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How should a Robot React before People's Touch?: Modeling a Pre-Touch Reaction Distance for a Robot's Face

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***Abstract*— This study addresses the pre-touch reaction distance effects in human-robot touch interaction with an android named ERICA that has a feminine, human-like appearance. Past studies on human-robot interaction, which enabled social robots to react to being touched by developing several sensing systems and designing reaction behaviors, focused on after-touch situations, i.e., before-touch situations received less attention. In this study, we conducted a data collection to investigate the minimum comfortable distance to another's touch by observing a dataset of human-human touch interactions, modeled its distance relationships, and implemented a model with our robot. We experimentally investigated the effectiveness of the modeled minimum comfortable distance to being touched with participants. Our experiment results showed that they highly evaluated a robot that reacts to being touched based on the modeled minimum comfortable distance.**

***Index Terms*—Human-robot interaction, Human factors**

I. Introduction

THE physical existence of social robots enables us to interact with them through haptic interactions. Human science literature has broadly reported haptic interaction and positive effects in both physical and mental perspectives [1-6]. Following these results, robotics researchers also reported similar positive effects of haptic interaction with robots, e.g., mental therapy effects of a seal robot for elderly care [7], stress buffering effects [8], motivation improvements for monotonous tasks [9], encouraging prosocial behaviors [10] [11], encouraging self-disclosure behaviors, and motivations to interact with a robot [12, 13]. In addition, robotics researchers investigated what kinds of behaviors are essential for natural reactions to being touched by interaction partners [14, 15].

These studies identified the potential of haptic interaction with social robots and provided essential knowledge for haptic interaction design. However, they focused on the behaviors or the effects of haptic interaction "after" being touched; less focus has been directed at how to deal with a robot's pre-touch behaviors. How should robots behave before they are touched? Perhaps they should react at a certain distance to another's hand like humans do for more natural interactions. Unfortunately, the effects of such pre-touch reactions remain uninvestigated as well as what reaction distance is actually deemed appropriate.

In human science literature, people choose certain distances from others in conversation situations. Such knowledge was summarized as proxemics by E.T. Hall [16], and many social robots employ its knowledge to interact with people for more natural distance relationships [17-30]. Inspired by Hall's study on proxemics, the ultimate goal of our study is to gather knowledge about it in touch interactions, particularly "before" being touched situations. We defined the specified proxemics in before-being-touched situations as pre-touch proxemics, which will provide knowledge for robots to achieve natural behaviors or reactions for touch interactions with people.

As a first step for this goal, we investigate the minimum comfortable distance between a face and a hand in touch interactions, because such knowledge will be the foundation for touch reactions for social robots in haptic interactions. We conducted a data collection with human participants who moved their hands toward the faces of others and measured the minimum comfortable distance between their faces and the hands to identify the permissible boundaries around the face. Next we analyzed these collected data and implemented the boundary information in ERICA (Fig.1), our social robot, [31]. Finally we experimentally investigated whether our model can provide natural impressions to people who moved their hands toward it. Thus, this study answers the following two questions:

- What is the minimum comfortable distance in human-human touch interaction around the face?
- Should a robot react before being touched by a person? If so, should its reaction obey the minimum comfortable distance of people?

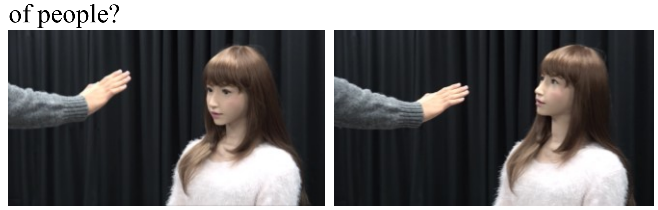

Fig. 1. ERICA reacts before being touched.

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II. Related Work

A. Human-Robot Touch Interaction

In touch interactions with people, sensing capabilities are essential for social robots. Several researchers have developed sensing mechanisms and/or algorithms for such robots [32-34]. Due to an increase of sensing capabilities in touch interactions, robotics researchers have started to investigate the positive effects on people of haptic interaction with social robots [35, 36]. For instance, Paro, a touchable seal robot, is a pet-type social robot for the mental health support of the elderly [7].

Researchers have also addressed the effects of verbal/non-verbal cues during haptic interactions. For the effects of the latter, Hirano et al. investigated how gaze behaviors and touch styles changed the impressions of touch interactions [37]. Chen et al. investigated the effects of verbal cues in a nursing context and studied how the timing and the contents of verbal cues change the impressions of being touched [14]. From another perspective, researchers focused on dance situations where both verbal/non-verbal cues are essential for collaboration between robots and people [38-40].

These research works identified the effectiveness of touch interaction with social robots and provided appropriate design policies for haptic interactions. However, these studies mainly dealt with after-touch situations and focused less on before-touch (potential/imminent touch) situations. In this study, we conducted a data collection between humans to construct per-touch proxemics knowledge and implemented it in our robot to investigate its effectiveness and validity for human-robot touch interactions in before-touch situations.

B. Proxemics in Human-Robot Interaction

Proxemics is one common theory about the use of space for humans in social situations [16]. Researchers often refer to this knowledge when developing social robots that interact with people to adjust the distance based on their relationships: socially-aware navigation [17, 18], path planning [19] [20], approaching, [21], and showing friendliness [22]. From another perspective, researchers investigated which features influence the minimum comfortable distance between people and robots: the personality of the people [23-25], the robot size [26], and verbal information and body postures [27, 28]. In addition, other researchers assumed that distances can be used to estimate the personality of the interacting partners through interaction activity with social robots [29, 30].

Several researchers have modeled such personal spaces around people. For example, Amaoka et al. defined personal space as two Gaussians with more space in the front [41]. Svenstrup et al. identified a personal space that is larger behind the individual [42]. Related to the above previous work, both of these studies enabled social robots to interact with people considering appropriate distance relationships based on the interacting situations.

On the other hand, proxemics is less focused on haptic interaction situations because its knowledge is mainly derived from analyzing conversational situations [16]; the minimum comfortable distance relationship reflects the body parts of the interacting people. In other words, it remains unknown how robots should react when they are touched. In this study, we focused on haptic interactions and the minimum comfortable distance relationship between the touched body part (i.e., the face) and the part doing the touching (i.e., the hand) in close-distance relationships, which is the main difference between proxemics and pre-touch proxemics.

III. Analyzing Minimum Comfortable Distance

To investigate the minimum comfortable distance for touching in human-human interaction, we conducted a data collection with human participants.

A. Data Collection

1) Overview

In this data collection, we gathered distance data between the hand of a person who is going to touch (toucher) and the face of a person about to be touched (evaluator). As a first step for knowledge about pre-touch proxemics, we focused on the distance around the face to investigate the relationship between the evaluator's gaze direction and the toucher's touch angle to identify a minimum comfortable distance. If the gaze direction strongly influences this distance, such knowledge will be useful for investigating and designing the minimum comfortable distance for other body parts.

We gathered data from both female and male touchers/evaluators, because past studies reported that the gender of the interacting partners influences the minimum comfortable distances of the proxemics perspective [43-45]. We expect similar effects will occur in touch situations.

2) Procedure

We followed the similar approaches of past proxemics studies that investigated the minimum comfortable distance between people and robots [23-28]. For example, many studies fixed the evaluators' positions including the face direction, and then others or robots slowly approached the evaluators. When they felt discomfort based on the encroaching of others, they expressed it, and the distance of the discomfort was recorded as the minimum comfortable distance. By following these procedures, the touchers slowly stretched out their hands toward the evaluators' face and freely decided their initial hand positions to cover various angles. When the evaluators wanted the hand's approach to stop, they clicked a mouse and these clicking sounds were audible to the touchers. When they heard the clicks, they were instructed to immediately stop moving their hands. Thus, we measured the minimum comfortable distance between their faces and the hands of the touchers.

Figure 2 shows the environment of the data collection. A pair of one toucher and one evaluator enter the room, and then the evaluators sat on a chair in the middle of the room. The experimenter asked them to look at a mark on the front of the chair to maintain their gaze direction. The touchers stood around the evaluators at a distance of 1.0 m (adjusted based on the arm's length of the touchers). The nine candidates of the standing positions are shown as 0 to 8 (Fig. 2, left). We asked the participants to continue the data collection as much as possible within the time, not decided the number of touching.

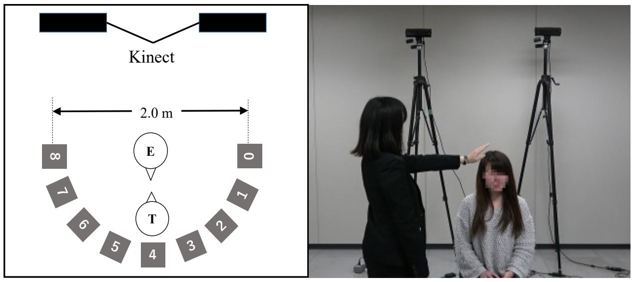

Fig. 2. Data collection environment: Toucher stands at "6" and stretches her hand toward evaluator.

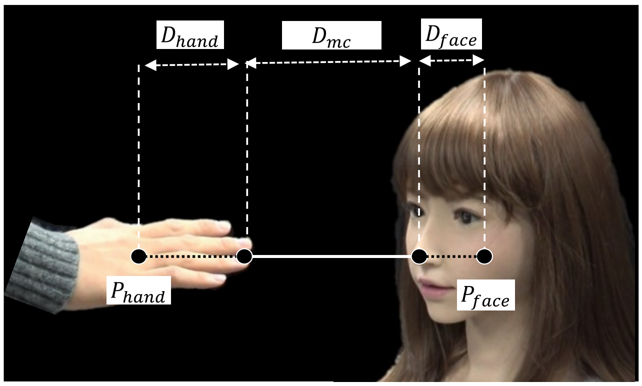

Fig. 3. Distance definitions in our date collection.

3) Recording data

To automatically track the respective positions of the hands and the faces of the touchers and the evaluators, we used two Kinect V2 sensors mounted behind the latter. Kinect's library provides highly stable and reliable 3D positions of each joint of the toucher, including the center of the hands (P_{hand} in Fig. 3) and the 3D head positions of the evaluators (P_{face} in Fig. 3). We recorded all the position data from the Kinect V2 sensors and the timing of the mouse clicks by the evaluator. To calculate the minimum comfortable distance between a toucher's hand and an evaluator's face (D_{mc} in Fig. 3), we subtracted the size of their hands (D_{hand} in Fig. 3, directly measured beforehand) and the average Japanese face size (D_{face} in Fig. 3, 9 cm for females and 10 cm for males, based a previous work [46]).

We used a multiple Kinect V2 for our joint position tracking system because we wanted a marker-less joint tracking system. We were concerned that attaching markers to the evaluators' faces and the touchers' hands would influence the minimum comfort distance because their physical existence might change the before-touch feelings. Even though a past study argued that this sensor is suitable for applications that require joint-position accuracy that does not exceed a couple of centimeters [47], it focused on the accuracy of a whole body tracking algorithm for upper limbs in a rehabilitation process, which is quite different from our study that is focusing on the positions of the touchers' hands and the evaluators' faces. For the above reasons, we chose multiple Kinect V2 sensors. To increase the accuracy of the recognized joint positions, we calibrated the relative positions of multiple sensors and used their absolute positions to integrate their joint position data. If one Kinect sensor failed to estimate the joint positions, we used the other Kinect data if the estimated data were continuous and stable.

B. Analysis

In our data collection, 40 pairs of participants (10 pairs are female touchers and female evaluators, 10 pairs are female touchers and male evaluators, 10 pairs are male touchers and female evaluator, and 10 pairs are male touchers and male evaluators) participated in the cumulative total. Their average ages and SDs were 21.825 and 1.53, respectively. The total number of distance data was 11699 (average per toucher and SD were 292.5 and 81.1). Due to the personal differences in the minimum comfortable distance, the touch speed, the preparation time for data collection, occlusions due to the body sizes of the participants, the number of data for each participant was different. So we averaged the minimum comfortable distances for each evaluator and used them for analysis.

Based on these data, first, we investigated the average minimum comfortable distance of all the participants; the values and their SD were 19.97 cm and 8.484. We analyzed these data based on the following four viewpoints to scrutinize what factors influence minimum comfortable distance:

1) Gender

Since past studies reported that females preferred shorter personal distances than males [43, 44], we expected gender to influence the minimum comfortable distance (Table I). Therefore, we conducted a two-factor ANOVA with minimum comfortable distance as a dependent variable, the toucher's gender, and the evaluator's gender. There were no significant differences in the toucher's gender ($F(1, 39)=.012$, $p=.914$, $\eta2 = .001$), the evaluator's gender ($F(1, 39)=.020$, $p=.888$, $\eta2 = .001$), or in their interaction ($F(1, 39)=3.844$, $p=.058$, $\eta2 = .096$). The additional data collection suggests that the minimum comfortable distance increases with the opposite gender, but it did not show a significant effect. For reference, multiple comparisons with the Bonferroni method for interaction effects did not show any significant differences/trends. Thus, at least in this data collection, the gender of the touchers did not significantly affect the minimum comfortable distance.

2) Angle

Next we investigated the angle effects of the minimum comfortable distance because we thought that the touch direction might influence it (Table II). We used the average minimum comfortable distance by combining both genders in this analysis because gender did not show any significant differences in the above analysis. First, we conducted a paired t-test that compared the minimum comfortable distances when the touchers' hands approached from the right ($M=19.738$, $SD=8.96$) or the left ($M=19.811$, $SD=8.80$) and found no significant differences ($t(39)=0.188$, $p=.851$, $d=.003$). Next we conducted a paired t-test that compared the minimum comfortable distances when the touchers' hands approached from above ($M=18.438$, $SD=8.54$) or below compared to the heights of the evaluators eyes ($M=19.442$, $SD=11.38$) and identified no significant difference ($t(39)=1.135$, $p=.263$, $d=.018$). Note that "right" means that the angle between the evaluator's face and the toucher's hand is on "stage right" from the front of the evaluator's face when the evaluator clicked the button.

Thus, neither right/left nor upper/lower angles between the touchers' hands and evaluators' faces significantly affected the minimum comfortable distance.

3) Speed

Next we investigated how the speed of the touchers' hands influenced the data collection. Even though we asked the participants to move their hands slowly, they performed the action at slightly different speeds, which might have affected the minimum comfortable distance. We investigated the relationship between the speed of their hands and the minimum comfortable distance and found a weak positive correlation (r=0.197, p<.001). Of course, if their hands are approaching faster, evaluators might feel more anxious and respond quickly, but in our settings the speeds within the touching situation only showed a weak positive correlation with the minimum comfortable distance.

4) Acclimation

Finally, we investigated whether the evaluators' minimum comfortable distances changed as time progressed (Table II). In this data collection, since the evaluators experienced many touching interactions, their perceptions might have been influenced. We conducted a paired t-test that compared the minimum comfortable distances between the averages of the first 10 (M=21.283, SD=9.00) and the last 10 bits of data (M=19.324, SD=9.62), and found a significant trend (t(39)=1.804, p=.079, d=.028), but the difference was less than 2 cm. Thus, in this data collection, acclimation due to a large number of touching interactions did not significantly affect the minimum comfortable distance.

TABLE I. AVERAGE AND SD OF MINIMUM COMFORTABLE DISTANCE BY GENDER

		Toucher	
	Gender	Male	Female
Evaluator	Male	17.609 (7.638)	22.729 (8.913)
	Female	22.639 (10.844)	16.914 (7.112)

TABLE II. AVERAGE AND SD OF MINIMUM COMFORTABLE DISTANCES BY CONSIDERING ANGLE AND ACCLIMATION (P-VALUES CORRESPOND TO PREVIOUSLY COMPUTED T-TESTS)

Angle	Right	Left	p-value
	19.738 (8.96)	19.811 (8.80)	0.851
	Upper	Lower	p-value
	18.435 (8.54)	19.442 (11.38)	0.263
Acclimation	First ten times	Last ten times	p-value
	21.283 (9.00)	19.324 (9.62)	0.079

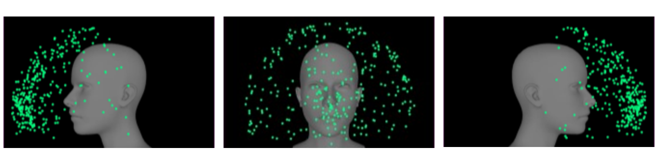

Fig. 4. Toucher's hand positions when an evaluator clicked button to stop the hand

C. Summary

Based on the above analysis, several factors, such as gender and the right-left and upper/lower angles, did not show significant differences in the minimum comfortable distances. The acclimation effects showed a significant trend but the difference was less than 2 cm. Therefore, we used the average minimum comfortable distance of all the gathered data by combining the genders, the hands, and the angles: 20 cm as a reaction distance. Fig. 4 shows an example of the distributions of the minimum comfortable distances from an evaluator; the data are distributed around 20 cm from the face, regardless of the angles.

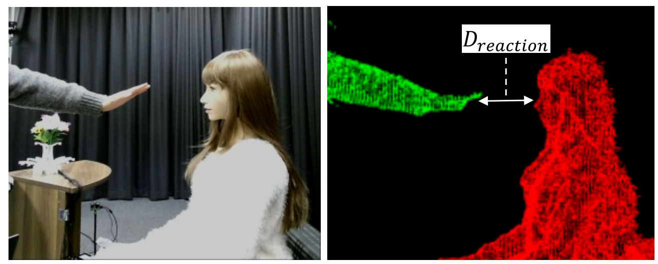

Fig. 5 Clustering results by depth data from a Kinect V2 sensor

Fig. 6 Reaction to being touched in touch condition

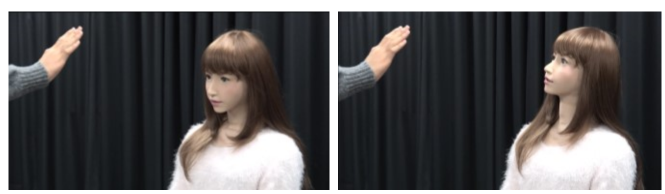

Fig. 7 Reaction to a potential touch in intimate-distance condition

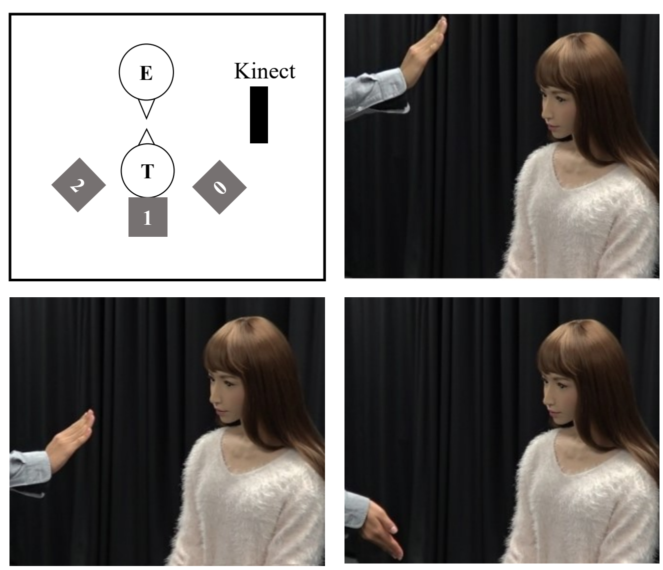

Fig. 8 Experiment environment and touching angles

IV. Experiment

A. Hypothesis and Predictions

Past studies revealed the effectiveness of human-robot touch interaction and achieved appropriate reactive behaviors for robots after their touches. However, the reaction behaviors of the pre-touch situations received less focus; e.g., the robots in past studies generally reacted after being touched, not before. From a proxemics perspective, the intimate distance for close people was 45 cm, which can be used for touch interactions, but these definitions were defined based on the analysis of conversational situations, not pre-touch situations. Therefore, the appropriate pre-touch reaction distance remains unknown.

To identify an appropriate reaction distance, we developed a model of minimum comfort based on the observations of the pre-touch reactions of people. Regardless of the gender relationships between touchers and evaluators, the average minimum comfortable distance was 20 cm. If our modeling is appropriate, the robot should be perceived as more humanlike, more natural, and create more positive impressions than a robot that reacts after being touched or reacts at an intimate distance to a potential touch. We made the following three predictions:

Prediction 1: If the robot reacts at 20 cm to a potential touch, its reaction distance will be perceived as *more humanlike* than a robot that reacts after being touched or at 45 cm.

Prediction 2: If the robot reacts at 20 cm to a potential touch, its reaction distance will be perceived as *more natural* than a robot that reacts after being touched or at 45 cm.

Prediction 3: If the robot reacts at 20 cm to a potential touch, people will more positively evaluate it than one that reacts after being touched or at 45 cm.

B. Robot System

To verify our predictions, we used ERICA, an intelligent, conversational android characterized by its human-like appearance [31], and a Kinect V2 sensor to detect the positions of the nearest object to ERICA's face. We also employed a PCL library [48] to make a clustering 3D object and FLANN [49] to measure the reaction distance (Fig. 5, right, $D_{reaction}$). The average calculation frequency was less than 100 msec in our settings.

C. Conditions

Our experiment had a within participant design. Each participant joined the three conditions described below. Their order was counterbalanced. In each condition, when the distance ($D_{reaction}$) was lower than the threshold values, the robot immediately looked at the participant's face.

Even though we found a significant difference between approaches from above or below, it was only 3 cm. This difference is significant, but its size is small. Rather than focusing on only a few cm of difference about the minimum comfortable distance, we compared different thresholds.

Touch: In this condition, the robot reacts to being touched by a participant after she/he actually touched the robot's nose (Fig. 6). $D_{reaction}$ is 0 cm. Since this condition is only semi-autonomous, to accurately react to the timing of being touched, the operator controlled the robot's reaction behavior.

Proposed: In this condition, the robot reacts to a potential touch from a participant when $D_{reaction}$ is less than 20 cm (Fig. 1). The robot is fully autonomous in this condition.

Intimate-distance: In this condition, the robot reacts to a potential touch when $D_{reaction}$ is less than 45 cm (Fig. 7). The robot is fully autonomous in this condition, too.

D. Participants

Thirty people participated: 15 women and 15 men whose average ages were 23.0, SD 2.58.

E. 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, we explained to the participants that the robot will react to being touched by them based on the robot's minimum discomfort distance. We asked them to slowly move their hand as if to touch the robot's face until it reacts to the potential touch. We explained that our experiment has three conditions, and in each one we asked the participants to approach the robot's face from three different standing positions (0, 1 and 2, left-top of Fig. 8) and three different angles (above, front, and below, Fig. 8) by both hands. In each condition the participants did the 3 positions x 3 angles x 2 hands = 18 hand approaches to experience sufficient pre-touch interactions. As they reached out with their arms to touch, we asked them to maintain a slow and constant speed to avoid speed effects. The order of each condition was counterbalanced, and after each condition they filled out questionnaires about their feelings to the robot's reactions.

F. Measurements

To investigate their feelings based on the different reaction distances of the robot to the participants, we measured with questionnaires three subjective items on a 1-to-7 point scale (7 is most positive): the feeling of humanlike-ness about the reaction distance ("I think that the robot's reaction distance is human-like"), the naturalness of the reaction distance ("I think that the robot's reaction distance is natural"), and their overall feelings about the robot ("I have a good impression of the robot overall").

V. Results

A. Verification of Prediction 1

Figure 9 shows the questionnaire results about the humanlike-ness of the reaction distance. We conducted a two-factor mixed ANOVA for the gender and distance factors, and the results showed significant differences in the distance factor (F(2, 56)=25.783, p<.001, $\eta 2$ =.479), but no significant differences in the gender factor (F(1, 28)=2.240, p=.146, $\eta 2$ = .074) or the interaction effect (F(2, 56)=0.680, p=.511, $\eta 2$ = .024). Multiple comparisons with the Bonferroni method revealed a significant difference for the distance factors: proposed > intimate (p=.040), proposed > touch (p<.001), and

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intimate > touch (p<.001). Therefore, the participants perceived more humanlike-ness about the reaction distance in the proposed condition than in the alternative conditions; prediction 1 was supported.

B. Verification of Prediction 2

Figure 10 shows the questionnaire results about the naturalness of the reaction distance. We conducted a two-factor mixed ANOVA for the gender and distance factors, and the results showed significant differences in the distance factor (F(2, 56)=71.493, p<.001, $\eta 2$ =.719). We found a significant trend in the gender factor (F(1, 28)=3.891, p=.058, $\eta 2$ = .122) but no significant difference in the interaction effect (F(2, 56)=0.579, p=.564, $\eta 2$ = .020).

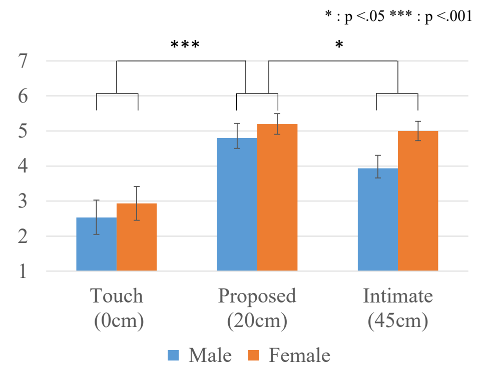

Fig. 9. Questionnaire results of humanlike-ness of reaction distance: Only significant differences compared to proposed conditions are shown.

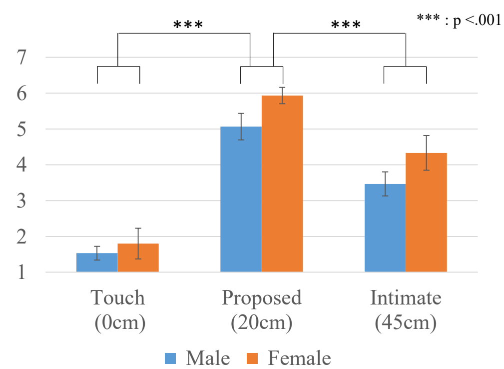

Fig. 10. Questionnaire results of naturalness of reaction distance: Only significant differences compared to proposed conditions are shown.

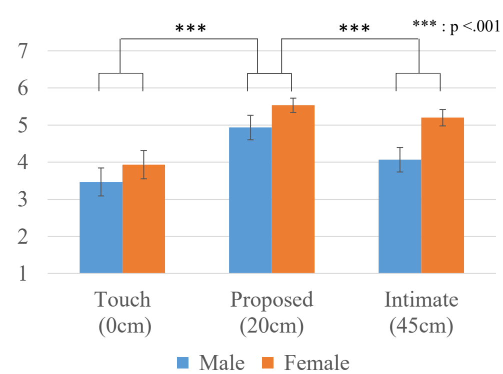

Fig. 11. Questionnaire results of total feelings: Only significant differences compared to proposed conditions are shown.

Multiple comparisons with the Bonferroni method revealed a significant difference for the distance factors: proposed > intimate (p<.001), proposed > touch (p<.001), and intimate > touch (p<.001). The participants perceived more naturalness about the reaction distance in the proposed condition than the alternative conditions; prediction 2 was supported.

C. Verification of Prediction 3

Figure 11 shows the questionnaire results about their overall feelings of the robot. We conducted a two-factor mixed ANOVA for the gender and distance factors, and the results showed significant differences in the distance factor (F(2, 56)=21.658, p<.001, $\eta 2$ =.436) and the gender factor (F(1, 28)=4.324, p=.047, $\eta 2$ =.134) but no significant differences in the interaction effect (F(2, 56)=1.129, p=.331, $\eta 2$ = .039).

Multiple comparisons with the Bonferroni method revealed a significant difference for the distance factors: proposed > intimate (p=.007), proposed > touch (p<.001), and intimate > touch (p<.001). The participants evaluated the robot more highly in the proposed condition than in the alternative conditions; prediction 3 was supported.

VI. Discussion

A. Implications

Our study clarified the minimal comfortable distance toward a potential touch around a face by observing human-human interaction and investigated whether a robot should react before being touched by a person by following the minimum comfortable distance of people. For the former result, even if we only conducted a data collection with Japanese participants of certain ages, our analysis of the gathered data offers enough scientific contribution to both the human-human and human-robot interaction communities. For example, even though several famous researches (which provided such human behaviors as proxemics, e.g., personal space [16], modeling of participation roles [50] [51] and Midas-touch effects, e.g., prosocial behaviors caused by a touch [52]) investigated limited situations, they provided basic knowledge that contributed to the knowledge building process in human-human interaction [43-45] and human-robot interaction [23-30] studies. With the scientific findings from our current study, people can better ponder which distance thresholds are appropriate for different kinds of robots, different situations, cultural effects, and so on.

For the second point, our experiment results showed that pre-touch reaction behaviors play critical roles in the perceived feelings of robots. People preferred a robot that reacts at a certain distance before a potential touch more than a robot that reacts after being touched, and establishing an observed minimum comfortable distance from people was preferred over existing distance thresholds based on conversation situations. Such different preferences to pre-touch reactions might be caused by the mental model held by people to our robot's human-like appearance. People might assume that since the robot has human-like capabilities to being touched, they prefer a robot that reacts before being touched as people do. Of course, distance knowledge may not be applicable for quite different kinds of robots, especially pet types that don't have non-humanlike appearances. In other words, pre-touch reaction behaviors should mimic people's mental models of robots that can be changed due to appearances and cultural differences [53, 54]. For example, if we use for touch interactions a simpler robot, such as a ball-type model, an appropriate reaction distance to a potential touch might change. When people's hands did not approach within the view of a human-like robot, e.g., trying to touch it from behind, reacting after being touched is better, even if it can technically detect people's touch regardless of its face direction with additional sensors, such as embedded depth sensors.

B. Gender Effects

The experiment results in human-robot interaction showed a significant trend about the naturalness of the reaction distance in the gender factor, where female participants are more inclined to judge the robot's behavior as natural. Moreover, as shown in Tables I and II, the comfortable minimum distance from a person of the same gender is slightly smaller than from the opposite gender, even without significant differences. Two reasons might explain these phenomena. Past studies showed that females are more receptive to being touched or to close-distance interaction than males, and they also deem a same-gender touch as more acceptable than an opposite-gender touch [43-45]. To investigate the effect of the robot's gender on the naturalness of the reaction distance, using a different android with a male appearance is needed.

A past study provided several guidelines for touch interaction design between people and robots, including gender effects [55]. Even though we found no significant differences about the minimum comfortable distance and feelings, the genders of the touchers and the evaluators influenced their touch interactions. Since the past study did not focus on the minimum comfortable distance for touch interaction [55], we believe that our current study will contribute to such guidelines from a distance-threshold perspective based on actual observations of human-human interaction.

C. Limitations

On the other hand, we need to carefully contemplate the experiment results of this study. Since we only used a specific android robot with a female appearance, to generalize our experimental results we must test different types of androids: male appearances, female appearances of different ages, non-humanlike and/or such gender-neutral appearance robots as Pepper. Investigating the touching of other body parts (shoulders or hands) would also enrich our knowledge about pre-touch reaction distances.

Moreover, the relationship and context in touch interactions influence the minimum comfortable distance, e.g., a robot that is used as a home-assistant might build friendly relationships with users through long-term interaction, and their distance might become shorter. In addition, in this study the robot only showed a simple reaction. If it hesitated to being touched, even if the distance is not human-like, such feelings will increase, and the total feeling might decrease.

VII. CONCLUSION

In this study, we focused on pre-touch proxemics in the context of human-robot touch interactions. For human-like reactions for robots that are being touched, first we conducted a data collection to identify the minimum comfortable distance in human-human touch interactions. Data analysis from the pre-touch interaction data showed that the average minimum comfortable distance is 20 cm between faces and the hands of others.

To enable our robot to react to being touched at that minimum comfortable distance, we implemented a depth sensing system to measure the distance between a robot's face and a human hand. We experimented with 30 participants to investigate whether the robot should react before/after being touched and whether its reactions should adhere to the observed minimum comfortable distance of people. We compared three reaction distances for the robot to being touched: 0 cm as an actual being touched distance, 20 cm as an observed minimum comfortable distance in human-human touch interaction, and 45 cm as an intimate distance in conversation situations.

We found that a robot that reacts before being touched was evaluated more highly by the participants than a robot that reacts after being touched. A robot that reacts at the human minimum comfortable distance (20 cm) was evaluated more highly than a robot that reacts at the intimate distance (45 cm). This knowledge will contribute to building pre-touch proxemics and designing reaction behaviors for social robots when they might be touched by interacting partners.

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