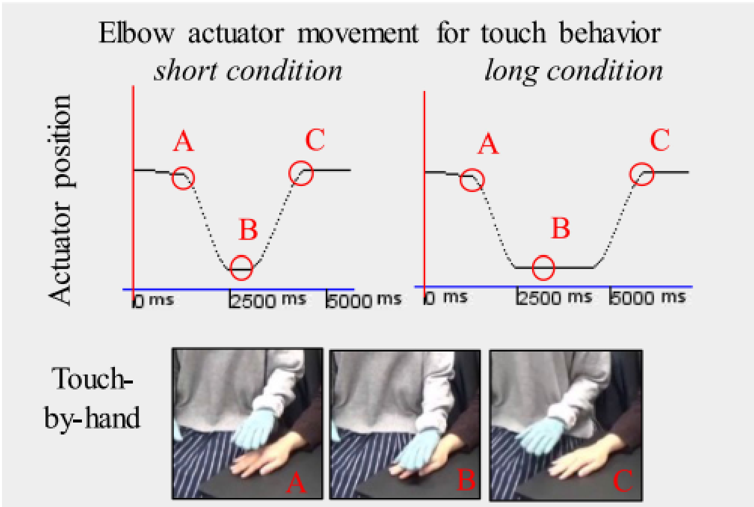

Figure 2.3: ERICA's touch behavior design in *touch* condition.

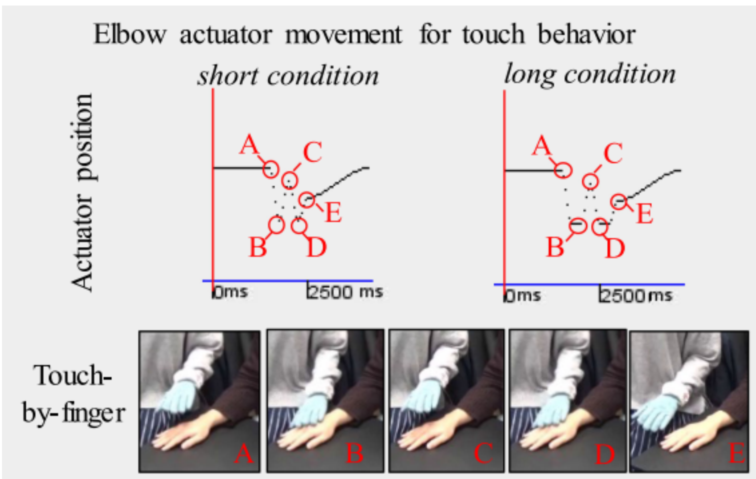

Figure 2.4: ERICA's touch behavior design in *pat* condition.

made the following three hypotheses about the relationships between emotions and touch characteristics.

- **Prediction 1**: When ERICA expresses a happy emotion, a short touch will be perceived as stronger and more natural than a long touch. When she expresses a sad emotion, a long touch is perceived as stronger and more natural than a short touch.
- **Prediction 2**: When ERICA expresses a happy emotion, a pat type touch will be perceived as stronger and more natural than a contact-type touch. When she expresses a sad emotion, the contact-type touch will be perceived as stronger and more natural than the pat-type touch.
- **Prediction 3**: When ERICA expresses a happy emotion, a finger touch will be perceived as stronger and more natural than a hand touch. When she expresses a sad emotion, a hand touch will be perceived as stronger and more natural than a finger touch.

2.5.2 Participants

Twenty-two native Japanese (11 females and 11 males whose ages ranged from 19 to 39 and averaged 29.0) participated in our experiment. They were recruited from commercially available lists to provide a wide range of backgrounds and lifestyles. None had ever interacted with an android that touched them.

2.5.3 Conditions

This study had a within-participant experiment design, i.e., each participant experienced all the combinations (16 trials) of the touch characteristics.

- Emotion factor: happy and sad (Section 2.3).
- Length factor: short and long (Section 2.4.1).
- Type factor: contact and pat (Section 2.4.2).
- Part factor: hand and finger (Section 2.4.3).

2.5.4 Procedure

Before the experiment, the participants were given a brief description of its purpose and procedure. This research was approved by our institution's ethics committee for studies involving human participants. Written, informed consent was obtained from all of them.

First, I explained that the android expresses specific emotions with a touch, facial expressions, and speech. The participants sat next to ERICA on her left (Fig. 2.1). Then I calibrated the table markers to reproduce identical touch behaviors for all the participants. At the beginning of the experiment, ERICA greeted them and briefly introduced its purpose and procedure from her own perspective: thanking them for helping her collect data to improve her interpersonal-touching ability. Then she told them that she would randomly select an emotion and express it with different touch behaviors and asked the participants to compare its strength and naturalness to baseline conditions.

First, ERICA randomly selected one of the two emotions, only used facial expressions and a set of fillers and sentences to express that emotion (i.e., happiness or sadness without any touching), and identified that this was the baseline condition. Then she randomly selected one of the eight touch behaviors and expressed an emotion by touch and the same facial expression and the set of fillers and sentences. After experiencing ERICA's emotional expression combined with a touch, the participants completed questions (Section 2.5.5). ERICA repeated the above procedure until the participant experienced both emotions. The orders of the touch behaviors and emotions were counterbalanced.

2.5.5 Measurements

To compare and investigate the perceived emotional impressions from ERICA's emotional expressions with a touch to the baseline (i.e., without touching), I asked the participants to compare two aspects, strength ("degree of strength of the perceived emotion through the android's behaviors") and naturalness ("degree of naturalness of the touch behavior to express the emotion") on questions to the baseline condition, which I evaluated on a 1 to 7 point scale. Directly in front of the participant, I put a computer on another desk with a program that displayed a question each time ERICA finished a touch behavior (Fig. 2.5).

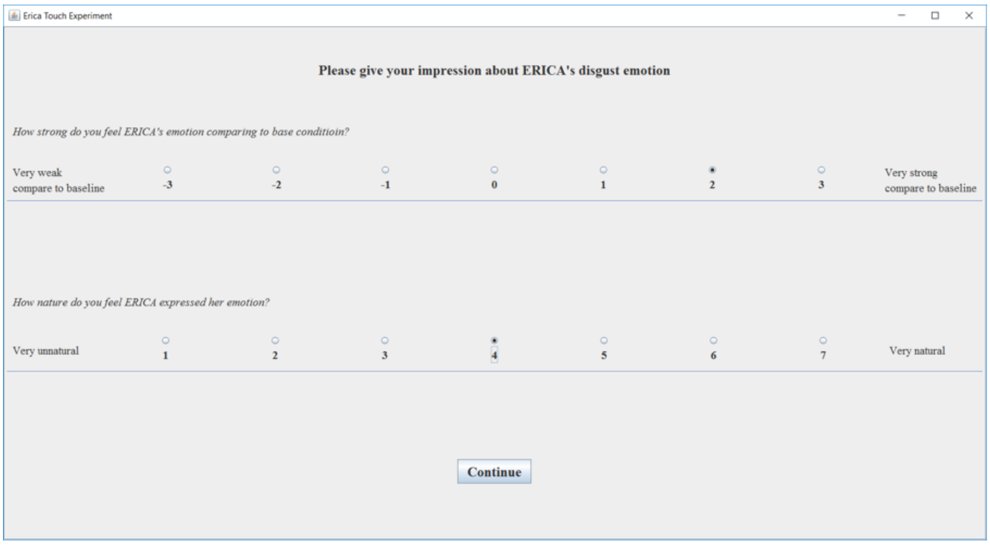

Figure 2.5: The user interface of the interactive questionnaire. It should be noticed that in the actual experiment, questions were asked in Japanese.

2.6 Results and analysis

2.6.1 Analysis on strength impression

I conducted a four-factor mixed ANOVA for each scale on length, type, part, and emotion for the strength impressions. For the sphericity of the analysis, note that since the number of the levels of the repeated measures is two, sphericity has not been violated in this setting. I identified the significant main effects in the type factor (F(1,21)=5.143, p=.034, partial $\eta 2$=.374) and in the part factor (F(1,21)=10.337, p=.004, partial $\eta 2$=.330). I also identified the simple interaction effects between emotion and length (F(1,21)=15,717, p=.001, partial $\eta 2$=.428) and emotion and type (F(1,21)=22.066, p=.001, partial $\eta 2$=.512). No other simple main and interaction effects were significant (Table 2.1). To verify our predictions, I conducted a multiple comparison of the interaction effects.

2.6.2 Analysis on naturalness impression

I also conducted a four-factor mixed ANOVA for each scale on length, type, part, and emotion for the naturalness impressions. I identified the

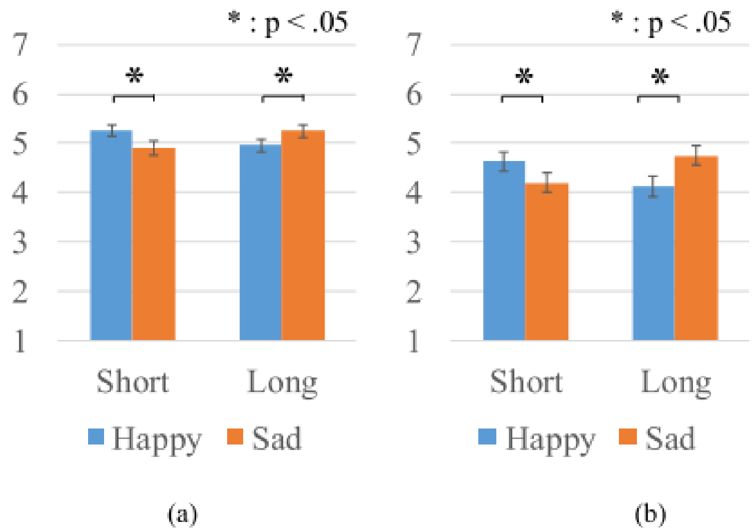

Figure 2.6: Average values of strength (a) and naturalness (b) of touch length and emotion factors.

significant main effects in the part factor (F(1,21)=49.941, p=.001, partial η2=.704) and the simple interaction effects between emotion and length (F(1,21)=14.384, p=.001, partial η2=.407) and emotion and type (F(1,21)=28.453, p=.001, partial η2=.575). No other simple main and interaction effects were significant (Table 2.2). To verify our predictions, I conducted a multiple comparison of the interaction effects.

2.6.3 Verification of prediction 1 on touch length

In our analysis of the strength and naturalness impressions, I found interaction effects between emotions and length. Therefore, I conducted multiple comparisons with the Bonferroni method of the simple main effects and identified significant differences in both the strength and naturalness impressions (Fig. 2.6). For strength, I found significant differences in happy with short > long (p =.022) and sad with long > short (p =.030). For naturalness, I found significant differences in happy with short > long (p =.008) and sad with long > short (p =.006). Therefore, prediction 1 was supported: short was appropriate for happy emotions, and long was appropriate for sad emotions.

Table 2.1: Statistical results of strength impression (bold indicates the p-value less than 0.5)

Source	p
Length(L)	0.877
Type(T)	**0.034**
Part(P)	**0.004**
Emotion(E)	0.868
L*T	0.406
L*P	0.713
L*E	**0.001**
T*P	0.409
T*E	**0.001**
P*E	0.649
L*T*P	0.926
L*T*E	0.530
L*P*E	0.943
T*P*E	0.441
L*T*P*E	0.626

Table 2.2: Statistical results of naturalness impression (bold indicates the p-value less than 0.5)

Source	p
Length(L)	0.835
Type(T)	0.086
Part(P)	**0.001**
Emotion(E)	0.656
L*T	0.883
L*P	0.318
L*E	**0.001**
T*P	0.494
T*E	**0.001**
P*E	0.331
L*T*P	0.316
L*T*E	0.767
L*P*E	0.838
T*P*E	0.762
L*T*P*E	0.334

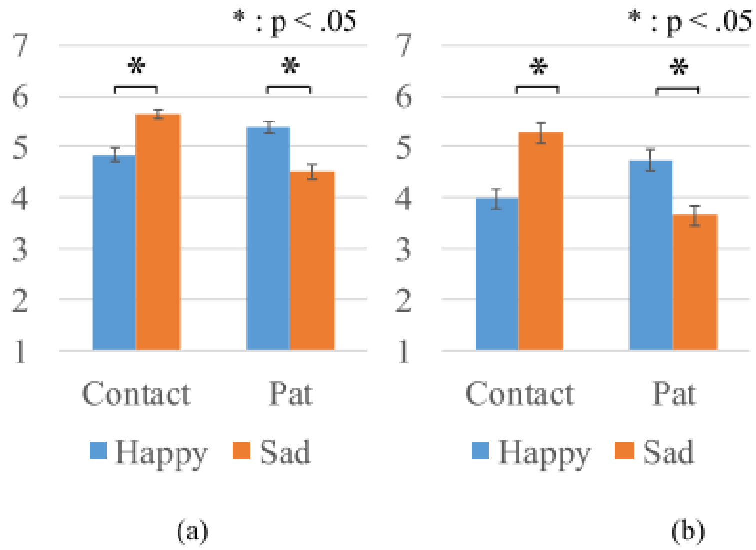

Figure 2.7: Average values of strength (a) and naturalness (b) of touch type and emotion factors.

2.6.4 Verification of prediction 2 on touch type

In our analysis of the strength and naturalness impressions, I also found interaction effects between emotions and type. Therefore, I conducted multiple comparisons with the Bonferroni method of the simple main effects and identified significant differences in both the strength and naturalness impressions (Fig. 2.7 For strength, I found significant differences in happy with pat > contact (p =.012) and sad with contact > pat (p =.001). For naturalness, happy with pat > contact (p =.030), and sad with contact > pat (p =.001). Therefore, prediction 2 was supported; pat was appropriate for happy emotions, and contact was appropriate for sad emotions.

2.6.5 Verification of prediction 3 on touch part

In our analysis of the strength and naturalness impressions, I did not find any interaction effects between emotions and part (Fig. 2.8); I only found a significant difference of the effect in the part factor. Finger touches are better than hand touches for both the happy and sad emotions based on strength and naturalness perspectives (p=.004 and p=.001). Prediction 3 was not supported.

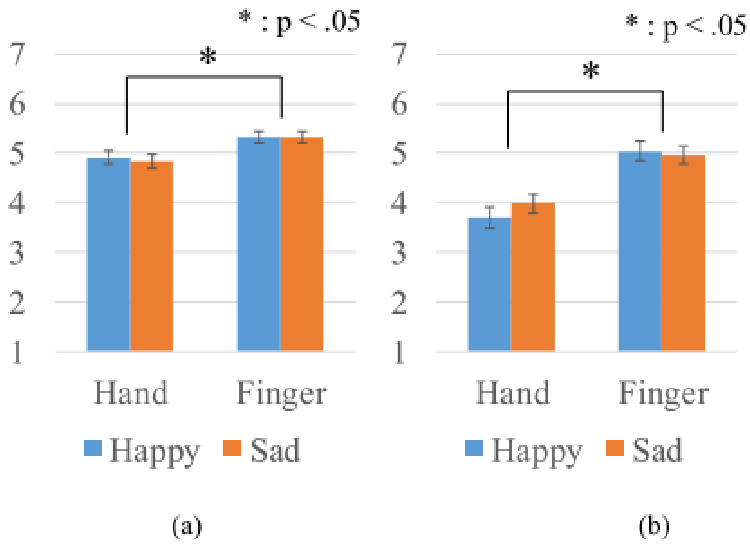

Figure 2.8: Average values of strength (a) and naturalness (b) of touch part and emotion factors.

2.6.6 No gender effects

I conducted a five-factor ANOVA by considering the gender factor. However, our results did not show any significant effects of gender. One possible inference about why there is no significant effect in the gender effects is the toucher's gender (i.e., female-appearance robot). If I conducted the same experiment with a male-type android, gender effects might be apparent due to gender combinations.

2.6.7 Additional analysis

As an additional analysis, I compared the relationships between each combination of touch characteristics and its perceived strength and naturalness. I can see that most touch behaviors have their evaluations exceed the baseline conditions with a few exceptions mainly in the *short-hand-pat* combination in perceived naturalness as shown in Fig. 2.9 and Fig. 2.10. However, I did not compare the effectiveness of each touch characteristics with the baseline.

I conducted a two-tailed binominal test (I classified question results into two classes: strong/natural (5 to 7) or weak/unnatural (1 to 4)) to investi-

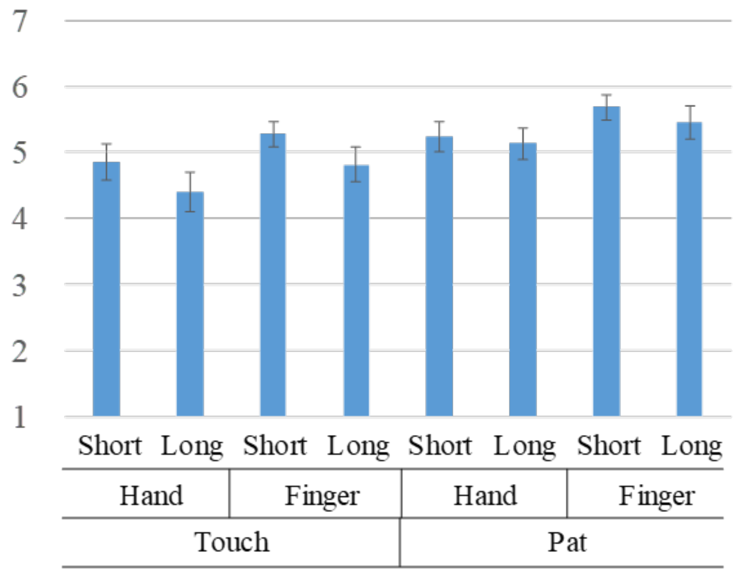

Figure 2.9: Perceived strength in each combination of touch characteristics

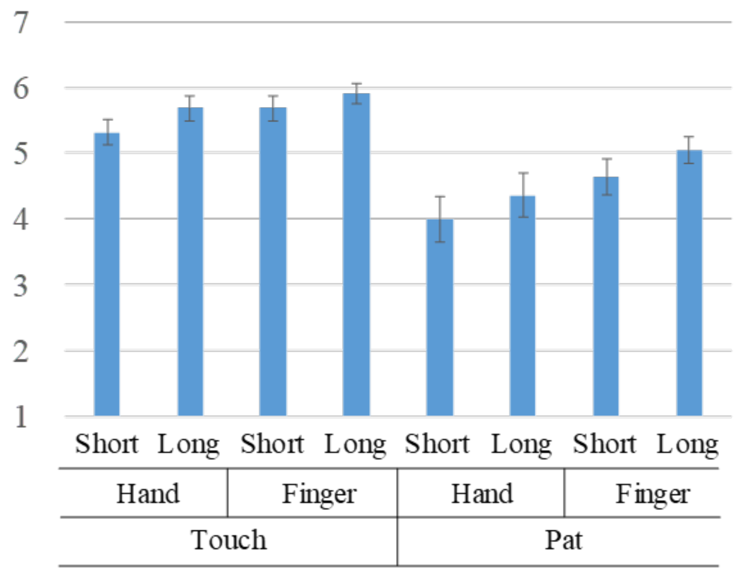

Figure 2.10: Perceived naturalness in each combination of touch characteristics

gate whether each touch is significantly strong or natural compared to the baseline. Our results showed similar trends to the ANOVA results as shown in Table. 2.3 and Table. 2.4

Our analysis results showed similar trends between the perceived strength and naturalness. Therefore, I investigated the correlation between strength and naturalness (happy: $r=0.69$, $p<.001$, sad: $r=0.61$, $p<.001$). Although these values show a positive correlation in each emotion, they are not strong (i.e., not larger than .80).

2.7 Discussion

2.7.1 Design implications

Our experimental results showed that choosing appropriate touch characteristics is helpful for designing stronger and more natural touch behaviors for robots that are expressing happy and sad emotions. At least for our robot, ERICA, which has a feminine-like appearance, short patting by fingers and longer contacting by fingers were better touch behaviors for expressing happy and sad emotions compared to contacting by hands. Even if other kinds of robots need touch interaction to show their emotions, the results suggest that touch length and types are more useful than the touch part.

Based on our data analysis, at least two touch characteristics are important: touch length and touch type. Even if hypothesis 3 is not supported, the statistical analysis showed a significant main effect in the part factor for both the strength and naturalness impressions (strength: finger > hand, $p=.004$, naturalness: finger > hand, $p=.001$). These results suggest that the touch part (i.e., finger or hand) might not be explained from the aspects of arousal/valence. But an android that is touching with her fingers might be considered more appropriate by the participants based on the results of our experiments.

In a past study that described how people conveyed their emotions to a robot by touch [31], I found several common characteristics with our study. For example, that study reported that the mean duration touch is relatively long in sad emotions. Our study also showed that a longer touch provided stronger and more natural impressions to express sad emotions. Comparing

Table 2.3: Strength impressions with two-tailed binomial test (bold indicates the p-value less than 0.5)

Length	Type	Part	*p*
Short	Touch	Hand	0.134
Short	**Touch**	**Finger**	**0.001**
Short	**Pat**	**Hand**	**0.004**
Short	**Pat**	**Finger**	**0.001**
Long	Touch	Hand	0.286
Long	**Touch**	**Finger**	**0.017**
Long	**Pat**	**Hand**	**0.001**
Long	**Pat**	**Finger**	**0.001**
Short	**Touch**	**Hand**	**0.001**
Short	**Touch**	**Finger**	**0.001**
Short	Pat	Hand	0.832
Short	**Pat**	**Finger**	**0.017**
Long	**Touch**	**Hand**	**0.001**
Long	**Touch**	**Finger**	**0.001**
Long	Pat	Hand	0.134
Long	**Pat**	**Figner**	**0.001**

Table 2.4: Naturalness impressions with two-tailed Binomial test (bold indicates the p-value less than 0.5)

Length	Type	Part	*p*
Short	Touch	Hand	0.832
Short	**Touch**	**Finger**	**0.017**
Short	Pat	Hand	0.832
Short	**Pat**	**Finger**	**0.001**
Long	**Touch**	**Hand**	**0.017**
Long	Touch	Finger	0.832
Long	Pat	Hand	0.523
Long	Pat	Finger	0.052
Short	Touch	Hand	0.832
Short	**Touch**	**Finger**	**0.017**
Short	**Pat**	**Hand**	**0.017**
Short	Pat	Finger	0.832
Long	Touch	Hand	0.052
Long	**Touch**	**Finger**	**0.001**
Long	Pat	Hand	0.052
Long	Pat	Finger	0.523

the effects of touch characteristics between touches from people and robots might be interesting to investigate how people's perceptions are different toward them.

2.7.2 Different touch characteristics

I focused on three kinds of touch characteristics based on arousal/valence perspectives. However, other kinds of touch characteristics should be considered. In our study, the robot's touches were relatively light for safety considerations, but applying greater strength might be one essential characteristic to express such emotions as anger. Using such other touch behaviors as gripping or stroking is another crucial factor for expressing emotions and should be implemented in future robot touch designs.

Our robot only touched the hand of the participants. Testing people's impressions when they are touched on the forearms, shoulders, or even faces would deepen our understanding of the relationships between touch characteristics and the emotions expressed by robots. Such elements as contact temperature [79] or applied pressure [80] are also critical factors that affect people's perception when they are being touched.

From another perspective, the position relationship between robots and people also have an influence. In this study, participants sat next to the robot where they could easily see its facial expressions and touch behaviors, but in real settings, people can touch others under various positional relationships. Since such relationships also limit the potential touch part and its characteristics, investigating these effects is another interesting future work.

2.7.3 Expressing other emotions

In this study I only focused on happy and sad emotions, because the former is often used in HRI applications [68, 69, 70, 71, 72, 73] and the latter is an contrary emotion following Russell's definition [45]. Comparing the effects of touch characteristics from arousal and valence perspectives might illuminate human-robot touch interaction designs. I did not investigate whether our knowledge is applicable for expressing the other four emotions from Ekman's basic emotions.

Social interaction scenarios for using these four emotions in current human-robot contexts are relatively less significant than the happy and sad emotion pair. However, social robots will need to express more complex feelings to interact with people in daily environments. Thus, investigating the relationships between touch characteristics and all the basic emotions is an interesting future work.

2.7.4 Gender, appearance, and hand Shape Effects

In this study I used an android with a feminine appearance, although human-science literature argues that perceived gender changes the touch impressions [81, 82]. Since another study also reported that gender influences the perceived impressions of a robot's touch [83], I should address the effects of a robot's gender and appearance before applying our knowledge to other robots. A masculine-looking robot might increase the knowledge's usefulness.

Moreover, our android has hands that resemble human hands. Recent social robots, like Pepper, have human-like hands, but many have a more machine-like appearance and simple-shaped hands like Robovie [84]. Such robots might have difficulty changing the part characteristics (i.e., hand or finger). Moreover, I put gloves on the robot's hands to avoid mismatched impressions between her appearance and the feeling of her touch, because such impressions often produce uncanny valley effects. In touch situations, researchers must consider the uncanny valley effects from movements or touch feelings as well as appearances. Even if the appearances are human-like, inappropriate movements and touch feelings easily evoke uncanny valley effects and unnatural feelings to interaction with the robot. At a minimum, touch feelings should match the assumption caused by its appearance. Based on these considerations, more knowledge about the combinations of other touch characteristics is needed for designing a robot's touch behaviors in emotional interaction.

Chapter 3

Express Intimacy Through Touch

3.1 Introduction

In the first study, I propose a design method by combining different touch characteristics to construct various hand touch behaviors for our android. By assigning two behavior variants to each touch characteristic and mapping the variant using Russell's arousal/valence circumplex model, those hand touch behaviors can convey happy and sad emotions to human participants. Now I have a fundamental structure of designing robot hand touch to express basic emotions, it is time to verify whether our android's hand touch may have the same social properties like that of humans. When we touch another person, depending on the different level of relationship, we often implicitly use different characteristics such as touch type (e.g., patting, touching, gripping and stroking) as well as touch different body parts. If social robots interact with people that includes touch behaviors in long-term scenarios, e.g., health-care, they must choose appropriate touch characteristics to match the perceived relationships with their users.

Indeed, in the first study, I have asked participants for their impressions about our android's touch after the experiment. Many of the participants reflected that some of the touch behaviors were quite intimate. This raised a quite interesting question: if those designed touch behaviors were perceived by our participants as natural and stronger in expressing emotions, they should also be able to deliver a feeling of intimacy with the correct combination of touch characteristics.

Therefore, the second study focusing on the relationships between touch

Figure 3.1: ERICA touches a participant in the experiment.

characteristics and perceived intimacy. Based on the first study, I include a new touch characteristics, i.e., *place*, indicating a human's body part that the android intent to touch, as it is one of the factors that can directly reflect level of intimacy in human-human touch behaviors [81]. I also chose to focus on the touch characteristics *type* which had the most effects from the first study. I conducted an experiment to investigate the effect on perceived intimacy with these two touch characteristics (*type* and *place*) and using the happy emotion from the first study. The result indicated that *place* was not as effective of increasing perceived intimacy as I original presumed. And conducted a second experiment to investigate the other two touch characteristics, *part* and *length*. I continued using the android ERICA (Fig. 3.1). Thus, this study answers the following question:

- What combinations among touch characteristics are appropriate to increase perceived intimacy via touch?

3.2 Related Work

Researching on the social utilities of physical interactions in HRI domain is sparse and are mostly focused on psychological effects. For example, past studies reported that touch interaction with robots and/or huggable devices can attenuate physiological stresses [20, 53, 85, 86]. One other work reports that hug from human to robot can increase perceived intimacy [87]. The problem is that all these studies do not have touch interactions from robot to human, let along using a robot's hand to proactively touch human. Therefore, by following the first study of this thesis, I decided to use the combinations of different touch characteristics to design robot hand touch behaviors and study the relationship between those touch characteristics and perceived intimacy.

3.3 Emotion and touch settings

Firstly, to investigate perceived intimacy of people via robot's touch, I focused on what kind of emotion will be appropriate. Typically the definitions of Ekman's six basic emotions [55] are used to design robot's emotions in human-robot interaction. However, in the context of investigating perceived intimacy, it would be better to focus on positive emotion such as happy because positive emotions and perceived intimacy would be strongly related compared to negative emotions. Based on these reasons, I focused on the relationships between perceived intimacy and touch characteristics with which robots express happy emotion.

About touch settings, in human-human interaction, people can touch a part of another person's body to express emotions. A past study investigated the body locations that were touched by participants to convey different emotions and concluded that they touched the hands/forearms to express happiness [57]. From a different perspective, another study concluded that participants mainly touched hands/forearms for both happy/sad emotions [31]. Based on these considerations, I chose a participant's hand and forearm as the robot's touch targets in this study.

The scenario setup is identical to that of the first study. To guarantee that all the participants experienced the same interactions with identical touch behaviors, I positioned them next to the robot (Fig. 3.1), allowing them to easily observe its facial expressions as well as its touching behaviors. I

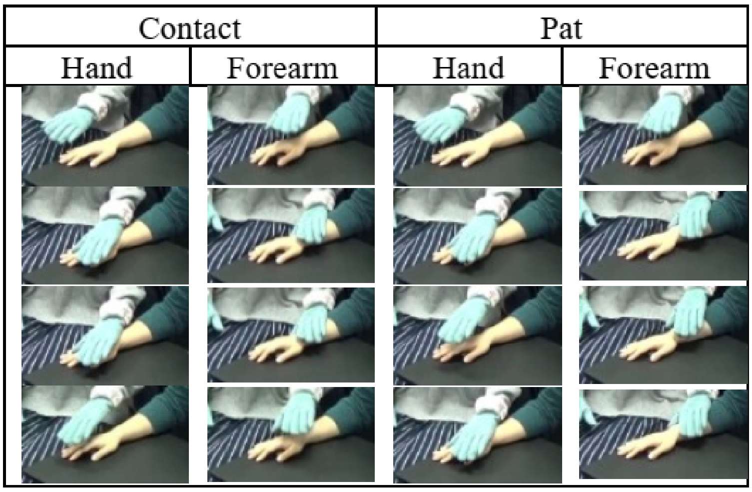

Figure 3.2: ERICA's *touch* and *pat* touch behaviors.

placed markers on a table to indicate where the participants should put their palms and forearms. I asked them to keep their right hands and arms on those markers when ERICA performed her touch behaviors. The details of the touch characteristics are explained in the following section.

3.4 Robot setup

The robot setup in this second study is identical to the first study.

3.5 Touch characteristics: type and place

To change the perceived intimacy via a robot's touch, I focused on touch characteristics that can show different touch stimuli. Firstly, I investigate two kinds of related touch characteristics first, type and place as shown in Fig. 3.2 and Fig. 3.3, because investigating all possible combinations of touch characteristics would greatly complicate our analysis. Note that because this study include a new touch characteristic *place*, the different *type* of touch behaviors described in the first study has also been adjusted so that the robot would touch different body parts of a human.

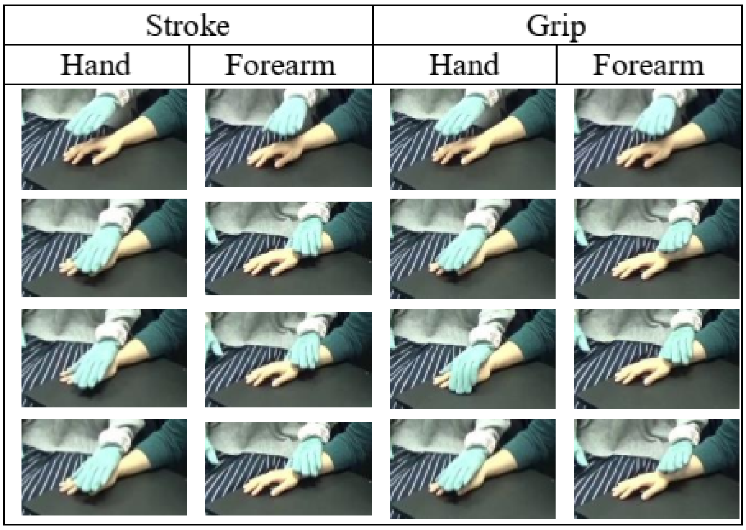

Figure 3.3: ERICA's *stroke* and *grip* touch behaviors.

3.5.1 Type of touch

A past study reported that participants felt high valence with more pulses in touch stimuli [77]. Assuming that high valence might influence the perceived intimacy, I prepared different kinds of touch based on pulse perspectives: a simple touch is a singlepulse type and a pat-like touch is a multi-pulse type. In the context of showing intimacy, grip and/or stroke touches might also be useful. In fact, such touch types are used between people who have very close relationships, including lovers, family members, and close friends. Therefore, I prepared four touch types: touch, pat, grip, and stroke. The duration of all the touch behaviors were around two seconds.

3.5.2 Place of touch

Although people express different emotions by touching various body parts [32, 81], e.g., hands, elbows, upper torso, etc., past researches focused less on comparing intimacy perspectives. Since they reported that people mainly touched hands or forearms to convey happiness, I chose hand and forearm as our targets

3.6 Experiment on type and place

In this experiment, I conducted data collection and analyzed the data to answer our research questions: what combinations among touch characteristics are appropriate to increase perceived intimacy via touch. I note that due to the difficulties of complex combinations between all the types and places of touch, I did not predict beforehand which combination is better between them.

3.6.1 Participants

We recruited twenty-two native Japanese (11 females and 11 males whose ages ranged from 19 to 39 and averaged 29.0) through local commercial recruiting website. The participants came with a wide background and none had ever interacted with an android that touched them.

3.6.2 Conditions

I adopted a within-participant experiment design. Each participant was interacted with the android with all the combinations of the touch characteristics (type and place) for a total of eight different touch behaviors.

- **Type**: four different touch types were prepared for the robot to interact with a participant: touch, pat, grip and stroke.
- **Place**: the robot was designed to touch two different body parts of each participants: hand and forearm.

3.6.3 Procedure

Before the experiment, all participants were given a brief introduction about its purpose and procedure and written consents were collected from all of them. This research was approved by our institution's ethics committee for studies involving human participants.

At the start of the experiment, participants were asked to sit next to ERICA on her left side as shown in Fig. 3.1. I then calibrated the table and markers to make sure that all participants could experience identical touch behaviors from the android. A computer was put in front of the participants with a user interface program prepared on the screen. After calibration, participants were given the instruction to start the experiment by pressing a START button on the computer screen whenever they were ready. Once the button was pressed, the experiment started.

At the beginning of the experiment, ERICA greeted the participant, briefly re-introduced the experiment's purpose and procedure from a first-person perspective, and expressed her thanks for helping her collect intimacy data to improve her interpersonal touching ability. This approach helped participants get accustomed to her social presence. Then, ERICA told them that she would randomly select a touch behavior to perform the touch and asked the participants to compare the perceived intimacy from the touch comparing to a baseline condition.

After ERICA finished her introduction, she told the participants that she would only use facial expression, a filler and a sentence to express the feeling of friendliness as the baseline condition, i.e., without touch interaction. Then, she sequentially selected the touch behaviors that were counterbalanced beforehand. While touching the participants, ERICA used the same facial expression, the filler and the sentence. ERICA then repeated until the participants experienced all eight touch behaviors. The participants were instructed to complete questionnaires on the computer screen right after each touch interaction.

3.6.4 Measurement

In this first experiment, I collected two questionnaire items: perceived intimacy and naturalness for each touch behavior comparing to the baseline condition. A 1 to 7 point scaled were used for evaluating the expression. 1 represents the perceived intimacy/naturalness are much weaker than the baseline, and 7 represents the perceived intimacy/naturalness are much stronger.

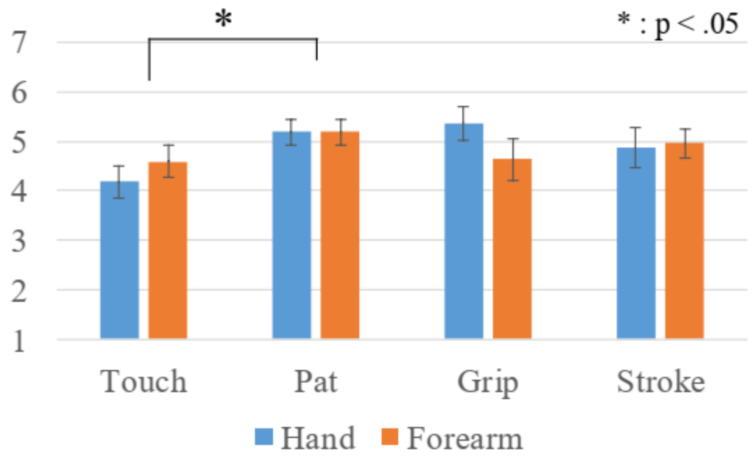

Figure 3.4: Questionnaire results about intimacy.

3.6.5 Results

Firstly, I conducted a two-factor mixed ANOVA for each touch characteristics on type and place about perceived intimacy (Fig. 3.4). I identified the significant main effect in the type factor (F(3,63)=3.892, p=.013, partial $\eta 2$=.156). I did not identify the significant main effect in the place factor (F(1,621=0.096, p=.759, partial $\eta 2$=.005) and the interaction effect (F(3,63)=2.054, p=.115, partial $\eta 2$=.089). Multiple comparisons with the Bonferroni method of the simple main effect in the type factor was only significant, pat > touch (p=.010).

Next, I conducted a two-factor mixed ANOVA for each touch characteristics on type and place about perceived naturalness (Fig. 3.5). I identified the significant main effect in the type factor (F(3,63)=5.012, p=.004, partial $\eta 2$=.193). I did not identify the significant main effect in the place factor (F(1,621=0.057, p=.814, partial $\eta 2$=.003) and the interaction effect (F(3,63)=1.798, p=.157, partial $\eta 2$=.079).

Multiple comparisons with the Bonferroni method of the simple main effect in the type factor was only significant, pat > touch (p=.012) and grip > touch (p=.031).

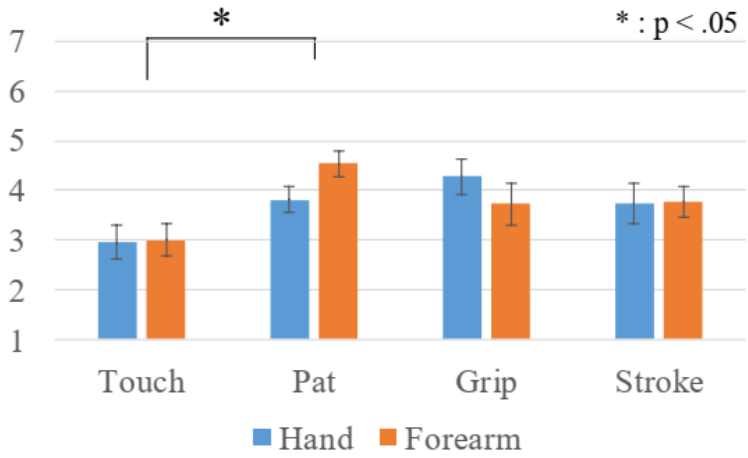

Figure 3.5: Questionnaire results about naturalness.

3.6.6 Discussion about touch and place

The experiment results suggest that the pat behavior is better way to show high intimacy and naturalness compared to touch behavior, and the place of touch would not have significant effects in the context of intimacy and naturalness. There are no significant differences among pat, grip and stroke behaviors, but pat was the only item that had average naturalness higher than the middle value (i.e. 4.0). Based on these results, a use of pat behavior seems appropriate to increase perceived intimacy and naturalness via touch.

These results raise a different question: why a grip and a stroke did not show strong intimacy in this study? One possible answer is a relationship between the robot and participants. Grip and stroke might only be considered appropriate between people who have more intimated relationship. But in this study the participants and the robot did not build such relationships, rather the robot is a stranger for the participants. In such relationship, a grip and a stroke might not be considered natural in touch interaction. In fact, the average naturalness of these behaviors is less than the middle point.

3.6.7 Different touch characteristics on a pat behavior

The experiment results and above discussion makes a new research question about touch characteristics: what kinds of touch characteristics are appropriate to increase perceived intimacy when the robot uses a pat behavior?

Because in this study I only investigated the type and the place factors, but other touch characteristics exists, e.g., length of touch or the body part of the robot that used to touch a person, like the robot's hand or fingers, which I will refer as touch-part.

For example, for the touch behaviors described earlier, I fixed the touch length around two seconds to avoid over complexing the variety design of touch behaviors. However, a past study reported that participants perceived a longer touch as a significantly negative valence perspective [76]. Moreover, a previous study focused on the intensity of the touch stimuli [77] and reported that a high intensity showed a greater arousal than a low intensity without any significance about valence. If we changed the touch-part of the robot (e.g., hand or finger), the gross area and the total touch pressure will change and then touch intensities also changed. Such different touch style might change perceived intimacy via robot's touch. To investigate the answer of this new question, we decided to conduct an additional experiment.

3.7 Second experiment on length and touch-part

In this second experiment, I again conducted data collection and analyzed the data to investigate whether length and touch-part have influences to perceived intimacy when the robot used the pat behavior. I fixed the touch place to be the participants' hand, and only used pat behavior based on the first experiment. For this experiment, I follow the same procedure with the same participants of the first experiment. In addition, I use the same measurements to evaluate user impression of *length* and *touch-part* characteristics.

3.7.1 Conditions

I adopted a within-participant experiment design. Each participant was interacted with the android with all the combinations of the touch characteristics, length and touch-part, for a total of four different touches behaviors.

- **Length**: two different length conditions were prepared for the robot to interact with a participant: short and long. About the short touch, due to a lack of published references, I heuristically decided the actual lengths that enable people to feel the differences between them by

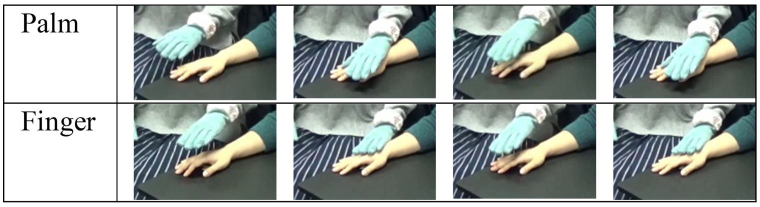

Figure 3.6: ERICA's pat behaviors (palm or fingers)

conducting a small pilot study within our laboratory. I used 0.5 second contact duration for the short touch as explained in Section 2.4.1 (Fig. 2.3). About the long touch, I used the same touch behavior in the first experiment (i.e., two seconds).

- **Touch-Part**: I used the two different touch parts, palm and finger, as explained in Section 2.4.3 (Fig. 3.6).

3.7.2 Results

I conducted a two-factor mixed ANOVA for each touch characteristics on length and touch-part about perceived intimacy (Fig. 3.7). I identified the significant main effects in the touched-part factor (F(1,21)=8.284, p=.002, partial η2=.381). I did not identify the significant main effect in the length factor (F(1,21)=0.091, p=.766, partial η2=.004), and the interaction effect (F(1,21)=1.147, p=.296, partial η2=.052).

I also conducted a two-factor mixed ANOVA for each touch characteristics on length and touched-part about perceived naturalness (Fig. 3.8). I identified the significant main effects in the touched-part factor (F(1,21)=13.776, p=.001, partial η2=.396). I did not identify the significant main effect in the length factor (F(1,21)=3.415, p=.079, partial η2=.140), and the interaction effect (F(1,21)=0.287, p=.598, partial η2=.013).

3.7.3 Discussion about touch length and touch part

The experiment results suggest that the touch-part has significant effect toward perceived intimacy and naturalness when the robot pat the participants' hands. On the other aspect, the length of touch did not show any

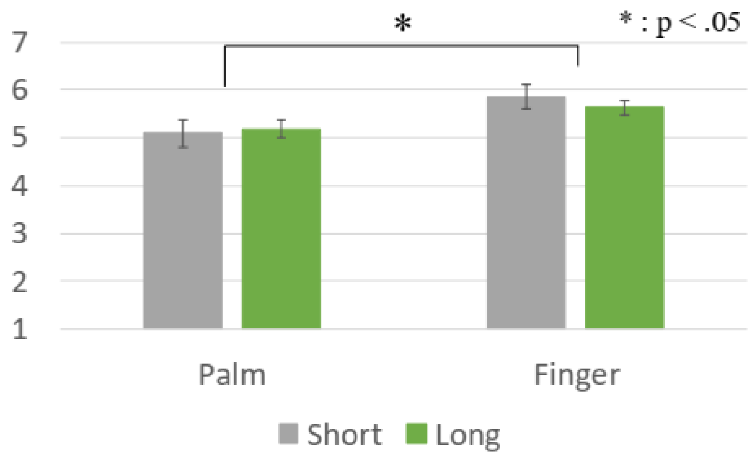

Figure 3.7: Questionnaire results on intimacy when robot used *pat* behavior.

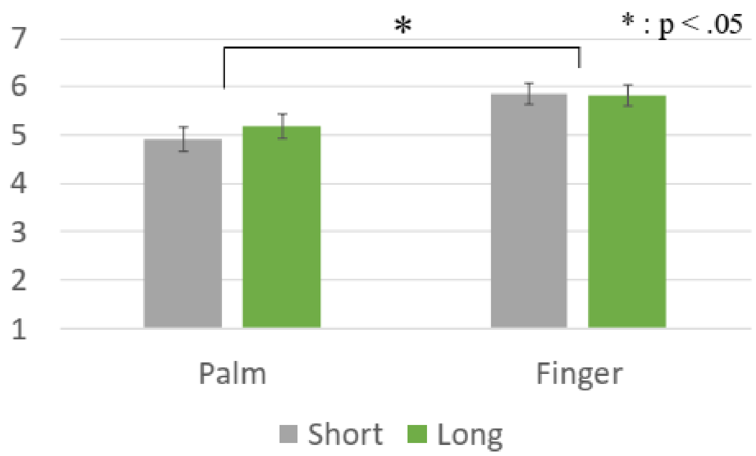

Figure 3.8: Questionnaire results on naturalness when robot used *pat* behavior.

significant effects in this study. These results would suggest that one better touch style to show intimacy and naturalness is a pat behavior by using fingers.

These results might support our discussions based on the first experiment; touched by fingers might be more appropriate when the robot is a kind of a stranger for participants, because touched by a palm generally be used between people who have friendlier relationship.

3.8 Conclusion

I investigated the relationship between an android's touch characteristics and its perceived intimacy in the context of expressing typically used emotion (i.e., happy) in human-robot touch interaction to an interacting person. Although human beings often convey emotions by touching others, such knowledge is sparse for designing appropriate touch behaviors for a social robot. Therefore, firstly I selected two kinds of touch characteristics (type and place) and investigated the effects of these characteristics on happy emotion. As a result, I found that a pat behavior is effective to express more intimacy via touch. On the other hand, touch places did not have any significant effect in the context of perceived intimacy.

By considering of the first evaluation analysis, I again conducted an additional experiment to investigate different types of touch characteristics: length and touch-part. As a result, I found that a finger-touch is perceived more intimate compared to a palm-touch. On the other hand, touch length did not have any significant effect in the context of perceived intimacy. Based on these analyses, I concluded that a pat by the fingers are respectively better touch behaviors to be perceived more intimate when the robot expresses happy emotion, at least for our robot, ERICA who has a feminine appearance.

Although I focused on four kinds of touch characteristics, other kinds must also be considered. For example, applying more physical strength while touching is one critical characteristic for greater intimacy. Of course, applying a stronger force introduce safety concerns cues. The contact temperature [79] is another characteristic that might affect people's perception when they are being touched.

3.8.1 Limitations

This study has several limitations. I need to carefully contemplate our analysis results. Since I only used a specific android robot with a female appearance. To generalize our experimental results we must test different types of android robots: different appearances, including gender, age, as well as robots with more robotic appearances such as Pepper and Robovie. Therefore, the knowledge from this study may only be applicable to social robots that are designed for such interactions. Moreover, how people interpret touch behaviors often reflects social status [76], interpersonal relationships, cultural backgrounds, and gender [88]. We need to consider what touch characteristics are commonly accepted or rejected in haptic communication to express emotions.

From another perspective, the realistic feeling of the robot's hand might be critical for a robot with a human-like appearance. In this study I used a glove to hide different touch feelings of the robot's touch, but if the robot can directly touch people without a glove, people might perceive different feelings due to the skin-to-skin touch.

Chapter 4

Modeling Touch Timing with Context

4.1 Introduction

Based on previous two studies, I demonstrate that an android's hand, with certain combinations of touch characteristics can express different emotions. However, the experiment results from Study 2 suggested that the "regular" patting touch behavior was more intimate than gripping and stroking. Even though I initially thought, based on common experience, stroking and gripping were more intimate touch behaviors. This contradiction suggested people may not perceive an intended emotion only by using touch characteristics.

Indeed, social touches are not isolated behaviors. They always occur under certain social scenarios to manifest specific emotions[32]. With external stimuli, social touches are triggered under specific timing[89]. For example, a couple sitting in a cinema may immediately touch each other when they feel scared or surprised, e.g., watching a horror movie. On the other hand, couples that are deeply moved by a heartwarming movie may touch each other after their emotion has built up. Although I have investigated the effectiveness of touch characteristics such as type, length, part and place in study 1 and 2, it remains unknown how to model the appropriate touch timing to express its emotions. In other words, when should the robot touches?

4.2 Related work

A few studies conducted experiments that involved touch interaction where participants watched movies with robots, but unfortunately, these studies did not focus on touch timing for conveying specific emotions [90, 91].Based on these considerations, I decide to study what would be the appropriate touch timing to express emotions with social robots. To do this, I firstly conducted a data collection to gather both timing and duration data of touch behaviors to express heartwarming and horror emotions. I then developed a probabilistic model to identify appropriate touch timing for these two emotions and experimentally investigated the effectiveness of our developed model using ERICA. Through this, I answers the following question: when should a robot touch a person to express impressions of heartwarming and horror?

4.3 Target emotions, robot and touch behavior

4.3.1 Experiment setup and target emotions

In this study, we are trying to model touch timing to express emotions. For this purpose, sharing contexts is important for people to evaluate the appropriateness of touch timing. In particular, such timing depends on a situation to arouse emotion. Therefore, I prepared a situation where participants and the robot together watched videos, which were used as visual stimuli.

I chose the target emotions to investigate appropriate touch timings. Since past studies in human-robot interaction focused on expressions[68, 69, 70, 71], I focused on positive emotions (typically happiness) because they are an essential emotion to build friendly relationships with others with whom we interact. For example, past studies implemented functions to express happiness for social robots and showed positive effects in long-term human-robot interaction [74, 75]. Based on these results and following past studies, I decided to use videos for the experiment, which would be likely to arouse heartwarming feelings. I also chose to use heartwarming videos as there is a large number to choose from, enabling easy preparation of experimental video materials.

I simultaneously focused on a negative emotion (e.g., fear and sadness) as a counterpart to positive emotions. For this purpose, I used horror as a second target emotion. Similar to heartwarming movies, many existing horror (an intense feeling of fear) movies have similar merit to us. Moreover, a study on Japanese perceived emotions related to deeply heartwarming situations reported that Japanese people feel both happy and sad when they are moved [92]. Therefore, to avoid any effects caused by mixing happy and sad emotions in our comparison of positive/negative emotions. I did not use a sad emotion as a counterpart to positive emotions.

In summary, I used heartwarming or horror videos for data collection. The collected data is used to model appropriate touch timing to express the robot's heartwarming feeling or horror feelings.

4.3.2 Robot setup

Similar to previous studies that investigated human-robot touch interaction in the context of emotion expressions, I need a robot that can express various touch behaviors and has a human-like appearance. I used ERICA [43]. Each of her arm has ten degrees of freedom (DOF), allow gentle touch behavior design. The motion control system can update the target positions of each actuator on her arm every 50 milliseconds. Therefore, each frame of her behavior is updated accordingly. I used gloves on ERICA to avoid mismatched feelings between its appearance and touch feeling because ERICA's skin is a silicone-based design even though its appearance is human-like.

4.3.3 Touch behavior design

To decide what touch behaviors should be used to convey a feeling of heartwarming or horror, first, I consider the target body part of the touch. According to a past study that investigated the specific relationship maps of body regions where social touch is allowed, the hands are the most acceptable regions to be touched by another person, regardless of the relationship[76]. Therefore, ERICA touches the hands of the participants.

To create a natural social feeling in our experiment scenario, i.e., participants watch videos with ERICA. ERICA sat next to the participants (Fig. 4.1). I placed markers on a table to indicate where the participants should put their palms and forearms to guarantee that they all experienced the same interactions with identical touch behaviors.

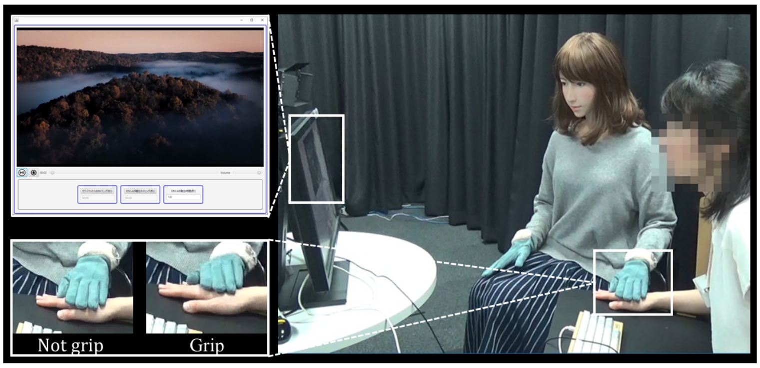

Figure 4.1: A participant is watching videos with ERICA.

Concerning touch behaviors, I followed similar settings of past studies that used a video stimulus to investigate touch effects [90, 91, 93], where the robot's hand is always touching the participants' hands. I employed a grip behavior because the robot can easily control the start/end timing in a contact situation. As support evidence, a past study also used a gripping behavior in a similar experiment setting for a remote-touch device [89].

In summary, participants in this study were always touched by ERICA when she conveyed specific emotions. In the data collection, I gathered data about the appropriate grip timing and touch durations of ERICA's grip to develop touch timing models for each emotion.

4.4 Data collection

4.4.1 Overview

For watching each video with ERICA, I designed a program to allow display video clips. A user interface allow participants to watch the video clips with ERICA while recording various data. And all the robot-participant interactions were executed without any interference during the whole experiment.

I directly gathered three pieces of information from the participants: the most appropriate climax timing of that video, t_{climax}; the timing for when the robot should start its grip as a reaction (or anticipation) to the climax, t_{touch};

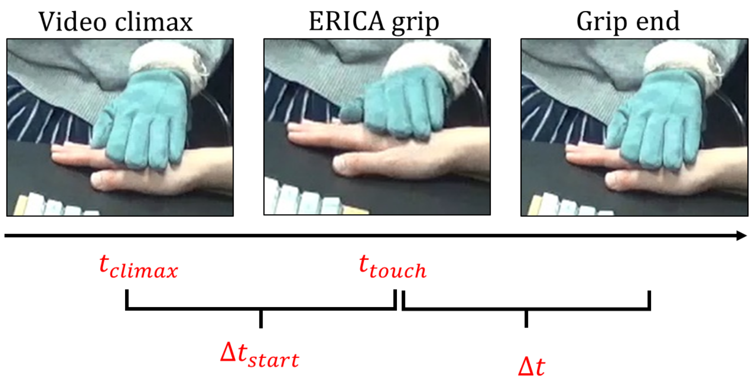

Figure 4.2: Illustration of t_{climax}, t_{touch}, Δt_{start} and Δt.

and the grip's duration, Δt. I also calculated Δt_{start} (i.e., $t_{climax} - t_{touch}$), which is the difference between the touch and climax as the timing features (Fig. 4.2). In this study, a climax of a video represents the moment of emotional peak of the story, which robot can use the moment to convey a feeling of empathy through touch.

The participants identified appropriate grip-timing characteristics when they sequentially watched video clips with ERICA. During this watching process, they input the grip timing (t_{touch}) and duration (Δt) for each video that they felt best expressed the invoked emotions that related to the video's content. They also reported the climax timing (i.e., t_{climax}) for each video to model the touch behaviors. For the video stimulus, I selected six clips from the trailers of commercial movies or advertisements from YouTube[1]. Since our target emotions are heartwarming or horror, I prepared three videos for each category and edited them from between 98 to 159 s (M = 118.3s, SD = 26.2 s) for the data collection.

4.4.2 Procedure

I gave our participants a brief introduction to the experiment and explained that we are collecting their impressions about how the robot should convey

[1] https://youtu.be/PFhQhpR5Z8M, https://youtu.be/r1gz-m5Ai_E, https://youtu.be/b2MH-yxIR4Y, https://youtu.be/4LYK0rTjlM8, https://youtu.be/dCPiAOiKSyo, https://youtu.be/gXfLl3qYy0k

emotions by touching. I obtained written consent from them. Our institution's ethics committee approved this research.

The participants sat on the left of ERICA. I calibrated the positions of the table and markers to guarantee that all participants experienced identical touch behaviors. After the experiment started, ERICA put her left hand on the participant's right hand (Fig. 4.1). I explicitly verified that the participants were correctly perceiving the grip behavior of the robot. I placed a computer monitor in front of the participants with a user interface to play the video clips.

The participants input three items on the user interface: t_{climax}, t_{touch}, and Δt (Fig. 4.1). After inputting these values and replaying the video clip, ERICA reacted by gripping based on these parameters. Our participants were allowed to watch the video, to modify these values, and to test ERICA's behaviors an unlimited number of times until they were confident that the timings were optimal. We explicitly verified that all participants did not have the experience to watch the movies beforehand and whether the participants felt that there was a climax in a video. Once the participants were satisfied with the parameter adjustments, they repeated the procedure for the remaining clips. I adopted a counterbalance design to play either the first three horror videos or the heartwarming videos and then vice versa.

4.4.3 Participant

We recruited through a local (Japan) commercial recruiting company 48 people (24 females and 24 males). Their ages ranged from 20 to 49. All of the participants are native Japanese speakers. They had diverse backgrounds, such as students and business people. None of them had ever watched videos with an android.

4.5 Hypotheses and predictions

For the modeling of touch timing characteristics to convey specific emotions, I hypothesized that the characteristics would be different between heartwarming (positive) and horror (negative) emotions. Past studies about heartwarming emotions reported that the continuation time of heartwarming emotion is relatively long after evoking it compared to negative emotions

[92, 94]. It may cause retroactive and relatively long reactions after a climax timing. On the other hand, negative emotional stimulus makes a rapid response compared to other emotional stimuli [95, 96]. It may cause proactive and relatively short reactions before a climax timing because increasing the level of fearfulness will be related to deciding fight or flight actions [97]. Based on these considerations, I made the following three hypotheses about grip timing and durations.

- Prediction 1: The t_{touch} for heartwarming emotion will be later from the t_{climax} compared to the t_{touch} for horror emotion.
- Prediction 2: The Δt_{start} is positive for heartwarming emotions (i.e., t_{touch} occurs after t_{climax}), while it is negative for horror emotion (i.e., t_{touch} occurs before t_{climax})
- Prediction 3: The Δt for heartwarming emotion will be longer compared to the Δt for horror emotion.

4.6 Data analysis

Our data collection gathered 288 t_{climax}, t_{touch}, and Δt items and calculated the Δt_{start} data from 48 participants with six videos. I excluded 20 items due to hardware troubles of our robot during the data collection. In total, 266 items were valid. Due to large variance of them, I calculated the Z scores of each Δt_{start} and Δt and selected those within a range of plus and minus three. This eliminated two outliers in each category, resulting in 262 items for analysis.

4.6.1 Analysis of t_{climax}, and t_{touch} for each video

Fig.4.3, Fig.4.4 and Fig.4.5 show the histograms of t_{climax} and t_{touch} for the three heartwarming videos. And Fig.4.6, Fig.4.7, and Fig.4.8 show the histograms of t_{climax} and t_{touch} for the three horror videos. As shown in each group of these figures, most of the participants selected similar climax timing during the data collection, although a part of participants defined different climax timing (e.g., the horror video 1 (Fig.4.6) has two peaks as climax timing).

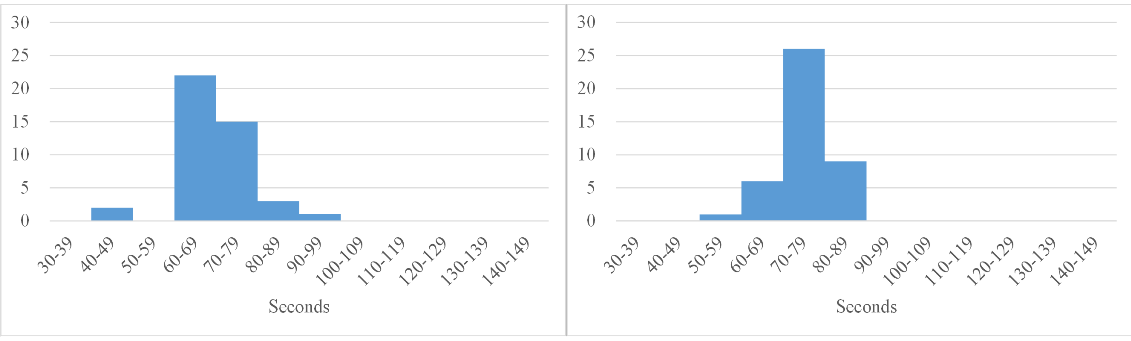

Figure 4.3: t_{climax} and t_{touch} of heartwarming Video 1, S.D. equal 8.3 and 6.7

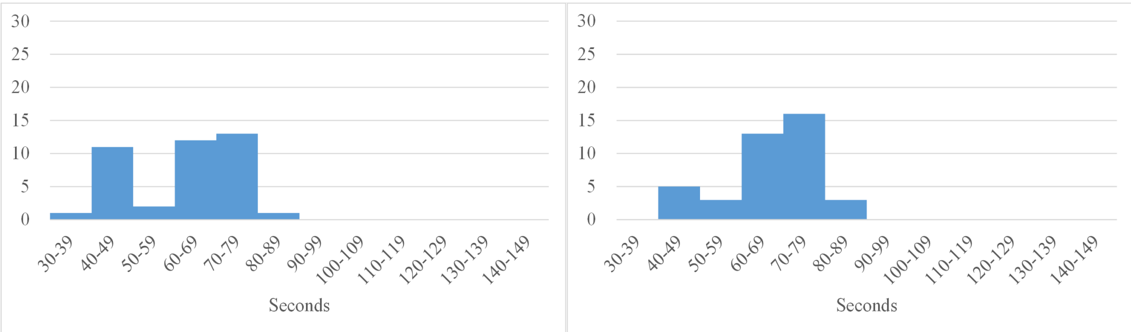

Figure 4.4: t_{climax} and t_{touch} of heartwarming Video 2, S.D. equal 12.3 and 11.3

Moreover, these figures show that t_{touch} are relatively shifted later (heartwarming) and earlier (horror) compared to t_{climax} distributions. These results would suggest that participants have different opinions on where the climax is, but their preferred grip timing are influenced by the video categories.

4.6.2 Analysis of Δt_{start}, and Δt

Figures 4.3 to 4.7 show the histograms of Δt_{start} and Δt for all the heartwarming/horror videos. Differences based on the clip category suggest that people have different assumptions about appropriate grip timing, typically, before the climax for horror and after for heartwarming. This also suggests that people's interpretation of when a robot should react to a climax might be based on video types. In addition, the distributions ofΔt_{start} acquired from horror clips were wider but high kurtosis than those from watching the heartwarming clips.

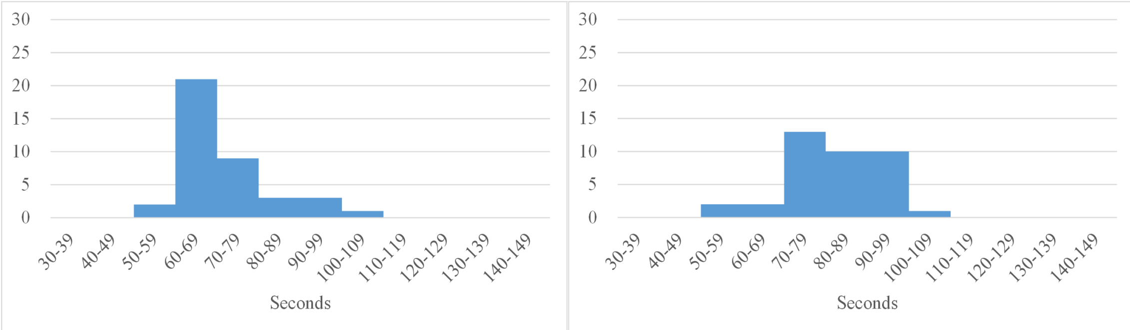

Figure 4.5: t_{climax} and t_{touch} of heartwarming Video 3, S.D. equal 11.3 and 11.0

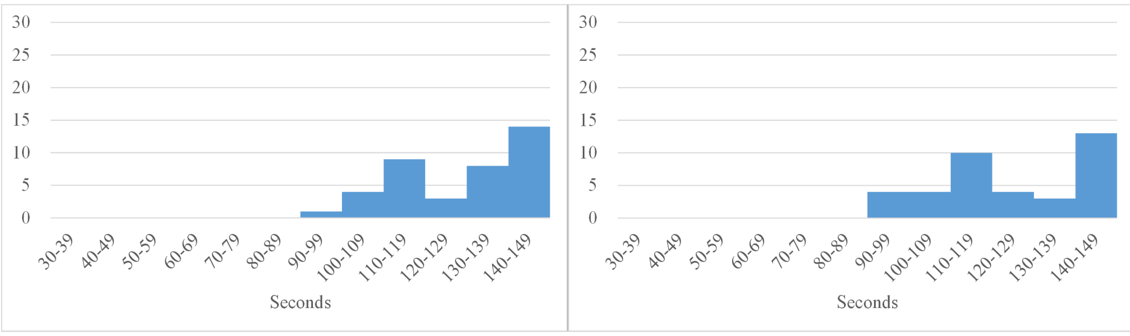

Figure 4.6: t_{climax} and t_{touch} of horror Video 4, S.D. equal 14.5 and 16.0

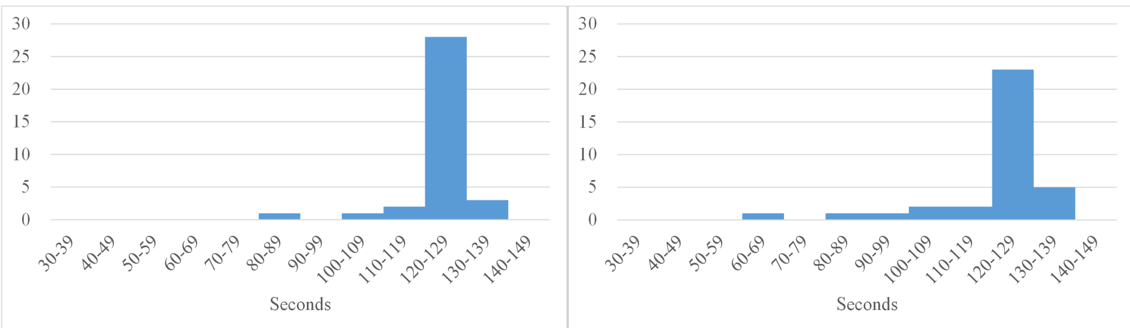

Figure 4.7: t_{climax} and t_{touch} of horror Video 5, S.D. equal 11.8 and 16.0

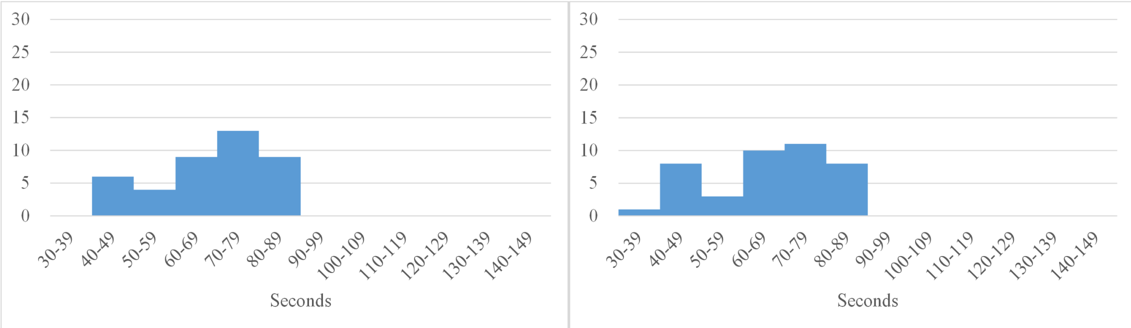

Figure 4.8: t_{climax} and t_{touch} of horror Video 6, S.D. equal 13.6 and 15.0

These results suggested that when anticipating the climax of a horror video, e.g., a jump scare, people expect an empathetic robot to touch them immediately before the scary scene. On the other hand, people tend to anticipate that an empathetic robot should touch them after an emotional moment during a heartwarming video.

I conducted a one-way repeated ANOVA as a statistical analysis to identify the effects of clip categories on grip timing (i.e., Δt_{start}). The results showed a significant difference in the video category factor ($F(1, 132) = 33.797$, $p < 0.001$, partial $\eta^2 = 0.204$). For Δt, I also conducted a one-way repeated measures ANOVA whose results showed a significant difference in the video category factor ($F(1, 132) = 7.226$, $p = 0.008$, partial $\eta^2 = 0.052$). These results showed that predictions 1, 2, and 3 are supported.

I also calculated the number of cases where the touch started before the climax timing, but the touch duration lasted over the climax timing (heartwarming videos: 20 out of 27 cases, horror videos: 56 out of 76 cases). I conducted a binominal test and found that most touch durations lasted beyond the climax timing (heartwarming: $p= 0.019$, horror: $p<0.001$). Thus, using a touch duration that lasts beyond the climax timing would be important to reproduce grip behaviors.

4.6.3 Modeling grip timing

The participants showed different grip timings due to the video categories, and typical differences found by histograms mainly reflected whether the grip timing was before or after the climax and its range. To deal with mathematical modeling, I used a fitting approach with probabilistic functions.

Table 4.1: R^2 for modeling touch timing Δt_{start}

Functions	R^2 for heart-warming videos	R^2 for horror videos
NIG	0.830	0.837
Beta	0.781	0.589
Normal	0.803	0.579
Triangle	0.667	0.404

Table 4.2: Parameters for fitted NIG model

	Heart-warming	Horror
α	1.603	0.137
β	0.043	-0.068
μ	6.154	-0.554
δ	13.780	5.539
mean	6.525	-3.710
std	10.890	7.838

To model grip timing, I compared the Δt_{start} histograms and probability distribution functions, including normal, beta, triangle, and normal-inversed Gaussian (NIG), and calculated their R squared values (R^2). Since the NIG showed a higher R^2 than the other functions, I chose the NIG with the parameters, as shown in Table 4.1 and 4.2. The fitting result is shown in Fig. 4.9

4.6.4 Modeling touch duration

Similar to the grip timing, the participants showed different touch durations due to the video categories, and typical differences found by histograms mainly reflected whether the touch duration was longer or shorter in heart-warming and horror categories.

To model touch duration, due to different shapes of the data distribution, as shown in 4.10, I compared the Δt with several probability distribution functions, including NIG, log-normal, and exponential distributions. Among the fitted results shown in Table 4.3, NIG also showed the best fitting results. Therefore, I also use the NIG model to model touch duration as well as the grip timing.

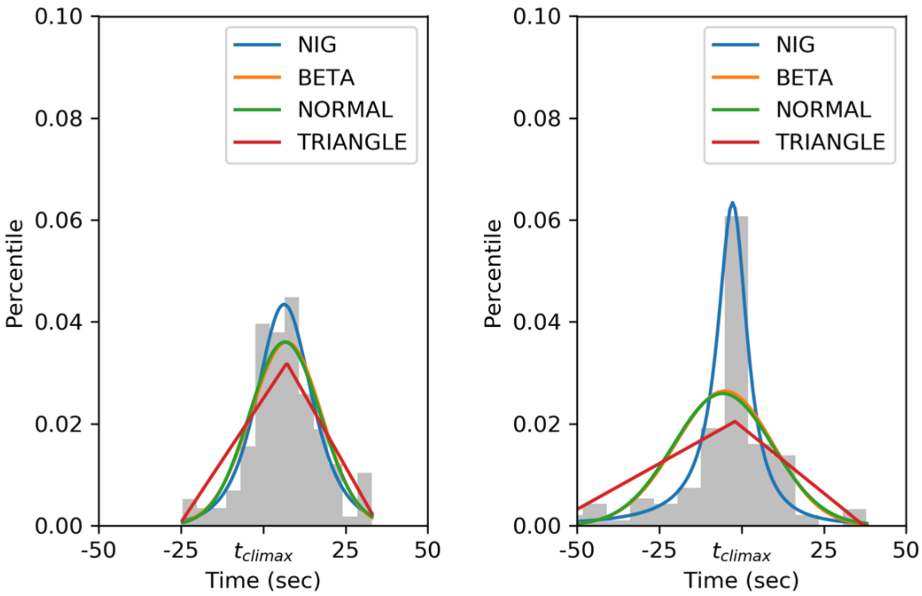

Figure 4.9: Modeling of touch timing Δt_{start}

Table 4.3: R^2 for modeling touch duration Δt

Functions	R^2 for heart-warming videos	R^2 for horror videos
NIG	0.650	0.966
Log.	0.698	0.963
Exp.	0.778	0.921

Table 4.4: Parameters for fitted NIG model

	Heart-warming	Horror
α	29.405	74.972
β	29.398	74.970
μ	0.109	-0.044
δ	0.186	0.082
mean	8.525	12.857
std	10.441	18.640

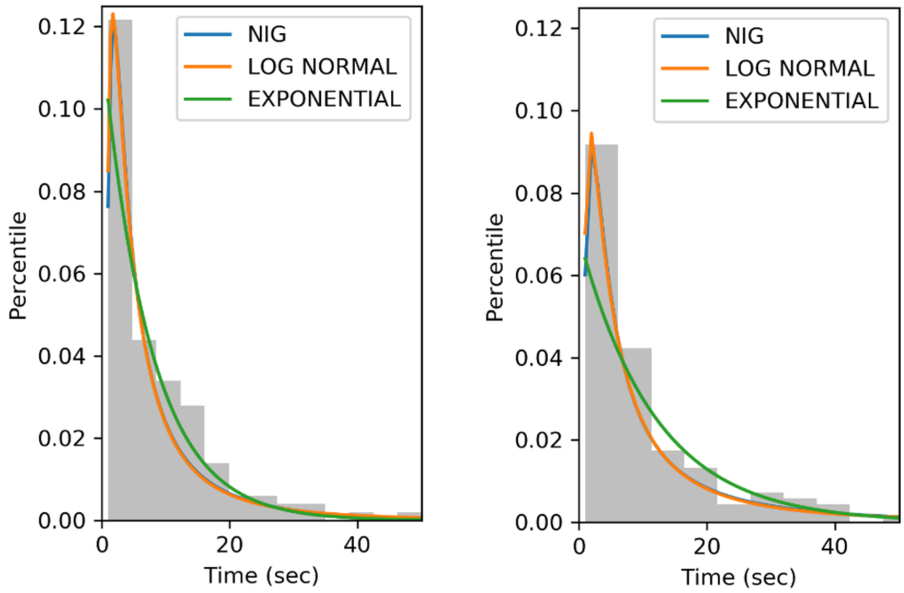

Figure 4.10: Modeling of touch duration Δt

4.7 Implementation and verification

Based on analyses, I implemented heartwarming/horror NIG models in ERICA. Based on the video's category information, she decided Δt_{start} using the corresponding heartwarming/horror NIG models. She also used the predefined t_{climax} of the video and the selected Δt_{start} to decide the grip timing when she is watching a video with a person. The robot also maintains its griping behavior using the Δt of the corresponding model.

To increase the realism of the situation, I enabled an idle movement function for her [43]. Without interfering with her touch behaviors, ERICA can breathe, make micro-body movements, and blink when watching the videos. Finally, I tested the developed system and confirmed that the robot autonomously decides the grip timing and durations based on the video information.

One concern from the implementation perspective is the relatively large standard deviations of the models. In extreme cases, 24.53 to 32.99 and -55.37 to 37.85 are the possible t_{start} ranges of the heartwarming and horror NIG models. Directly sampling from these ranges might fail to reproduce typical touch timings, i.e., reacting before the horror climax or after the

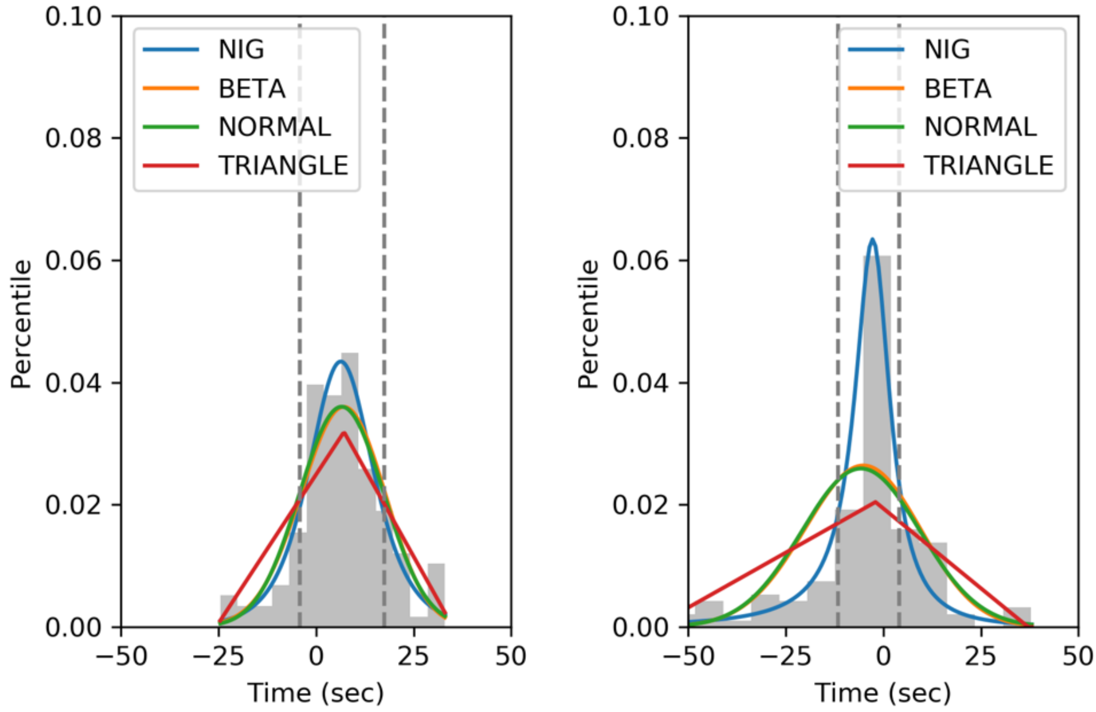

Figure 4.11: The dotted lines show the sampling range of Δt

heartwarming climax. I mitigated this problem by limiting the sampling range within one standard deviation (dotted lines in Fig. 4.11). If a sampled value falls outside the range, I sample it again until the value is within one standard deviation from the mean. Although this approach is rather ad-hoc, it effectively reproduced typical touch behaviors. Based on this implementation policy, the possible t_{start} ranges of the heartwarming and horror NIG models are -4.37 to 17.42 seconds, and -11.55 to 4.13 seconds.

For selecting touch duration Δt, I re-analyzed the touch data within one standard deviation sampling range, due to the above implication policies. First, 11 of 11 touches in the heartwarming videos and 49 of 59 touches in the horror videos started before the climax timing and ended after it, i.e., a similar touch characteristic from the original data. I again conducted a binominal test and found significant differences between them (heartwarming: $p<0.001$, horror: $p<0.001$). However, using a sampling method might fail to reproduce typical touch behaviors. Typical touches started before the climax timing and ended after it. But due to the likelihood of exceedingly small touch durations, for example, a sampled minus three seconds t_{start} and a sampled one second Δt means the touch will end two seconds before the climax. In fact, even though I limited the sampling ranges, Δt's sampling range are still relatively wide to reliably reproduce typical touch behaviors. For reproducing these touch behaviors, I simply used the mean values instead the sampling approach, i.e., Δt is 8.525 seconds for the heartwarming videos and 12.857 seconds for the horror videos.

4.7.1 Hypotheses and predictions

If our modeling is appropriate, a robot's touch that follows the model will be perceived as more natural than not following the model, and people will feel that they and the robot empathized with each other. Based on these hypotheses, I made the following three predictions:

- Prediction 1: If the robot touches the participant using the heartwarming NIG model when it is watching heartwarming videos with the participants, its touch will be perceived as more natural than a robot that uses the horror NIG model.
- Prediction 2: If the robot touches using the horror NIG model when it is watching horror videos with the participants, its touch will be perceived as more natural than a robot that uses the heartwarming NIG model.
- Prediction 3: If the robot touches with a NIG model for videos in the same category, the participants will feel that they and the robot empathized with each other.

4.7.2 System setup

I used ERICA again. To increase the realism of the situation, I enabled an idle movement function for her. Without interfering with her touch behaviors, ERICA can breathe, make micro-body movements, and blink when watching the videos. I prepared a UI to allow participants to watch videos with her.

4.7.3 Participants

We recruited 16 people (eight females and eight males) whose ages ranged from 21 to 48 and averaged 34. They had diverse backgrounds, and none joined the previous data collection for building the touch timing models.

4.7.4 Conditions

Our experiment had a within-participant design. Each participant experienced the four conditions (category factor: heartwarming video and horror video and model factor: heartwarming NIG and horror NIG) described below:

Category factor

This factor has two video conditions: heartwarming and horror. In the heartwarming video condition, the participants and the robot watched heartwarming videos together. In the horror video condition, they watched horror videos together. The details of the videos are described in the next subsection.

To prepare the video stimuli, I downloaded eight commercially available videos from YouTube[2]. Four videos (two heartwarming/horror) are identical materials from the data collection. I selected four new videos (two heartwarming/horror videos) for the experiment.

Model factor

This factor also has two NIG conditions: heartwarming and horror. In the heartwarming NIG condition, the robot samples from one standard deviation range of the heartwarming NIG, and in the horror NIG condition, it samples from the horror NIG, described in Section III, to determine the touch-timing characteristics.

[2] https://youtu.be/ftaXJlvn5f4, https://youtu.be/cPHLlSvKr8, https://youtu.be/hJxvt5LNnKg, https://youtu.be/7sVl_Mi9d0Q, https://youtu.be/b2MH-yxIR4Y, https://youtu.be/4LYK0rTjlM8, https://youtu.be/dCPiAOiKSyo, https://youtu.be/gXfLl3qYy0k

To control the touch timing in both conditions, since the robot needs to know the t_{climax} for each video, I conducted a preliminary survey for these eight videos. Fifteen participants from our institutions, who had no knowledge of our study whose ages ranged from 24 to 35 and averaged 26, answered the climax timing of each video. I used the average of the largest clusters of the histograms of the climax timing as t_{climax} for each video. I edited the videos so that they only had one typical climax timing (i.e., extracted t_{climax} for the robot) and at least 30 seconds remaining from the climax to the end of the video to leave enough time for finishing the robot's touch based on our implementation.

4.7.5 Measurements

To compare and investigate the perceived naturalness of ERICA's touch behaviors, the participants compared two aspects in the first questionnaire: Q1) the naturalness of touch (degree of naturalness of touch behavior to express emotion) and Q2) the naturalness of touch timing (degree of naturalness of touch timing). Participants answered this questionnaire for each video.

Moreover, I asked the participants about their perceived empathy with ERICA from two aspects in the second questionnaire: Q3) the perceived empathy to ERICA (degree of perceived empathy to ERICA) and Q4) the perceived empathy from ERICA (degree of perceived empathy of ERICA to you). Participants answered this questionnaire after each condition (i.e., one time for each condition). For these questionnaires, I used the response format on seven-point scale, i.e., describing the options ranging from most negative to most positive.

In the second questionnaire as a manipulation check, I asked the participants about their perceived emotions from the robot's touch. The only emotional signal from the robot is her grip behavior; she did not say anything through the entire experiment and maintained a neutral facial expression. Although I thought that the perceived emotions probably depended on the category factor, confirming them is important. I asked the participants to select the top two perceived emotions (Q5/Q6) from Ekman's basic six emotions[55].

4.7.6 Procedure

Before the experiment, the participants were given a brief description of its purpose and procedure. This research was approved by our institution's ethics committee for studies involving human participants. Written, informed consent was obtained from them.

First, I explained that they would watch a series of heartwarming/horror videos with ERICA who would keep touching their hand during the process. Sometimes she would grip it to convey emotion. The participants sat on ERICA's left. To reproduce identical touch behaviors for all the participants, I asked them to put their right hands on markers of the table. After the experiment started, participants used a UI to play the videos. When a video started, ERICA put her hand on the participant's hand and gripped at a selected moment that lasted a certain duration using the mechanism described in Section III. After each video, ERICA resumed her default pose, and the UI showed Q1 and Q2 from the first questionnaire. If the video is the final stimulus for each condition, the UI also showed the second questionnaire from Q3 to Q6.

I adopted a counterbalanced design for each factor. All horror videos or all the heartwarming videos were played randomly during which ERICA drew samples from either the horror or the heartwarming NIG. Then the videos were played again as ERICA drew samples from the second NIG. These steps were repeated for the remaining videos.

4.8 Result

4.8.1 Manipulation check

Table 4.5 and table 4.6 show the integrated number of perceived emotions from Q5/Q6. The total number for each NIG is 32 because I asked about two perceived emotions, which depended (by touching) on the category factor; the majority of the perceived emotions for the heartwarming and horror categories are happy/sad and fear/surprise. For the former, similar to a past study that investigated expressions of deeply heartwarming emotion in Japan found out that it could include opposite emotional nuances such as joy or sadness[92], the participants selected happy and sad emotions as

Table 4.5: Perceived emotions from heartwarming category

	Happy	Sad	Surprise	Fear	Disgust	Anger
HeartwarmingNIG	16	15	1	0	0	0
HorrorNIG	16	15	1	0	0	0

Table 4.6: Perceived emotions from horror category

	Happy	Sad	Surprise	Fear	Disgust	Anger
HeartwarmingNIG	0	0	10	16	6	0
HorrorNIG	0	0	15	16	1	0

perceived emotions. For the latter, participants reported typical emotions, i.e., surprise and fear about horror videos.

4.8.2 Verification of predictions 1 and 2

Figure 4.12 (left) shows the questionnaire results of the naturalness of touch. I conducted a two-way analysis of variance (ANOVA) for each factor on category and model. The sphericity of the analysis has not been violated in this setting. I identified the significant main effect in the model factor (F(1,15)=16.736, p<.001, partial η2=.527). I did not identify a significant main effect in the category factor (F(1,15)=1.306, p=.271, partial η2=.080) or in the interaction effect (F(1,15)=1.823, p=.197, partial η2=.108).

Figure 4.12 (right) shows the questionnaire results of the naturalness of the touch timing. I conducted a two-way ANOVA for each factor on category and model. The sphericity of the analysis has not been violated in this setting. I identified the significant main effect in the model factor (F(1,15)=47.481, p<.001, partial η2=.760). I did not identify a significant main effect in the category factor (F(1,15)=0.148, p=.706, partial η2=.010) or in the interaction effect (F(1,15)=575, p=.021, partial η2=.328)

These results show that the participants evaluated the touches higher with the horror NIG regardless of the video categories. Thus, prediction 2 was supported, but not prediction 1.

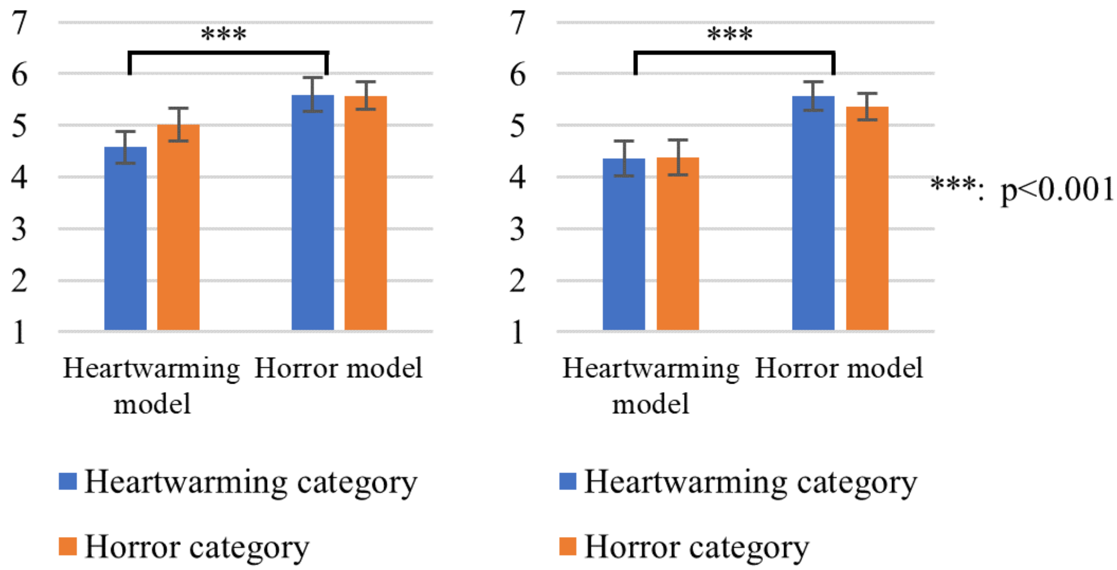

Figure 4.12: Questionnaire results: naturalness of touch (left) and naturalness of touch timing (right)

4.8.3 Verification of prediction 3

Figure 4.13 (left) shows the questionnaire results of the perceived empathy to ERICA. I conducted a two-way ANOVA for each factor on category and model. The sphericity of the analysis has not been violated in this setting. I identified the significant main effect in the category factor (F(1,15)=9.765, p=.007, partial $\eta 2$=.394). I did not identify a significant main effect in the model factor (F(1,15)=0.256, p=.620, partial $\eta 2$=.017) or in the interaction effect (F(1,15)=0.016, p=.900, partial $\eta 2$=.001).

Figure 4.13 (right) shows the questionnaire results of the perceived empathy from ERICA. I conducted a two-way ANOVA for each factor on category and model. The sphericity of the analysis has not been violated in this setting. I identified the significant main effect in the category factor (F(1,15)=21.626, p<.001, partial $\eta 2$=.590). I did not identify a significant main effect in the model factor (F(1,15)=.852, p=.371, partial $\eta 2$=.054) or in the interaction effect (F(1,15)=.028, p=.868, partial $\eta 2$=.002).

These results show that participants felt empathy with the robot when they watched horror videos, regardless of the NIG models. Thus, prediction 3 was not supported.

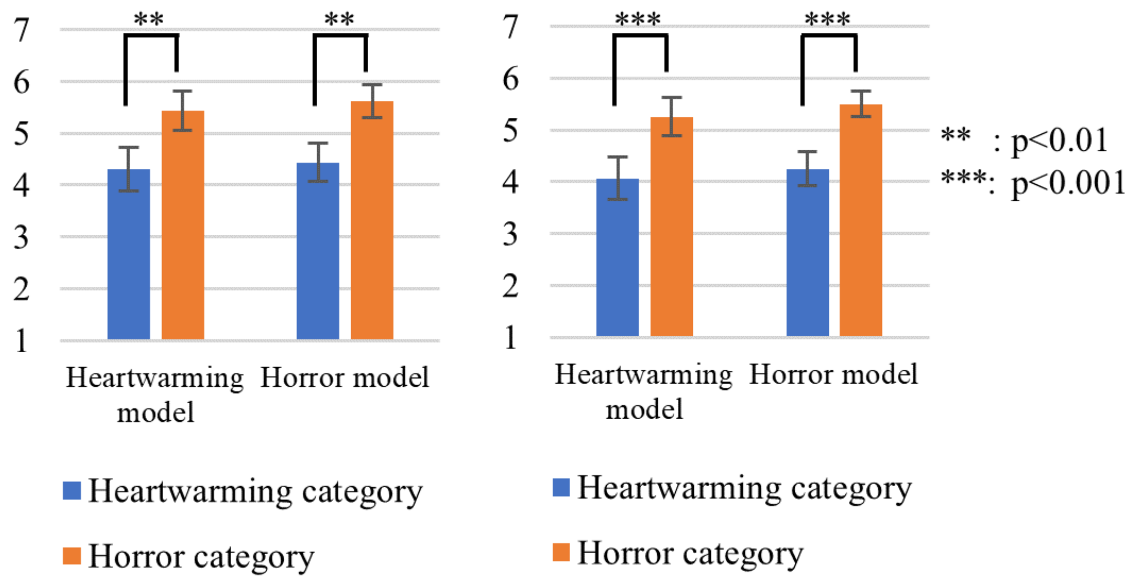

Figure 4.13: Questionnaire results: perceived empathy to ERICA (left) and perceived empathy from ERICA (right)

4.9 Discussion

4.9.1 Model validity

I applied two video stimuli in each video category that was used in the data collection experiment in the verification experiment. I did not think that combining the old and new video stimuli was problematic because the participants who trained the models at the first experiment and evaluated them at the second experiment are different. But evaluating the models with only new video stimuli would provide additional evidence of effectiveness.

Figure 4.13 (left) shows the questionnaire results of the naturalness of touch with only new videos. I conducted a two-way ANOVA for each factor on category and model. The sphericity of the analysis has not been violated in this setting. I identified the significant main effects in the model factor ($F(1,15)=13.720$, $p=.002$, partial $\eta 2=.478$) and in the category factor ($F(1,15)=6.505$, $p=.022$, partial $\eta 2=.303$). I did not identify a significant main effect in the interaction effect ($F(1,15)=2.517$, $p=.133$, partial $\eta 2=.144$).

Figure 4.13 (right) shows the questionnaire results of the naturalness of

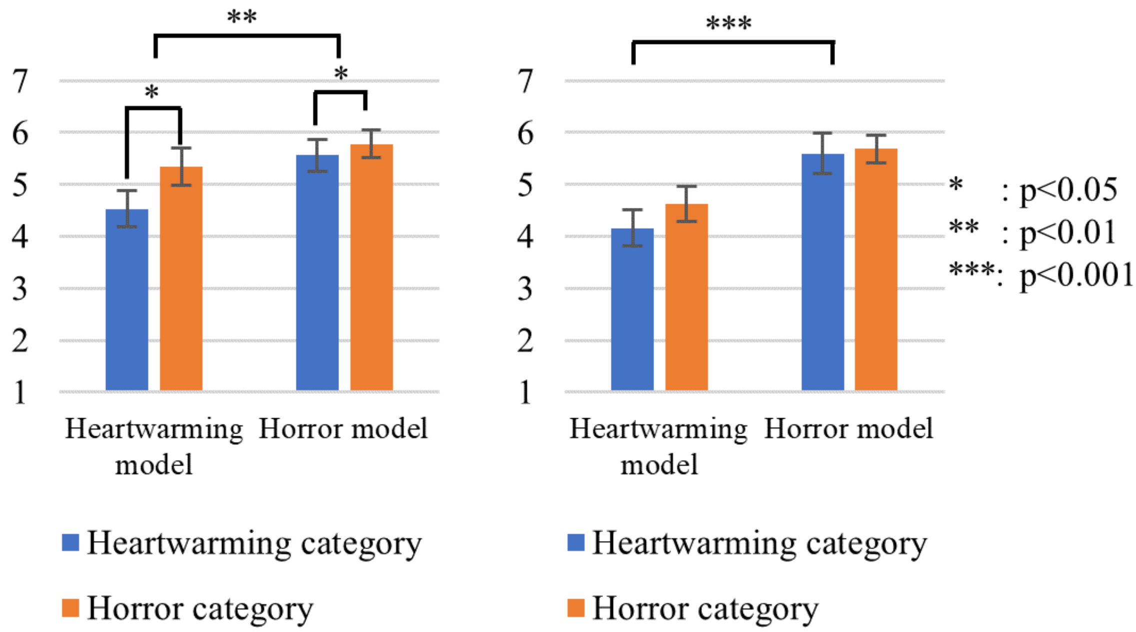

Figure 4.14: Questionnaire results using only new videos: naturalness of touch (left) and naturalness of touch timing (right)

touch timing for only new videos. I conducted a two-way analysis of variance (ANOVA) for each factor on category and model. The sphericity of the analysis has not been violated in this setting. I identified the significant main effect in the model factor ($F(1,15)=30.612$, $p<.001$, partial $\eta 2=.671$). I did not identify a significant main effect in the category factor ($F(1,15)=1.086$, $p=.314$, partial $\eta 2=.068$) or in the interaction effect ($F(1,15)=.789$, $p=.388$, partial $\eta 2=.050$). These results show that the models are effective for video stimuli that are not used in the data collection. I note that the statistical analysis for only the videos in the data collection showed similar trends.

4.9.2 Design implications

Different from our hypotheses, the experiment results showed a better impression invoked with the horror NIG model where the robot and the participants watched both heartwarming and horror videos together. This result provides design implications for a robot's touch behavior.

First, as a touch behavior implementation for a social robot, touch timing before a climax provides better impressions than touch timing after the climax, at least in a touch-interaction scenario where videos were the only external emotional stimuli that people intended to watch with a robot. One technical consideration is how to estimate the climax timing. Several past studies proposed methods to identify highlighted movie scenes by information processing [98, 99]. Such an approach would be useful to define climax timing for videos.

Second, our result suggests that directly using the parameters observed from human behaviors might overlook better parameters for the behavior designs of robots in emotional interaction contexts. From our study, even with an abundant number of participants for data collection, the observed touch models, i.e., heartwarming NIG, failed to reflect the people's actual expectations in evaluation.

Why did the observed heartwarming NIG model show disadvantages? One possible reason is that the setting was different between the data collection and the experiment. During the data collection, the participants were allowed to watch the videos repeatedly to identify the robot's touch-timing characteristics. They already knew the climax timing of the video. On the other hand, in the experiment, they had no prior knowledge about the video stimuli or their climax timing. In such situations, I thought that touch timing before the possible climax would be interpreted more favorably because such touch timing might demonstrate a sense of empathy to people who have been touched in this way.

In addition, even though the estimated emotions by participants are fitted to the video categories, there were no significant effects for perceived empathy. Expressions of emotions via only touches might be an implicit way. It would enable participants to estimate expressed emotions by ERICA, but she and participants did not express their perceived emotions explicitly. To perceive empathy, feeling and sharing other's emotions explicitly would be important. Therefore, such implicit expressions might not be enough to increase perceived empathy. As I described the next subsection, using different modalities to express emotions explicitly might be effective in increasing perceived empathy.

4.9.3 Different modalities and touch characteristics

I only focused on touch timing and duration to convey emotions in human-robot touch interaction. However, such other modalities in verbal/nonverbal behaviors as facial expressions [43, 68, 100, 101], whole-body gestures [102, 103], and voice characteristics like tone or pitch [15, 104] are also critical in real settings. Mixing different modalities might contribute to increase the perceived empathy, but heeding appropriate behavior designs of each modality is needed to avoid mismatch expressions.

In this study, I employed a grip behavior that conveyed both heartwarming and horror emotions. Other characteristics, such as pressure (e.g., strength) or touched part (e.g., touching a person's upper arm), might also influence the perceived impressions. Although the focus of this study is to model appropriate touch timing, investigating integrated multi-modal effects is another potential future works.

4.9.4 Gender and appearance effects

Gender and appearances would obviously have influenced both the emotional expressions and the perceived emotions from the same stimulus [105]. In human-human interaction, social expectations of expressing horror to a partner and heartwarming emotions could be different due to gender factors [106, 107]. These results suggest that a grip behavior from a masculine-looking android might be perceived differently in emotional expression compared to a feminine-looking android. Although such gender effects are beyond the scope of this study, interesting future work might investigate the effects of perceived robot's gender using masculine-looking androids [108, 34].

4.9.5 Other limitations

Since I only used a specific android robot with a female appearance, before generalizing our experimental results, we must test different types of robots, as described in Section 4.9.2. In addition, the android in this study has hands that resemble human hands and can perform gripping behaviors. For robots without such kind a hand structure, other touch characteristics must be considered.

I only used heartwarming and horror videos as emotional stimuli because these emotions are typically used in human-robot interaction studies as well as in human science literature. Investigating appropriate touch timing for different emotions is needed to convey such emotions by touch.

Chapter 5

General Discussion

5.1 Possible applications

5.1.1 Enriching human-robot interactions

One of the most direct applications would embed the hand touch behaviors into our android's interaction loop with users. Since this thesis has developed and proved the type of hand touch that can convey happy emotions, implementing that could make a huge difference in the first impression when people interact with our android. For example, it would be amazing if our android could pat a visitor's hand with a warm smell, then greet the visitor by his or her name after asking the visitor in the introduction session when meeting our android for the first time. Indeed, embedding proactive touch behaviors with other modalities will greatly enrich human-robot interactions.

5.1.2 Improving robot social utility by providing soothing touch

Another possible application is to use the hand touch behaviors to provide soothing touch services in psychological therapy, especially by using androids for such tasks. According to WHO 2021 report, about 3.8% of the world's population is affected by depression. Due to the lock-down during the pandemic, this number could be even higher. Also considering it may be necessary to restrict social contact to prevent the spreading of the disease, using Androids, or a robot arm paring with a VR device [35] to provide such therapy during might be a viable solution.

5.2 Limitation

Due to the fact of lacking relevant studies in robot proactive social touch when I started the work of this thesis, the research scope is limited to a handful of touch characteristics and the research story might not be as fancy as, say, using deep learning to study meta problems. And the probability NIG models may seem primitive and the implementation method may be quite simple, that is due to the data I able to collect is quite limited. However, if this research area keeps developing, combining other data collection technologies, e.g., motion capture, etc, would greatly improve modeling capabilities.

Following the above, one other big limitation for this thesis under the current research setup is that the data source was limited. Specifically, recruiting participants was the only method to collect data. If I could set up scenarios in which people may interact with the robot freely with systems that can collect interaction data automatically, it would greatly boost the research efficiency. After all, data are becoming the new blood that is pumping up model research combined with deep learning. On the other hand, all studies in this thesis are conducted with the mindset of creating applicable autonomous robot behaviors. All experiments were designed only requiring minimal experimenter interference, i.e., it only required one click of the "START" button to finish one experiment from beginning to the end, and no Wizard-of-Oz method was used.

The other limitation is that I was not able to systematically compare the touch behaviors to other modalities. Rather, this thesis treats touch behaviors as the upgraded method of expressing emotions. As in Study 1, the experiment results proved that all touch behaviors can convey an emotion with higher strength compared to only using speech and facial expression. After that, I did not compare the touch behaviors I conclude for expressing happiness and sadness with the corresponding method in gesture. One reason is that there lack clear reference of what would be the correct gesture for an android to express happy and sad emotions, even though one reference could be potentially used to construct a happy or joyful gesture [109]. The other reason is the lack of time and resources to perform extra experiments and design emotional gestures. However, it would be nice to perform a comparison study in the future.

Due to the android's appearance and voice, she is usually perceived as a female, which could incur gender effects during experiments. Also, an android is a specific type of robot. The touch behaviors of an android may not directly apply to other types of robots. Luckily, the touch characteristics and touch timing models can be abstracted and generalized to any type of robot with an arm and palm-like structure.

For the touch behaviors themselves, I was not able to control the exerted force due to lacking corresponding sensors and mechanisms in the robot. However, using a mechanical arm to study robot touch behaviors could make it possible to precisely measure things like downward force.

It should also be pointed out that all experiment participants were Japanese, while traditionally, only Japanese nobles were allowed to touch others with a gloved hand. This might make some participants feel awkward. But the experiment results were valid as participants understand they were interacting with a robot that had no social-status prejudice. And the benefit of using gloves overweight the potential awkwardness, e.g., mitigate unnatural feelings of the robot's silicon skin.

5.3 Discussions

5.3.1 Physically presented robot vs. virtual agent

To perform touch behaviors, physical coexistence is required. In human-human interactions, physical presence have proved to facilitate higher level of trust [110], reduce stress [111] and strengthen relationship within couples [112]. While the current development trend of interaction technologies are biasing virtual reality (VR) and argument reality (AR) as substitutions of physical interaction due to changes of social norms[113, 114] and the global pandemic [115], physical presence are still irreplaceable [116].

The same concept applies to social robots. Although virtual agents are easier to create and with more complex facial expressions or body language, and one may argue that the physically co-existed robot may not always be more effective than the virtual counterpart [117], it is generally agreed that physical robots receive more positive evolution [118]. Therefore, I deeply believe that physical robots will play more crucial roles in the success of social robots.

5.3.2 Sensing technologies

To enable the robot to perform touch behaviors automatically with the safety of users as the first priority, sensing technology is the key. For sensing the contact information of touch behaviors, it is important to install touch sensors onto the robot surface, or "skin" for an android. Multiple potential solutions are presented. For example, the human-skin-like multi-touch sensor structure [119], using multi-directional touch sensor to simulate human fingertips [120], or use graphene touch sensor that can respond to pressures contact area [121], etc.

Sensing the proximity of the robot is also important. It helps the robot to estimate the relative distance with the user and calculate the movement trajectory. The solution could include using a depth camera [122], using capacitive sensors to measure the presence of conductive objects [123], or using a combination of capacitive and inductive transducers to create sensing solutions [124], etc.

5.3.3 Implementations touch behaviors to other types of robot

Modern robots have distinct physical structures and even focusing on social robots (in comparison to industrial robots), the parts that can be considered as 'hand' are very different. To list a few in fig. 5.1, Sony's famous Aibo robot has a paw-like structure, the Nao robot has a hand with three fingers, while the COZOM robot shown in fig. 1.1 has no hand at all. Luckily, most of the touch characteristics can be directly applied regardless of the robot type. For example, all the robots can use *length*, i.e., how long the physical contact last, to change conveyed emotions.

Notice that in this thesis, ERICA can successfully touch participants' hands because they are requested to put their hands at a fixed location where

Figure 5.1: (Left) NAO with a three finger hand; (Middle) AIBO with a paw; (Right) ERICA the andriod with human-like hands;
(NAO's Image modified from https://aibo.sony.jp/)
(AIBO's Image from https://bit.ly/3MHg71b)

ERICA could reach to. In actual interaction scenarios, users' position is very likely to be dynamic, meaning the robot need to have extended sensory ability to recognize the appropriate body parts and adjust its movements before performing successful proactive touch behaviors. The robot's size and shape also need to be considered. For example, AIBO is a puppy-like robot. Instead of using human-inspired touch behaviors, it might be more appropriate to imitate human-dog touch interactions.

5.3.4 Embedding touch interactions in long-term scenarios

As one of the essential functions of social touch is to intensify the expressed emotion, natural touch interactions should in consistence with the process of gradually building up a relationship between the robot and users. Therefore, it is better to implement proactive touch behaviors in long-term scenarios in conjunction with other modalities. Otherwise, a robot's proactive touch behaviors towards a person in the first minute of interaction might scare people rather than convey friendliness.

Chapter 6

Conclusion

6.1 Conclusion

This thesis contribute to the body of knowledge on human-robot physical interaction by exploring the design and implementation methodology of convey various emotions through robot proactive hand touch. The knowledge will benefit social robotics to open up a new channel to naturally express robot emotions in a more intense manner.

In summary, I extracted four touch characteristics based on human touch behaviors based on arousal/valence perspective, i.e., *length*, *type*, *part* and *place*. By combining these touch characteristics, I successfully implemented various proactive hand touch behaviors using Android ERICA and satisfied the first research objective. By designing two behavior variants for each characteristic and map them based on arousal/valence quadrant (fig. 6.1), I evaluated the perceived strength and naturalness of these touch behaviors and proved that the android can indeed convey happy/sad emotion and a feeling of intimacy through touch, thus fulfilled the second research objective. I modeled touch timing using NIG and implemented the proactive touch in video-watching scenarios by using heartwarming and horror video clips as emotional stimulus. With this, I successfully implemented the touch behaviors in context to interaction scenarios and the third research objective is met.

Of course, this thesis also opens more challenges for future research and I will discuss some of them below.

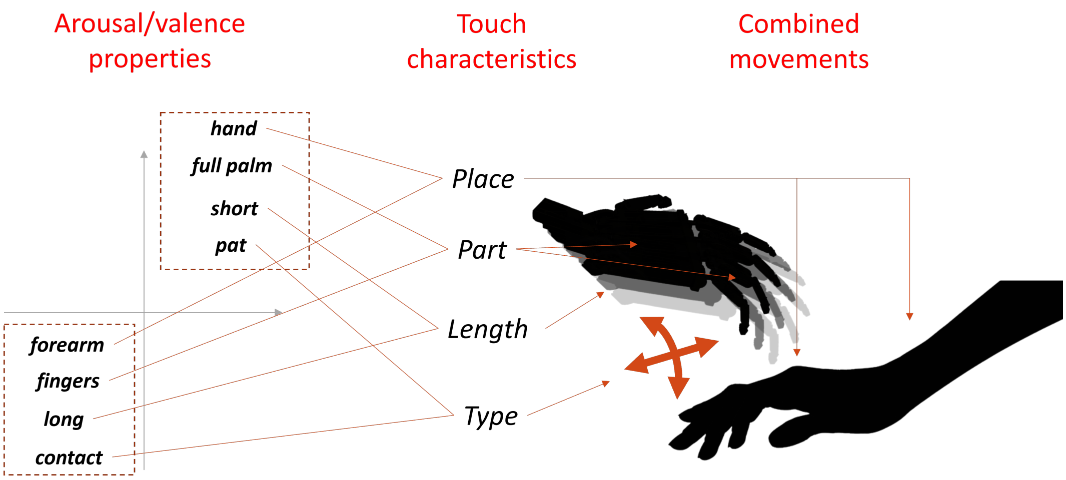

Figure 6.1: Summary of touch characteristics and their quadrant on Russell's circumplex model

6.2 Future Work

6.2.1 Design robot-compatible touch interactions

As been discussed previously, social robots have dramatically different sizes, physical structures, and roles. Therefore, some of those robots may not able to use the hand-to-hand touch behaviors I have developed in this thesis. Specifically, some robots do not have a hand "structure" but do have movable body part(s), e.g., the COZMO uses a bumper bar like structure as its "arm" with one DOF (fig. 6.2). It can use this "arm" to *pat* its user with different *length* to show emotions. And we just need to make sure this little robot can reach to its users and the touch area should not be limited to users' hands, e.g., the robot can touch users' feet if they are standing or hands if they laying on the ground etc.

6.2.2 Multi-modailty touch interaction design

Realistic social interactions can involve complex language communications, gestures and facial expressions. For example, interactions for health-care robots deploying in a clinic environment might require different communication patterns from the health-care robots deployed in users home. Even

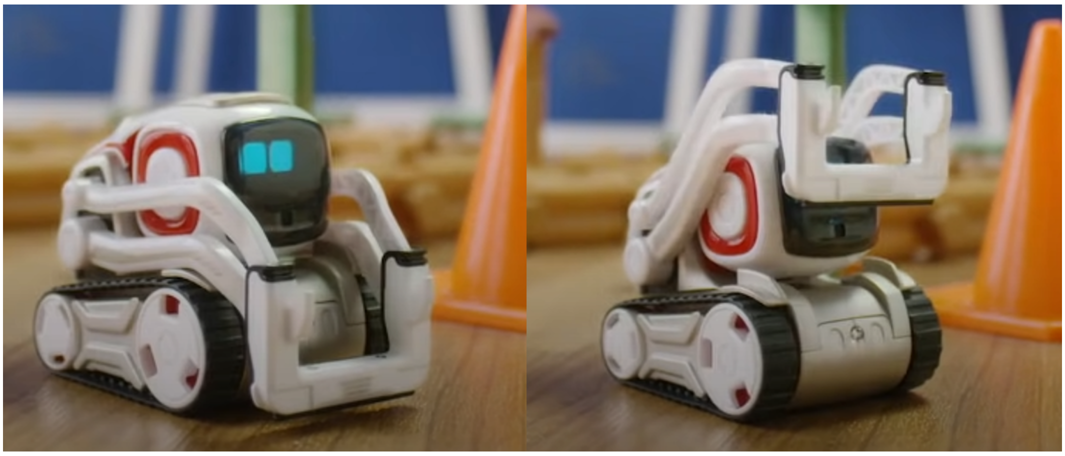

Figure 6.2: Robot COZMO's bumper bar like "arm", pictures edited and captured from https://www.youtube.com/watch?v=BWymDFX8PlY

the same touch behaviors may convey different feelings under different scenarios with other modalities affecting the overall emotional expressions. Therefore, we need further researches to design touch patterns that can dynamically match other modalities for expressing intended emotions in such scenarios, ideally matching the same level of expressiveness of human-human emotional interactions.

6.2.3 Context-aware emotional touch

Touch interactions are naturally perceived as a more intimated behaviors comparing to other modalities. And a robot proactive touch without any foreshadowing interactions may startle its users rather than convey friendliness. Therefore, like that in human-human interactions, a robot's touch behaviors should also be designed in context with the relationship progression with its users. As such emotional interaction will eventually lead to a sense of intimacy, we need to design touch behaviors that can match the level of intimacy in long-term interaction scenarios, and explore features that can help distinguish subtle difference of intimacy when using touch characteristics to construct those behaviors.

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Related Publications

International Journal Publications

1. Zheng, X., Shiomi, M., Minato, T., and Ishiguro, H. (2019), "What Kinds of Robot's Touch Will Match Expressed Emotions?", IEEE Robotics and Automation Letters, 5(1), 127-134.

2. Zheng, X., Shiomi, M., Minato, T., and Ishiguro, H. (2020), "How Can Robots Make People Feel Intimacy Through Touch?", Journal of Robotics and Mechatronics, 32(1), 51-58.

3. Zheng, X., Shiomi, M., Minato, T., and Ishiguro, H. (2020). Modeling the Timing and Duration of Grip Behavior to Express Emotions for a Social Robot. IEEE Robotics and Automation Letters, 6(1), 159-166.

4. Shiomi, M., Zheng, X., Minato, T., and Ishiguro, H. (2021). Implementation and Evaluation of a Grip Behavior Model to Express Emotions for an Android Robot. Frontiers in Robotics and AI, 8.

Workshop and Symposium

1. Zheng, X., D., Glas, M., Minato, Ishiguro, H., "Four memory categories to support socially-appropriate conversations in long-term HRI," Workshop on Personalization in Long-Term Human-Robot Interaction, IEEE HRI 2019, Daegu, South Korea

2. Zheng, X., Shiomi, M., Minato, T., and Ishiguro, H., "Preliminary Investigation about Relationship between Perceived Intimacy and Touch Characteristics", IEEE IROS 2019 late breaking results poster session

3. Zheng, X., Shiomi, M., Minato, T., and Ishiguro, H., “What kinds of robot’s touch will match expressed emotions”, 2nd International Symposium on Systems Intelligence Division, Osaka, Japan, February 2020

4. Zheng, X., D., Glas, and Ishiguro, H., Robot Social Memory System, 1st International Symposium on Systems Intelligence Division, Osaka, Japan, January 2019

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