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I am a warm robot: the effects of temperature in physical human–robot interaction

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SUMMARY
What factors affect users' perceptions of physical human–robot interactions? To answer this question, this study examined whether the skin temperature of a social robot affected users' perceptions of the robot during physical interaction. Results from a between-subjects experiment (warm, intermediate, cool, or no interaction) with a dinosaur robot demonstrated that skin temperature significantly affects users' perceptions and evaluations of a socially interactive robot. Additionally, this study found that social presence had partial mediating effects on several dependent variables. Important implications and limitations for improving human–robot interactions are discussed here.

KEYWORDS: Human–robot interaction; Social robot; Physical interaction; Social presence; Skin temperature.

1. Introduction

Do human–robot interactions affect the way people perceive, evaluate, and treat robots? There has been an increasing interest in and use of social interactive robots. Robots are no longer simple technological support tools for tasks; they are now becoming a part of our daily lives. Because of this, human–robot interactions may be one of the most important fields studying the adaptation of socially interactive robots to real life. There are numerous aspects to interaction. Touch is a primitive social skill used to communicate between humans. The effects of human touch have been studied in the context of online learning (e-learning),[42] social interaction skills in elderly populations,[3,4] and helping patients with physical troubles and improving children's social abilities.[7,13,31]

In the human–robot interaction field, many humanoid robots have been used to investigate the effects of touch interaction.[24,28,33] However, no study has tested the effects of active and large-scale physical touch (e.g., interaction between human and pet) in human–robot interaction. Additionally, although several studies have focused on physical touch in human–robot interactions, few studies have aimed to test the perceived sense of touch. Users can feel many things when they physically interact with a robot. People experience many features of touch, including the degree of strength and the texture and temperature of the object's surface.[10,11,14] Moreover, numerous studies have addressed the effect of temperature on human behavior. Griffitt and Veitch[17,18] found that there is a positive association between a comfortable environmental temperature and stable feelings. Cunningham[8] investigated the relationship between social behavior and environmental temperature, and the results demonstrate that the willingness of a participant is greater in cases where there is adequate sunshine. Those studies highlighted that temperature is capable of triggering changes in human behavior.

Therefore, when users physically interact with robots, they feel many aspects beyond physical touch. In this study, we focused on the effects of the temperature of the robot's skin in a physical human–robot interaction. The temperature of the robot's skin is often the first aspect of touch that users experience and may influence initial impressions of the human–robot interaction.

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The goal of this study was to investigate any notable effects of varying robot skin temperature on users' perceptions of the robot during a physical human–robot interaction. This paper first reviews the effects of touch and skin temperature in interactions with others. The results of a between-subjects experiment conducted to examine whether these factors affect the psychology of people involved in the physical human–robot interaction are then presented. Finally, we conclude with a discussion of significant findings, implications and future areas of study.

2. Literature Review

2.1. Human–pet interaction and human–pet robot interaction

Allen *et al.*[1] explored the responses of humans under stress with the presence of their pets and human companions. The results of that study showed that stress was more effectively moderated in the presence of human companions than with a pet. Lee *et al.*[29] examined how participants could recognize a pet robot's personality in two cases, introvert or extrovert, based on verbal and nonverbal cues. The results demonstrated that participants recognized the personality of the pet robot manifested through verbal/nonverbal cues and applied a personality-based social rule to the pet robot. Lee *et al.*[30] studied social interactions between humans and social agents in both embodied and disembodied interactions. This study concluded that the physical embodiment is essential for the design of social agents. Serpell[40] let participants who used to have their own pets spend 10 months with new pets and explored their health, mental state, and exercise levels. The results indicated that acquiring a companion animal had a positive effect on the participants' health.

2.2. Physical human–robot interaction

Many studies have focused on the effects of physical interactions.[5,12] Physical interactions between beings, such as a hug or a handshake, can affect aspects of a person's psychology. For example, a handshake, which is a widely used greeting, can be presented as a kind and positive way of expressing delight in meeting another person. It creates a positive impression and evaluation of each person.[12] In addition, hugging and kissing also affect psychological aspects (e.g., perceptions and evaluations of the other person) of people interacting with one another.[5]

The computers are social actors (CASA) theory was proposed to explain the social rules of human–computer interactions and human–robot interactions.[34,35] People tend to apply social rules from human–human interactions to interactions with computers, robots and other artificial objects. Additionally, the theory has been applied to studying interactions with social robots.[15] It may be because of these studies that advanced engineering technologies for many realistic and anthropomorphic features and functions support the acceptance of socially interactive robots. These types of robots are often perceived to be more anthropomorphic than other artificial agents.[29] Therefore, similar to human–human interactions, people may tend to be more accepting when they interact with socially interactive robots if they have prior experience with such a robot during a physical human–robot interaction. We thus hypothesized the following:

H1: Physical human–robot interaction will increase users' perceptions and acceptance toward socially interactive robots.

2.3. Temperature of the robot's skin

Information that is conveyed via tactile senses can also affect users' psychological perspectives, including temperature, which this study aimed to investigate. Temperature is one of the most intuitive factors that people perceive. Kolb *et al.*[27] have suggested that aspects of social cognition linking are affected by the temperature of people's environments. Although this study was based on human–human interaction, there was no physical interaction. Nie *et al*.[36] focused on the effects of handholding with differences in physical temperature between a person and a humanoid robot while watching a horror movie. In their study, handholding and physical temperature affected people's attitudes toward the robots. However, there were some crucial and significant limitations. First, the physical interaction in their experiment was too limited to generalize the results since they focused only on handholding between a human and a robot. Because they used a humanoid robot, they were not able to assess other types of physical interactions. Second, the robot in their experiment was only able to act passively, meaning that the robot did not react to people's actions. Third, they did not measure the mathematical degree of the robot's skin temperature and whether the participants perceived them as warm or cold. In the warm condition, they maintained the temperature of the robot's hand at 40°C. To address this problem, in this study we hypothesized that:

H2: The level of the robot's temperature in the human–robot interaction will differentially affect users' psychological perspectives toward the robots.

The third aim of this study was to explore which predictors play a significant role in increasing people's acceptance of a socially interactive robot and will improve the human–robot interaction. According to the CASA paradigm and traditional studies of human–human interactions,[11,24,28,33–35] social presence may be one of the strongest factors affecting human–robot interactions. Social presence in human–computer interactions has been defined as "the extent to which a medium allows customers to experience others as being psychologically present".[20,41] In the field of HRI, the definition of social presence has been slightly adapted and modified to reflect the specifications of social robotics. In this study, we followed the definition of social presence put forth by Lombard and Ditton[32] Heerink *et al.*[21] and Shin and Choo[41]. Heerink *et al.*[21] and Shin and Choo[41] define social presence in human–robot interactions as the extent of co-being in "the company of someone and the perceptual illusion of non-mediation". Additionally, Shin and Choo[41] have suggested that social presence could play a significant role in accepting artificial agents, including socially interactive robots. Furthermore, previous research has found that social presence should be considered one of the most important factors when interacting and designing socially interactive robots and improving human–robot interactions and relationships. Lee *et al.*[29] questioned if feelings of social presence mediated people's social responses toward robots during an interaction, and their results confirmed that those feelings were a significant mediator. Jin[23] tested the mediating role of social presence using a virtual spokes-avatar during interaction.

Accordingly, this study hypothesized that social presence would mediate people's perception and evaluation of the robot.

H3: Social presence will mediate people's perceptions and evaluations of the robot.

3. Methods

This study aimed to investigate the effects of a robot's skin temperature on the user's perception in a physical human–robot interaction. To test the above hypotheses, a between-subjects design was used and the robot's temperature was varied among four levels (cool, intermediate, warm, or no physical interaction) to examine the effects of the robot's skin temperature on the physical human–robot interaction.

3.1. Participants

Eighty participants with no physical impairment in South Korea were recruited for this experiment. Participants were randomly assigned to one of four conditions. Each participant received US $ 3 for his/her participation. Fifty percent of the participants were female. The age of the participants ranged from 18 to 49 (mean: 29.4 years, S.D.: 7.44).

3.2. Materials

A Pleo robot was used as the socially interactive robot. By installing heating and cooling rays under the skin of the robot, we were able to control the temperature of the robot's skin (Fig. 1).[7] Additionally, the robot was capable of moving its head and tail and could walk on four legs, similar to a dog. The robot's movements and reactions were controlled by a wireless computer.

A pretest was conducted to determine the temperatures to be used in the cool, intermediate, and warm conditions of the experiment. Fifteen respondents participated in this pretest. The temperature of the robot's skin was changed from 20°C to 0°C and 20°C to 40°C. The temperature of the robot's skin was continuously increased or decreased by 1°C every 30 s. Participants in this pretest were asked to complete a questionnaire to evaluate which temperature felt the coolest, warmest and most neutral on the robot's skin. Based on the results of the pretest, three temperatures were selected for use in the full study: cool, 9°C; intermediate/neutral, 18°C; and warm, 32°C.

The biggest challenge of the experiment was creating the proper environment that allowed for a sufficient number of physical interactions. To create an environment that would encourage enough physical interaction, we conducted a pretest to evaluate which movies would create the greatest

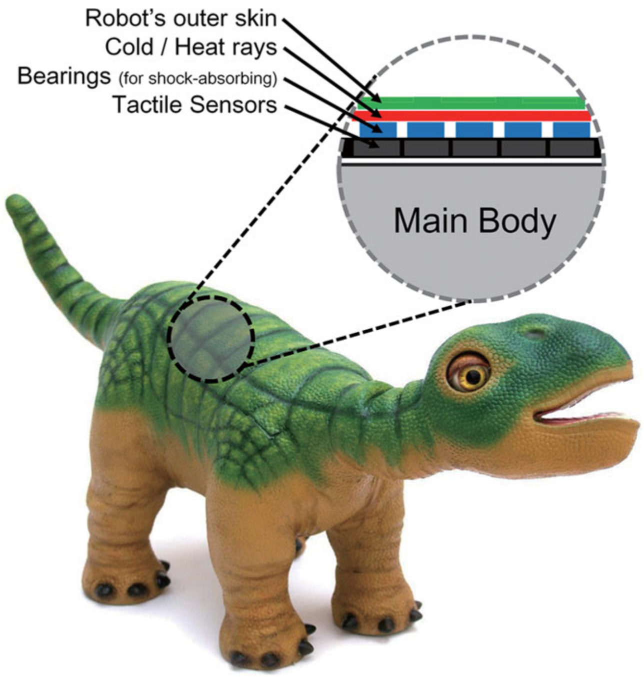

Fig. 1. (Colour online) A Pleo robot with cold/heat rays installed for our experiment.

Fig. 2. (Colour online) A sad movie that was used in our experiment.

number of interactions with the robot. To prevent a situation where participants would not interact with the robot and would not have any feelings toward the robot, we conducted another pretest where participants watched two movie clips from sad and scary movies to elicit emotional changes in the participants. For example, if a person's feelings shift from normal to a specific emotion, such as fear, the person will tend to have more physical interactions with other agents.[37] To select movies, we followed the procedures described by Park and del Pobil[37] and Nie *et al.*[36] First, we chose four horror movies and four sad movies. Then, we played these movies on a television screen for 10 min, and the respondents were asked to watch all of the movie clips. After that, the participants ranked the movies on a seven-point Likert scale questionnaire. Eventually, two clips were selected: the sad movie clip and the scary one (sad: 6.5 and scary: 6.7, Figs. 2 and 3).

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Fig. 3. (Colour online) A scary movie that was used in our experiment.

3.3. Measures

The questionnaire consisted of six themes referring to the following studies: Perceived friendship toward the robot used an index composed of five items adapted from Groom *et al.*[19] and Bartneck *et al.*[3]; perceived intention to own the robot used an index that included four items previously used by Park *et al.*[38] and Shin and Choo[41]; anthropomorphism was measured with an index consisting of four items adapted from Bartneck *et al.*[3]; perceived emotional stability was composed of eight items adapted from Chaturvedi *et al.*[6]; perceived pet likeness was composed of seven items adapted from Park *et al.*[39] and Hinds *et al.*[22]; and finally, social presence was composed of three items from Lee *et al.*[29], Shin and Choo[41], and Kim *et al.*[26] (Table I). All questionnaire items were revised by an expert panel of five professors in communications and psychology. Two rounds of a presurvey were administered to 30 university students and researchers majoring in robotics, communications, and psychology.

3.4. Procedure

Participants were welcomed to a sound-attenuated and bright room. The room was maintained at 18°C during the experiment. Participants were seated on a comfortable sofa in front of a TV screen. None of the participants had prior knowledge of the robot. To eliminate the effect of unfamiliarity to the Pleo robot, participants were allowed to interact with the robot at a neutral temperature without any interruption for 10 min. After the participants got used to interacting with the Pleo robot, they were told that they could hug, handle, and interact with the robot as they would their pets. During the experiment, participants were instructed to watch the movie clips for 10 min on the TV screen. The clips were randomly chosen from the two selected movies. Participants were divided into three groups depending on the Pleo robot's temperature: cool (9°C), intermediate (18°C) and warm (32°C). After watching the movie clips, participants were instructed to answer an online questionnaire that assessed their intention to own the robot, perceived friendship toward the robot, anthropomorphism, perceived emotional stability, immersive tendency and social presence with the robot (see previous section). Participants were thanked at the end of the experiment.

4. Results

One-way analysis of variance (ANOVA) was conducted to analyze the effects of skin temperature on the dependent variables, followed by *post hoc* analysis using Student's *t*-test. The results from the ANOVA and subsequent *post hoc* analysis found that participants who interacted with the robot with warm skin ($M = 5.51$, S.D. $= 0.97$) reported a significantly higher degree of perceived friendship than those who interacted with the robot with skin at an intermediate temperature ($M = 4.62$, S.D. $= 1.01$), with cool skin ($M = 4.49$, S.D. $= 0.97$), and with no physical interaction ($M = 4.14$, S.D. $= 0.92$)

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Table I. A list of the construct items used in the questionnaire.

Constructs	Items	Cronbach's α
Perceived friendship toward the robot	• PFR1: I liked the robot. • PFR2: The robot was friendly. • PFR3: The robot was kind to me. • PFR4: The robot was pleasant. • PFR5: The robot was nice.	0.91
Perceived intention to have the robot	• PIR1: I intend to keep this robot. • P1R2: I am very likely to keep the robot. • PIR3: If I had access to this robot, I would continue to use it. • PIR4: I intend to put efforts into keeping this robot.	0.93
Anthropomorphism	• ANT1: Lifelike • ANT2: Real pet-like • ANT3: Conscious • ANT4: Natural	0.84
Perceived emotional stability	• PES1: Optimism • PES2: Calm • PES3: Tolerance • PES4: Empathy • PES5: Pessimism (reversed) • PES6: Anxiety (reversed) • PES7: Aggression (reversed) • PES8: Apathy (reversed)	0.89
Perceived pet likeness	• PPL1: The robot's appearance was similar to a pet. • PPL2: The robot's actions were similar to a pet. • PPL3: The robot had pet-like characteristics. • PPL4: The robot looked like an artificial agent (reversed).	0.90
Social presence	• SP1: How much attention did you pay to the robot? • SP2: How much did you feel as if the robot was responding to you? • SP3: How much did you feel as if you were alone when you saw the movies (reversed)?	0.82

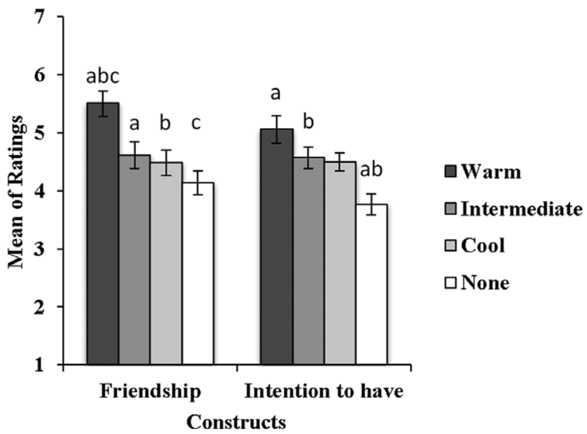

Fig. 4. Effects of robot skin temperature on perceived friendship toward the robot and intention to keep the robot. Friendship = perceived friendship toward the robot. Intention to keep = perceived intention to keep the robot.

($F[3, 76] = 7.256$, MSe $= 6.799$, $p < 0.001$). Additionally, participants who interacted with the robot with warm skin ($M = 5.06$, S.D. $= 1.08$), intermediate temperature skin ($M = 4.57$, S.D. $= 0.83$) and cool skin ($M = 4.50$, S.D. $= 0.68$) reported significantly higher degrees of perceived intention to own the robot than those in the no physical interaction condition ($M = 3.77$, S.D. $= 0.78$) [$F(3, 76) = 7.702$, MSe $= 5.666$, $p < 0.001$]. There was no difference found in terms of anthropomorphism ($p = 0.372$) (Figs. 4 and 5).

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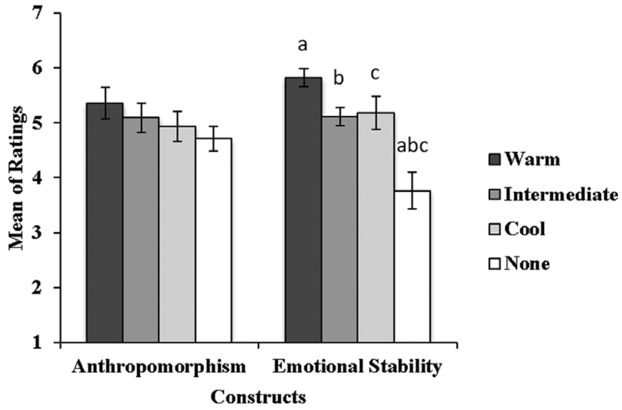

Fig. 5. Effects of robot skin temperature on anthropomorphism and perceived emotional stability. Emotional stability = perceived emotional stability.

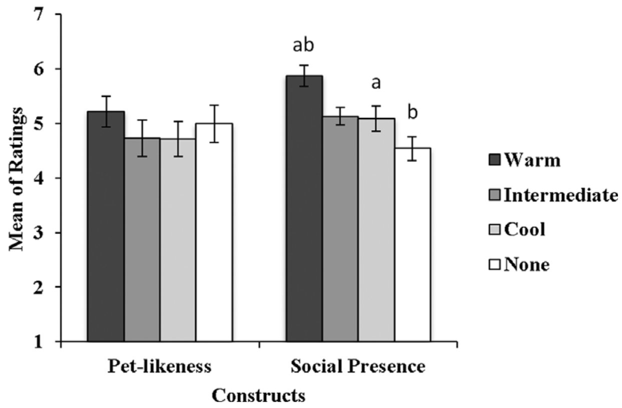

Fig. 6. Effects of robot skin temperature on perceived pet-likeness and social presence. Pet-likeness = perceived pet-likeness.

The skin temperature of the robot also significantly affected perceived emotional stability and social presence. Participants who interacted with the robot with warm skin ($M = 5.82$, S.D. $= 0.73$), intermediate temperature skin ($M = 5.10$, S.D. $= 1.20$) and cool skin ($M = 4.94$, S.D. $= 1.25$) were more emotionally stable than those in the no physical interaction condition ($M = 3.77$, S.D. $= 1.50$) [$F(3, 76) = 11.753$, MSe $= 14.936$, $p < 0.001$]. Participants who interacted with the robot with warm skin ($M = 5.88$, S.D. $= 0.85$) also reported a significantly higher degree of social presence than those who interacted with the robot with intermediate temperature skin ($M = 5.13$, S.D. $= 0.72$) or cool skin ($M = 5.09$, S.D. $= 1.04$), and those with no physical interaction ($M = 4.54$, S.D. $= 0.98$) [$F(3, 76) = 7.314$, MSe $= 6.009$, $p < 0.001$]. The skin temperature of the robot had no significant effect on the participants' perception of the pet-likeness of the robot ($p = 0.642$) (Figs. 5 and 6).

4.1. Mediation analysis

A mediation analysis per the guidelines of Baron and Kenny was used to examine hypothesis 3, which predicted that social presence would be a mediator between the temperature of the robot's skin and other dependent variables.[2,25] Results from the mediation analysis indicated that social presence with the robot mediated perceived friendship toward the robot and perceived emotional stability. The results are summarized in Fig. 7. Therefore, hypothesis 3 was partially supported.

5. Discussion

The results of this study extend previous literature on human–robot social interactions by exploring the effects of a robot's skin temperature on physical human–robot interactions. The results show that

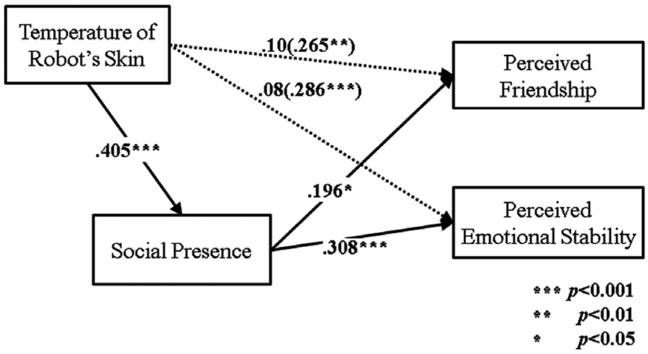

Fig. 7. A summary of the mediating effects of social presence.

the temperature of a robot's skin in these interactions affects people's perceptions of social robots. Additionally, the degree of the skin's temperature is one of the most crucial factors in determining people's perceptions of a robot. This study provides empirical evidence demonstrating that a robot's skin temperature in physical human–robot interactions significantly affects people's perceptions of the robot.

Similar to studies using the CASA paradigm and traditional human–human interaction paradigms, participants in this study felt that physically interacting with a social, warm robot created more positive, reliable and preferred responses. That is, the results indicated that people's perceptions of the robot, including perceived friendship toward the robot, perceived intention to own the robot, perceived emotional stability and social presence of the robot, positively increased from those in the no physical interaction condition to those interacting with the warm-skinned robot.

Generally, our hypotheses (H1 and H2) were supported. We found that a warmer robot elicited greater perceived satisfaction and a positive perception from participants, but there was essentially no difference between people's perceptions of the intermediate and cool skin conditions.

Similar to studies that have found that social presence mediates people's perceptions and evaluations during human–human interactions, this study partially confirmed the mediating effect of social presence in human–robot physical interactions. The extent of social presence in supporting people's positive perceptions and evaluation of the social robot in human–robot physical interactions was partially supported (H3). Generally, the mediating effect of social presence was already indicated in human–computer interaction and human–robot interaction.

6. Limitations and Future Work

Although this study makes a significant contribution to understanding the factors involved in creating successful human–robot interactions, there are some limitations. First, we did not consider variables related to the participants. Individual differences such as gender or age may significantly affect the users' perceptions and perspectives toward socially interactive robots. Second, this study used a Pleo robot, and if someone did not like dinosaurs, it would negatively affect that users' perceptions toward the robot. Third, there is a possibility that people may show different behavior in interactions with a humanoid robot, instead of a pet robot. For example, certain children tend to show different ways of interacting with different type of robots, i.e., mobile or humanoid robots.[9] Fourth, the generalizability of our results to individuals of different ages and cultural backgrounds is limited. There is a gap in cross-cultural understanding of the perceived value of pets and age can influence human–pet interaction.[16] Fifth, we did not evaluate other environmental factors that could have affected the perceived temperature, such as the humidity of the room and other tactile factors related to the points of contact in the human–robot physical interactions (such as tactile impression). Future studies could address these limitations with a larger number of participants and other types of human–robot interactions.

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