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Paper:

Gaze-Height and Speech-Timing Effects on Feeling Robot-Initiated Touches

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This paper reports the effects of communication cues on robot-initiated touch interactions at close distance by focusing on two factors: gaze-height for making eye contact and speech timing before and after touches. Although both factors are essential to achieve acceptable touches in human-human touch interaction, their effectiveness remains unknown in human-robot touch interaction contexts. To investigate the effects of these factors, we conducted an experiment whose results showed that being touched with before-touch timing is preferred to being touched with after-touch timing, although gaze-height did not significantly improve the feelings of robot-initiated touch.

Keywords: human-robot interaction, touch, communication cue

1. Introduction

A social robot is a kind of physical agent that can interact with people by touching in close distance. Touch interaction, which is strongly related to social bonding between people, provides both physical and mental merits [1–6]. By following these results, robotics researchers have also investigated whether touch interactions with robots provide similar positive benefits for people [7–11]. Touch interaction design is an essential factor for social robots that act in daily environments with people.

What are the key factors for achieving natural and acceptable touch interactions with robots? One active research topic related to this question is communication cues about touch, such as gaze [12–14], voice [15], body movements [16–18], and blinking behavior [19]. Due to multi-modal effects in touch interactions, i.e., other modalities that influence touch impressions, many researchers have focused on combinations of communication cues between touch and other modalities. For example, Hirano et al. investigated both gaze and touch style effects during touch interaction and showed how these cues change the perceived impressions to robot-initiated touch [12].

However, even though various kinds of research on communication cues in touch interactions have been conducted and appropriate interaction designs have been identified, one typical communication cue remains relatively overlooked: eye-contact height while being touched. We often establish eye contact at another's gaze-height by crouching or half-sitting before interacting with children, seniors, or patients who are sitting or lying on a bed (**Fig. 1**). Such gaze-height changes not only reflect a polite attitude but also signal the nonverbal timing of the start of an interaction. Several books and guidelines for interacting with people emphasize the importance of the eye contact's gaze-height before starting an interaction, especially in nursing contexts [20–22].

How does a robot's gaze-height during eye contact change people's impressions in touch contexts? Two studies investigated the effects of the robot's face height in conversational contexts. One reported that using a shorter telepresence robot is less persuasive [23], and another concluded that the robot's optimum height is about 300 mm lower than the gaze-height of the interact-

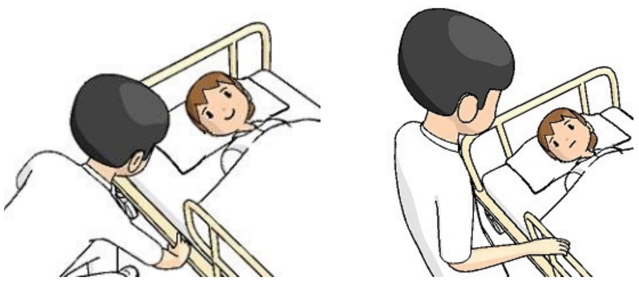

Fig. 1. Eye contact with (left) or without (right) crouching.

ing partners [24]. Unfortunately, the effects of changing the gaze-height before touching remain unknown. Since accumulating knowledge about gaze-related communication cues through touch will contribute to the design of human-robot touch interaction, we address the following research question:

- When the gaze-height is changed, how do gaze cues alter the perceived comfort of the robot's touch and human impressions to it?

We also focused on speech timing for explaining a touch's purpose, because in a nursing context, a person who touches a patient will usually say something related to that touch. In fact, in human science literature, a past study reported that patients want to know the reason for the contact before they are actually touched, suggesting that whenever possible nurses should obtain permission from their patients before touching them [25]. On the other hand, another study in human robot interaction reported that after-touch speech timing (i.e., a robot touches a participant and then explains its intention) is preferred to before-touch speech timing [15]. Therefore, similar to gaze-height effects, speech-timing effects remain unknown. Based on these considerations, in this study we address the following research question:

- How do speech-timing cues change the perceived comfort of a robot's touch and impressions of it?

2. Related Work

2.1. Gaze Behavior in Human-Robot Interaction

Many kinds of research works have investigated the effects of gaze behavior in human-robot interaction: conversational situations for such natural gaze behavior designs as three-person conversations [26], an information-providing scenario [27], a group-conversational situation with children at an elementary school [28], and a storytelling situation with preschool children [29]. Researchers also focused on the situations before conversations: an approaching situation for mobile robots [30, 31] and a patrolling situation for a guard robot [32] in shopping mall environments.

Related to human-robot touch interaction, Hirano et al. investigated gaze behavior effects and reported that a gaze behavior in which a robot maintained eye contact during a robot-initiated touch was preferred to a gaze behavior in which a robot first looks at the touching target and then maintains eye contact [12]. Note that their results identified a contradictory phenomenon compared to a handing-over situation [33]. In a handing-over situation, a gaze behavior in which a giver maintains eye contact during the handing-over was preferred less than a gaze behavior where a giver first looks at an object and then at a receiver. This opposite phenomenon between touch and handing-over interactions indicate that an appropriate gaze behavior depends on the situation.

From another perspective, studies focused on the effects of the robot's face height in conversational situations. Irene et al. investigated how the face height for telepresence robots influences the conversational partner and concluded that using a shorter telepresence robot is less persuasive [23]. On the other hand, Hiroi et al. reported that a robot's face should be lowered to create a better conversation setting [24]. Similar to comparisons of touch and handing situations, appropriate face height differs based on the robots and the context.

Although these studies provided useful knowledge for gaze-height design in human-robot interaction, room exists to research gaze behavior design in touch interaction settings because several studies reported contradictory phenomena. Touch interaction has also failed to receive adequate research attention. We explore the effects of gaze-height changes in touch situations.

2.2. Speech Timing in Human-Robot Interaction

Many kinds of research have investigated the effects of speech timing in conversational situations between robots and interaction partners. For example, Okuno et al. focused on a route-guidance setting and investigated the speaker/listener speech timing for smooth conversational interactions for a social robot [34]. Other research work described the importance of fillers in conversations [35], and another developed a generating-filler system for smooth turn-taking by a humanoid robot [36]. From another perspective, Shimada et al. focused on appropriate speech rates for a social robot by considering cognitive load during interactions [37]. A previous study in a nursing context on human-human touch interaction reported that patients wanted to know why a nurse was going to touch them, suggesting that nurses should provide prior-verbal warnings before touching their patients [25]. These studies provide useful designs and systems to appropriately control speech timing, but they failed to focus on touch situations or how speech timing changes the impressions of being touched by a robot.

On the other hand, in a past study about human-robot touch interaction [15], the experiment results showed that participants preferred a post-verbal warning after a robot-initiated touch to a prior-verbal warning. Since the effects of speech-timing in robot-initiated touching remain unknown, we explore them in touch situations.

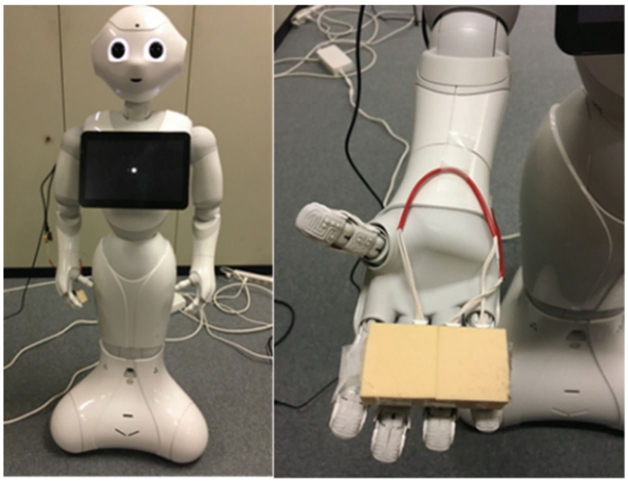

Fig. 2. Pepper with touch sensors in its hand.

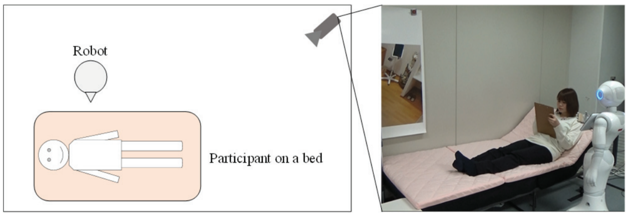

Fig. 3. Environment.

3. Experiment Design

3.1. Robot and Sensor

We used Pepper, which was developed by Softbank Robotics. It is 121 cm tall and has a total of 20 degrees of freedom (DOF), including enough degree of freedom in its waist to change its gaze-height by bending, as well as enough arm length to touch the people with whom it interacts. We prepared a touch motion for contacting the left shoulder of a participant in bed; its arm trajectory pattern is fixed to maintain consistency among participants.

To detect the physical contact between the robot's hand and people, we attached sensors to its hand touch (**Fig. 2**) for measuring the height changes on the top of a soft material with 16 measurement points. The maximum sensing frequency is 100 Hz. We installed two sensors on its right hand that touches the participants. When the sensors detect a certain amount of pressure, they send a signal to the robot to stop its touching motion.

3.2. Touching Situation

In our study that investigates the effects of a robot's gaze-height in a touch context, we employed a situation where a participant lies on a bed to mimic a past study [15] (**Fig. 3**). In this setting, the robot's default gaze-height is higher than the participant in bed, but if it bends down, its gaze-height will be similar to the bed's height.

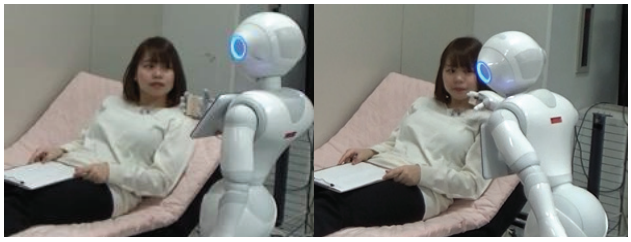

Fig. 4. Touch with crouching-down.

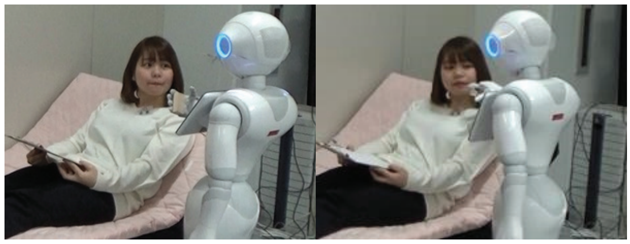

Fig. 5. Touch with looking-down.

3.3. Gaze-Height Design

To determine the robot's gaze-height design and its gaze control, we focused on the literature in human-human interaction [20–22] and studies that concentrated on the height of robot faces [23, 24]. These studies suggested that making eye contact at the same or a lower gaze-height than the interacting partner improves positive impressions such as friendliness. By considering these studies, we prepared the following two conditions. Note that we did not prepare a looking-up behavior due to the difficulties of maintaining a lower height than the gaze-height of participants in bed.

Crouching-down: The robot bends down and looks at the interacting target to make eye contact at the participant's gaze-height before touching the participant (**Fig. 4**).

Looking-down: Since the robot does not bend down in this behavior, it looks down at the interacting target during a touch (**Fig. 5**) and faces the participant to establish eye contact. However, its eyes are higher than those of the participants during the interaction.

3.4. Speech Timing Design

To design speech timing for a touch interaction, we followed the procedures of a previous study [15] that compared the voice cue timing effects in touch interactions and reported that people prefer speech (that explains the reason for the touch) after being touched than before being touched. To investigate the multi-modal effects of speech timing and gaze-height, we followed this speech-timing design.

Before-touch: The robot looks at the participant and announces, "I'm going to touch your shoulder to check on it," conveying its intention to touch before actually making contact (**Fig. 6**).

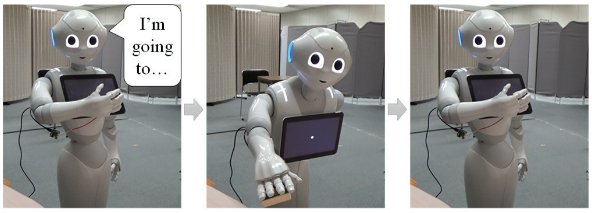

Fig. 6. Touch with before-touch timing.

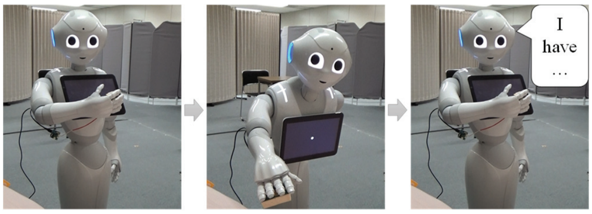

Fig. 7. Touch with after-touch timing.

After-touch: The robot looks at the participant and explains, "I touched your shoulder to check on it," justifying its touch after already making contact (**Fig. 7**).

3.5. Procedure

First, an experimenter briefly described the experiment's purpose and procedures. They provided a written consent form to participate in this study, which was approved by the Ethics Committee of the ATR. After obtaining signed consent from the participants, the experimenter clearly explained the procedures. We explained that the experimental setting assumed a medical context, and the robot would touch to check the status of the participant's shoulder. The experiment had a within-participant design. All participants experienced four sessions: combinations of two gaze behaviors (*crouching-down* and *looking-down*) and two speech timings (*before-touch* and *after-touch*). The order of the conditions was counterbalanced to avoid order effects.

In all the conditions, the robot stood next to a bed on which the participants were lying during the experiment. We adjusted the bed's height before the experiment to ensure the heads and shoulders of each participant were at the same height as the robot's eyes when the robot was crouching. Due to the hardware limitations of the robot, the bed angle was not flat. In all the conditions, the robot touched the participant's left shoulder using identical arm trajectories, stopped its arm when the touch sensor detected a certain amount of pressure, and patted the shoulder. Participants filled out questionnaires after each session.

4. Experiment

4.1. Hypotheses and Prediction

We assume that the *crouching-down* (i.e., lower gaze-height) and *before-touch* speech timing and behavior will positively affect the touch interactions based on past related works [20–22, 24, 25]. Therefore, we made the following two predictions about their effects:

Prediction 1: Touch interaction with a *crouching-down* behavior will be perceived as more positive than touch interaction with a *looking-down* behavior.

Prediction 2: *Before-touch* timing will be perceived as more positive than an *after-speech* touch.

4.2. Measurement

To investigate the effects of gaze-height and speech timing on the participant reactions, we measured four subjective items related to touch evaluations by questionnaires. One item asked about the comfort feelings of the robot's touch because a past study reported that gaze behavior influences a touch's comfort [12]. The remaining three items dealt with feelings toward the robot. In a nursing context, we employed two existing scales (likeability and safety) [38] that are related to the perceived feelings of touch. The following items were evaluated on a 1-to-7-point scale, where 1 is the most negative and 7 is the most positive:

- Comfortableness, i.e., a feeling of comfort of the touch interaction (one item, defined in a past study of human-robot touch interaction) [12].
- Likeability, which consisted of five items from the *GodSpeed* scales [38], where the Cronbach alpha (0.944 in this experiment) showed acceptable values for analysis.
- Safety, which consisted of three items from the *GodSpeed* scales [38], where the Cronbach alpha (0.842 in this experiment) also showed acceptable analysis values.

4.3. Participants

32 people (16 females and 16 males, 21 to 27 years old whose ages averaged 22.9, and standard deviation (S.D) was 1.69) participated in our experiment. They did not have any previous experiences physically interacting with Pepper. The robot touched their left shoulders with the same motion.

4.4. Results: Verification of Predictions

Figure 8 shows the results for *comfortableness*. The analysis identified significant differences in the speech-timing factor ($F(1,31) = 18.086$, $p < 0.001$, partial $\eta^2 = 0.368$). No significance was found in the gaze-height factor ($F(1,31) = 0.155$, $p = 0.696$, partial $\eta^2 = 0.005$) or the interaction effect ($F(1,31) = 1.108$, $p = 0.301$, partial $\eta^2 = 0.035$).

Figure 9 shows the results for *likeability*. The analysis identified significant differences in the speech-timing factor ($F(1,31) = 26.694$, $p < 0.001$, partial $\eta^2 = 0.463$). No significance was found in the gaze-height factor ($F(1,31) = 0.191$, $p = 0.665$, partial $\eta^2 = 0.006$) or the

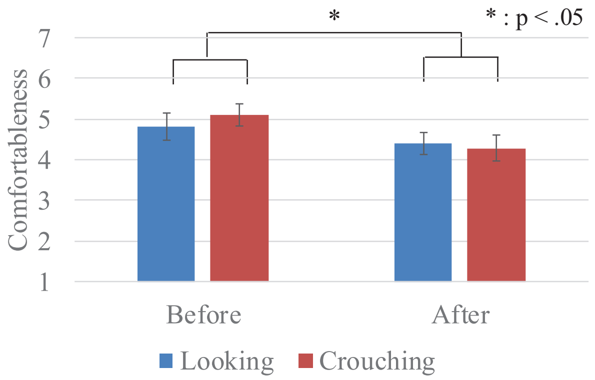

Fig. 8. Questionnaire results about comfortableness.

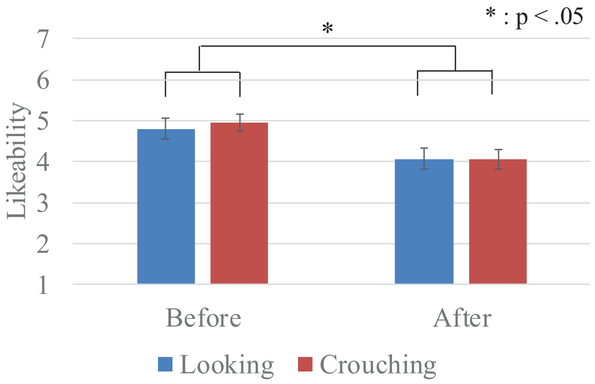

Fig. 9. Questionnaire results about likeability.

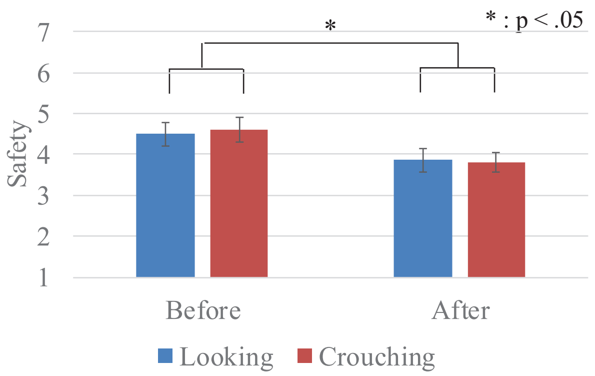

Fig. 10. Questionnaire results about safety.

interaction effect ($F(1,31) = 0.702$, $p = 0.409$, partial $\eta^2 = 0.022$).

Figure 10 shows the results for *safety*. The analysis identified significant differences in the speech-timing factor ($F(1,31) = 14.358$, $p = 0.001$, partial $\eta^2 = 0.317$). No significance was found in the gaze-height factor ($F(1,31) = 0.015$, $p = 0.904$, partial $\eta^2 = 0.001$) or the interaction effect ($F(1,31) = 0.585$, $p = 0.450$, partial $\eta^2 = 0.019$).

Based on the experiment results, prediction 2 was supported; the participants evaluated *before-touch* timing more positively than *after-touch* timing. On the other hand, the experiment results did not support prediction 1; the *gaze-height* factor did not show significant effects in human-robot touch interaction.

5. Discussion

5.1. Implication of Speech Timing

Interestingly, our experiment results contradict a past study in human-robot touch interaction [15], which concluded that *after-touch* timing was preferred by participants in robot-initiated touch situations in a nursing context. Our participants evaluated *before-touch* timing in the context of *comfortableness*, *likeability*, and *safety* to being touched by a robot. Our results identified the advantages of *before-touch* timing, which matches the results of a human-human interaction study in a nursing context [25].

What factors might have caused these wide discrepancies? One possibility is the robot's characteristics. Different appearances and touch feelings create different perceived reactions from participants. If we precisely mimic the past experiment procedures (except for the robot), the effects of its characteristics will be identified. Another possible explanation for the different speech timing result is the distance between the robot's hand and the participants' face. The minimum comfortable distance around a face is about 20 cm [39]. In our study, the robot touched the participants' shoulders, where the distance between its hand and their faces was less than 20 cm. Therefore, *before-touch* timing may mitigate resistance from participants to an undesired close distance between a robot's hand and their faces.

Cultural differences may not explain these contradictory phenomena. In our study we employed Japanese people who have fewer opportunities to touch others compared to Americans [40] or the British [41]. However, past human science research conducted in an American nursing context also recommended *before-touch* timing [40]. A research work about touch interaction at a Japanese nursing school also concluded that talking with *before-touch* timing is more critical for interaction with others by touching [42].

5.2. Implication of Gaze Height

Concerning gaze-height design, human science literature has reported the importance of making eye contact with interacting people at their gaze-height in various interaction situations to represent friendly, safe, and polite impressions [20–22]. However, our experiment results suggest limited positive effects for such eye contact in human-robot touch interaction situations.

Why did the gaze-height not show any significant effects? One possibility is the robot's gaze design. Pepper is designed to make eye contact from any angle using a hollowed eye design, which might provide different feelings to the participants regardless of the gaze-height. Another perspective is the posture of the participants. In this study, we adjusted the bed angle to make eye-contact with the robot due to the robot's hardware limitations, but different postures would create different impressions. Therefore, the gaze-height factor should be investigated with a different robot that has a human-like eye design.

5.3. Limitations

In this study, since we only used an existing robot (Pepper), generality about its appearance was limited. Feelings about being touched would undoubtedly be influenced if we used different robots (e.g., size, perceived gender, appearance, body temperature, surface, and so on). Nor did we investigate the effects of eye contact from a lower height than that of the participant, due to the robot's hardware limitations.

From another perspective, the part of the body that is touched by a robot may leave a different impression. We only investigated a robot that touched the left shoulder. If it touched a different part of the interaction target (head or hand), the perceived feelings to it would change. If a robot touched the hands or the face, the touch's characteristics (such as expressed emotions and behaviors [43], reaching trajectories, force, and duration) would also be different. Moreover, touch is only one communication cue; different types of touch such as a grip, stroke and so on can be combined to improve communication cues.

We note that the experiment was conducted with relatively younger participants; therefore, it would be better to investigate communication cue effects with participants who have different characteristics. We did not investigate their attitude toward the robots, and such impressions might have an impact on perceived feelings of a robot's touches. Moreover, we only measured subjective impressions of touch interaction, but objective behaviors such as facial expressions would help to understand the effects of a robot's touch and the participants' feelings.

6. Conclusion

We investigated the effects of gaze-height for making eye contact and speech timing on perceived feelings to robot-initiated touches. Based on past studies in human-human and human-robot interactions, we employed two gaze-heights for eye contact: crouching-down to the same level and looking-down from a higher level. Although such height differences influence communication cue effects in touch contexts, their effects remain unknown. In addition, we employed two speech timings (before-touch to convey a message prior to contact and after-touch to communicate that the contact is finished), because previous human-human and human-robot interaction research identified contradictory phenomena. We experimentally investigated the effect of these communication cues with a robot that touched the shoulders of participants in bed.

Our results showed that participants preferred *before-touch* timing over *after-touch* timing in the context of feelings of *comfortableness*, *likeability*, and *safety*. On the other hand, our results did not show significant effects of the gaze-height factor in robot-initiated touch interactions. We believe that the knowledge from this study will help future designs for human-robot interaction within close distances.

Acknowledgements

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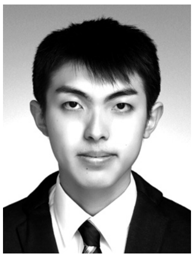

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