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Communication Cues in Human-Robot Touch Interaction

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ABSTRACT
Haptic interaction is a key capability for social robots that closely interact with people in daily environments. Such human communication cues as gaze behaviors make haptic interaction look natural. Since the purpose of this study is to increase human-robot touch interaction, we conducted an experiment with 20 participants who interacted with a robot with different combinations of gaze behaviors and touch styles. The experimental results showed that both gaze behaviors and touch styles influence the changes in the perceived feelings of touch interaction with a robot.

Author Keywords
Robot touch; social robot

ACM Classification Keywords
H.5.2. User Interfaces – *Interaction styles*

INTRODUCTION
Physical interaction, particularly haptic interaction, is one promising research path in the human-agent interaction research field. Because of its physical existence, which is an important advantage enjoyed by robots over CG agents, robots can communicate with people through haptic interactions that are well known to change the behaviors of others and facilitate their efforts in human science literatures [1-7]. In the research field of human-robot interaction, various research works have reported similar effects of haptic interaction between robots and people: mental therapy [8], increasing motivation [9], and attitude changes by touch [10-12].

However, these past research works on haptic interaction with robots mainly focused on the influences to people's feelings or behavior changes by physical interaction. In other words, they focused less on the communication cues of robots in such touch interactions. The following communication cues have been thoroughly investigated: gaze behavior in such contexts as approaching [13], encounter situation [14, 15], object-transfer [16, 17], and conversations [18-21]. We believe that this knowledge will increase the understanding of communication cues in human-robot touch interaction.

In this paper we deal with a robot's gaze as a major communication cue that increases the naturalness of touch interaction (Figure 1). We investigate which kinds of touching styles (touching a robot, touched by a robot, and mutual touch) are important to make touch interaction more natural.

DESIGN
In this section, first we describe the details of the robot used in the experiment, because its characteristics, such as appearance and size, are important for the design of communication cues. Next, we refer to related works about experiment designs, i.e., gaze behavior and touch styles in human-robot interaction, and describe the detailed designs of both gaze behaviors and touch styles that will be used in the experiment.

Robot
Figure 2 shows Pepper, a personal humanoid robot developed by Softbank. It has 20 DOFs: two DOFs in its head, shoulders, elbows and waist, one DOF for wrists, hands, and knee, and three DOFs for its wheels. The robot is 121 cm tall and is equipped with microphones, cameras, a depth sensor, touch sensors, and so on. It has five fingers on its hands.

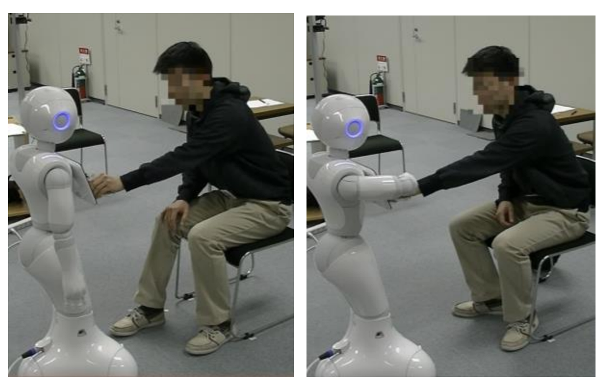

Fig. 1 Robot touches a person

Fig. 2 Pepper

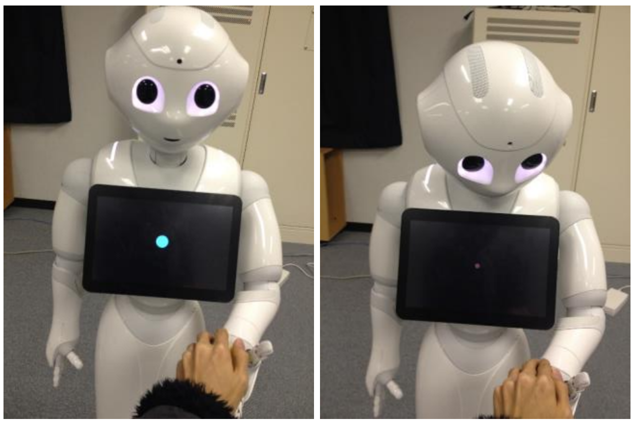

Fig. 3 Pepper's gaze behavior: looking at participant's face (left) and participant's hand (right)

Gaze design

Gaze behavior is essential for natural communication between people and such anthropomorphic agents as robots. Many research works have investigated gaze behaviors in human-robot interaction [13-21]. For example, Satake et al. developed a natural approaching model for a mobile social robot. While approaching, the robot's gaze behavior is important to share its intention to approach the target [13]. Hayashi et al. focused on encounter interactions in public environments where people and robots walk around and modeled the behaviors of human experts (guards) to show the robot's availability through gaze and roaming paths [14]. Seki et al., which also focused on a situation where a robot initiates a conversation with a person, included gaze behaviors to make interactions look more natural [15]. These research works deal with interactions before the robot meets people; of course, studies have also focused on the interaction after the robot meets people [18-21] in non-haptic interaction contexts, such as approaching and providing information.

To design gaze behaviors in touch interaction, we focused on a situation where a robot hands an item to people, because in such situations, the hands of the robot and the participants become closer like in actual touch interactions. We employed several gaze behaviors from the literature about hand-over research works, i.e., Gharb et al. who investigated the effects of gaze cues in hand-over situations [16]. According to their work, we investigated two kinds of gaze behaviors during haptic interactions: *face-only* and *face-hand-face*. We employed these two behaviors because the face-hand-face behavior was the most preferred pattern by participants in hand-over situations, and the face-only behavior received low evaluations in the prepared conditions, which can be used as a baseline condition.

Face-only

In this behavior, the robot looks at the interacting person's face during the touch (Fig. 3, left).

Face-hand-face

In this behavior, the robot looks at the interacting person's face first (Fig. 3, left), then at the person's hand (Fig. 3, right), and finally at the person's face again (Fig. 3, left). The duration of the gaze behaviors was 2250 ms, like in Gharb's work [16].

Touch design

Past research works related to touch interaction investigated three touch styles: touching a robot, touched by a robot, and mutual touch between a person and a robot. Researchers have mainly investigated the "touching a robot" style. For example, Shibata et al. developed a seal robot named Paro for therapy with senior citizens through interaction, including touching the robot [8]. The "touching a robot" style is also used to recognize touch interaction [22-24], where Cooney used inertia sensors to recognize full-body gestures by haptic interactions toward a humanoid robot [24].

A few research works investigated the effects of being "touched by a robot." For example, Cramer et al. argued that a touch behavior by a robot decreases machine-likeness but negatively affects its dependability [10, 11]. Tiffany et al. investigated the influence on the impressions of a robot's touches with verbal communication cues [12].

To the best of our knowledge, only Shiomi et al. investigated the effects of mutual touch in the context of increasing the motivation of the interacting person [9]. This research work reported that mutual touch provides facilitation effects, where people who did mutual touch with the robot continued a simple and monotonous task longer than people who did not touch the robot.

Based on these research works, we employed the following three touch styles. The details of each with Pepper are described below.

Touch-to-robot

In this touch style, first Pepper asked the interacting persons to "please touch my left hand" and then extended it (Fig 4). In this condition, Pepper did not actively touch the interacting persons. We put a round plastic yellow sphere in Pepper's left hand for uniform touch feelings among the other conditions.

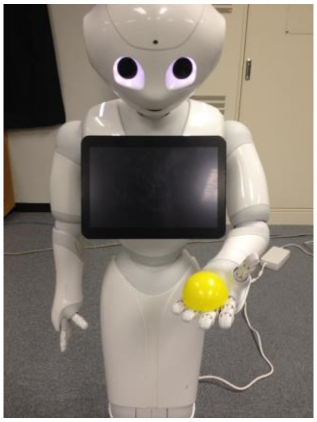

Fig. 4 Pepper extends its hand

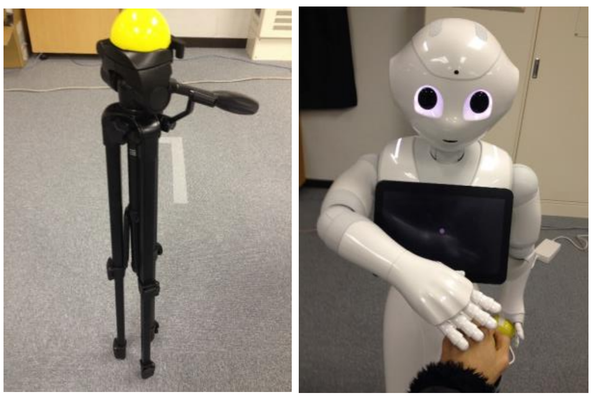

Fig. 5 Identical round plastic yellow sphere on the stand (left) and Pepper touches a hand (right)

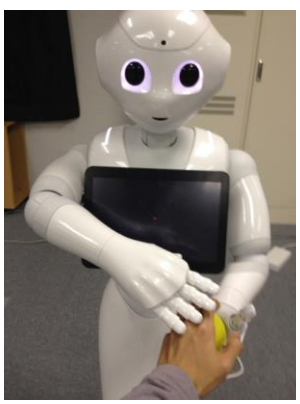

Fig. 6 Pepper touches person's hand, which also touches Pepper's left hand

Touched-by-robot

In this touch style, a stand is placed near Pepper on which the interacting person's hand is put. The stand's height is identical to Pepper's left hand in the *touch-robot* style, and the same round plastic yellow sphere is placed on the stand (Fig. 5, left). Pepper asked the interacting persons to "please put your hand on the stand." After they did so, Pepper touched the hand with its own right hand (Fig. 5, right). In this condition, Pepper actively touches the interacting person's hand, different from the *touch-robot* style.

To design Pepper's touching behavior, we employed the knowledge of human science literature that investigates the effects of touching speed on impressions [25]. Since this paper reported that touching at a speed of 5 cm/s was evaluated more positively than 0.5 or 50 cm/s, we set the speed of the robot's hand during the robot's touching to about 5 cm/s. Pepper's touching behavior is pre-programmed, and its hand follows a fixed trajectory, based on the human's hand size.

Mutual-touch

In this touch style, first Pepper asked the interacting person to touch its left hand, as in the *touch-robot* style. After the interacting person touched Pepper's hand, Pepper touches the hand with its own right hand, as in the *touched-by-robot* style (Fig. 6). Therefore, this condition mixes both the *touch-robot* and *touched-by-robot* styles; both Pepper and the interacting person touch each other. We used Pepper's identical touching behavior in this style: *touched-by-robot* style.

EXPERIMENT

We experimentally investigated the effects of communication cues between the combinations of the gaze and touch designs toward people.

Hypotheses and Prediction

Based on human-robot interaction research, gaze behavior is essential for more natural and acceptable interactions [13-21]. For this purpose, both eye contact and telling intentions by gaze behaviors are important. In particular, a recent work suggested that a combination of gaze behaviors at faces and objects produces more natural interaction feelings in hand-over interactions [16]. Because of the similarity between hand-over and touch, such gaze behaviors may make touch interactions more natural.

The touch style in haptic interaction is also essential to change the perceived feelings of people. Past research works commonly showed that the *touched-by-robot* style created negative feelings [10, 11], but the *mutual-touch* style created more positive feelings than the *touch-to-robot* style [9]. Based on these considerations, we made the following predictions:

Prediction 1: A touch interaction with a *face-hand-face* behavior will be perceived as more natural, more comfortable, and create a better impression in the participants than a touch interaction with a *face-only* behavior.

Prediction 2: A touch interaction with a *mutual-touch* style will be perceived as more natural, more comfortable, and create a better impression in the participants than touch interactions with both the *touched-by-robot* and *touch-to-*

robot styles. A touch interaction with the *touch-to-robot* style will be perceived as more natural, more comfortable, and create a better impression in the participants than a touch interaction with *touched-by-robot* style.

Environment

We conducted the experiment in a laboratory room. We placed in front of Pepper a chair in which the subjects sat during the experiment (Fig. 7).

Conditions

We used a within-participant experiment design to evaluate and compare the effects of communication cues: two gaze behaviors (*face* and *face-hand-face*) and three touch styles (*human touch*, *robot touch*, and *mutual touch*), as described in Section 2. An operator manually decided the timing to start Pepper's touching behavior.

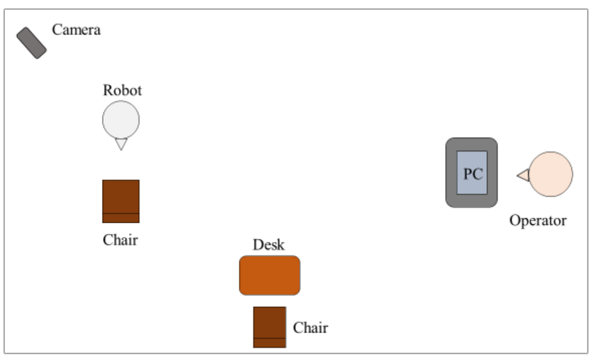

Fig. 7 Experimental scene

Participants

Twenty people (10 women and 10 men, who averaged 35.5 years old, S.D 9.7) participated in the experiment.

Procedure

Before the first session, the participants were given a brief description of our experiment's purpose and procedure. Since it had a within-participant design, each participant participated in six sessions of different conditions.

In all the conditions, after requesting touch initiation Pepper had a short chat with the subject, such as "I'm 121 cm tall and weigh about 28 kg. I'm lighter than you think, right?" We prepared six chat contents to avoid repeating them among the conditions. During the chat in the *touched-by-robot* and *mutual-touch* styles, Pepper patted the hand of the participants three times. The order of the conditions and the chat contents was counterbalanced. The participants filled out a questionnaire after each session.

Measurements

In this experiment, we measured three subjective items by questionnaire: the *feeling of naturalness* of the touch interaction, its *feeling of comfort*, and the *total impression* of the robot. The questionnaire item was evaluated on a 1-to-7 point scale.

RESULTS

Verification of Predictions

Figure 8 shows the *feeling of naturalness*. For it, we conducted a two-way repeated-measure ANOVA with two within-subject factors: gaze and touch. A significant main effect was revealed in the touch factor ($F(2, 38)=6.508$, $p=.004$, partial $\eta2=.255$). No significance was found in the gaze factor ($F(1,19)=0.195$, $p=.664$, partial $\eta2=.010$) and the interaction within these factors ($F(2,38)=0.108$, $p=.898$, partial $\eta2=.006$). Multiple comparisons with the Bonferroni method revealed significant differences in the touch factor: *touch-to-robot* > *touched-by-robot* (p=.007), but there was no significance between *touch-to-robot* and *mutual-touch* (p =.110) or *touched-by-robot* and *mutual-touch* (p =.975)

Figure 9 shows the *feeling of comfort*. For it, we conducted a two-way repeated-measure ANOVA with two within-subject factors: gaze and touch. A significant main effect was revealed in the gaze factor ($F(1, 19)=5.448$, $p=.031$, partial $\eta^2=.223$). No significance was found in the touch factor ($F(2,38)=1.893$, $p=.165$, partial $\eta^2=.091$) and in the interaction within these factors ($F(2,38)=0.437$, $p=.649$, partial $\eta^2=.022$). Multiple comparisons with the Bonferroni method revealed a significant difference in the gaze factor: *face-only* > *face-hand-face* (p=.031), but there was no significance between *touch-to-robot* and *mutual-touch* (p =.110) or *touched-by-robot* and *mutual-touch* (p =.975)

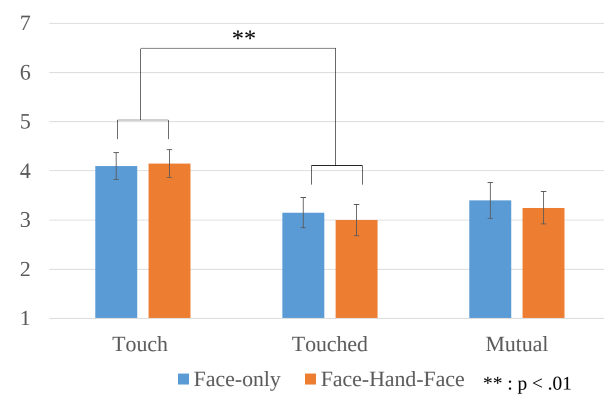

Fig. 8 Feeling of naturalness in touch interaction

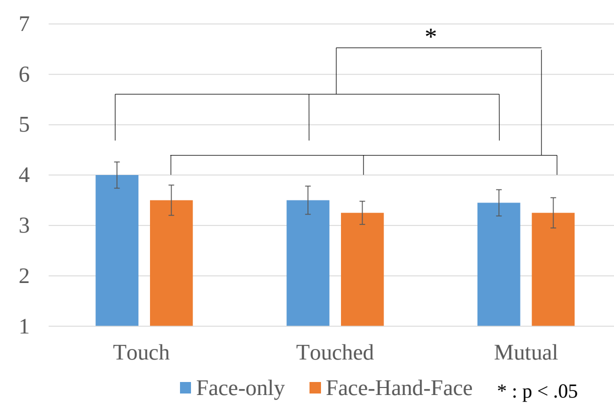

Fig. 9 Feeling of comfort in touch interaction

Figure 10 shows the *total impression*. For it, we conducted a two-way repeated-measure ANOVA with two within-subject factors: gaze and touch. A significant main effect was revealed in the touch factor (F(2, 38)=4,377, p=.019, partial η^2=.187). No significance was found in the gaze factor (F(1,19)=1.197, p=.288, partial η^2=.059) and in the interaction within these factors (F(2,38)=0.481, p=.622, partial η^2=.025). Multiple comparisons with the Bonferroni method revealed a significant trend in the touch factor: *touch-to-robot* > *touched-by-robot* (*p*=.061), but there was no significance between *touch-to-robot* and *mutual-touch* (p =.121) or *touched-by-robot* and *mutual-touch* (p =1.000).

These results show that prediction 1 was not supported; the opposite phenomenon was observed. Prediction 2 was partially supported.

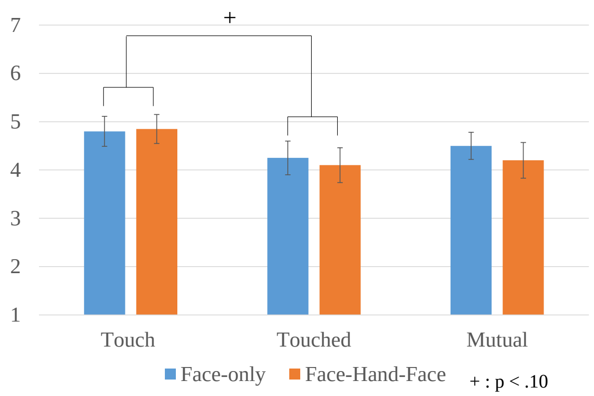

Fig. 10 Total impression of robot

DISCUSSION

Why did our participants prefer *face-only* gaze behavior to *face-hand-face* gaze behavior?

Past research work reports that a combination of eye contact and looking at an object increased impressions than just eye contact during a handing interaction [16]. But our research work showed an opposite result: people preferred eye-contact during a touch interaction. We assumed that both handing and touch situations are similar and required similar communication cues, but this assumption might be inappropriate. Future work will investigate gaze differences between handing and touching situations and unveil essential gaze behaviors in touch interaction.

Why didn't they prefer *mutual-touch* style to other touch styles?

In this work, the *mutual-touch* style did not show significant differences about feelings from other touch styles, unlike past research work. On the other hand, the *touched-by-robot* style showed more negative impressions than the *touch-to-robot* style, similar to past research work. We thought that additional factors might influence the impressions of touch interactions in addition to gaze and touch style. For example, a trajectory of touching and touch feelings is important for this purpose, and future work will investigate them.

Limitation

Since our experiment was conducted with an existing robot, Pepper, robot generality is limited. The effect shown in the experiment would probably be moderated if our participants interacted with a robot with a different appearance, size, and so on. Pepper's eye design is different from that of human eyes. Since this design simplifies making eye-contact with the interacting person, it also influences the perceived feelings in haptic interaction.

CONCLUSION

In this research work, we focused on the effects of communication cues toward perceived feelings to a robot in haptic interaction: gaze behaviors and touch styles. We employed two gaze behaviors during touch (looking at the face of an interacting person and looking at a face, a hand, and the face again) and three touch styles (a person touching a robot, a robot touching a person, and a person and robot touching each other) by considering past related works. To investigate the effects of these communication cues, we conducted a within-subjects experiment in which a robot interacts with participants through touch.

Our experimental results indicated that our participants preferred a gaze behavior that only looks at a face to a gaze behavior that looks at a face, a hand, and the face again. Moreover, they preferred a touch style in which a person initiates the touch of a robot rather than when a robot initiates the touch interaction. But unlike past research work, a touch style in which a person and robot touch each other is not preferred over other touch styles. We believe this knowledge will help robotics researchers who are focusing on haptic interaction of a social robot to design their behaviors.

ACKNOWLEDGMENTS

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