

# ■ Touching a Mechanical Body: Tactile Contact With Body Parts of a Humanoid Robot Is Physiologically Arousing

Jamy Li

University of Twente

and

Wendy Ju, Byron Reeves

Stanford University

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A large literature describes the use of robots' physical bodies to support communication with people. Touch is a natural channel for physical interaction, yet it is not understood how principles of interpersonal touch might carry over to a robot. Exploring how interpersonal rules surrounding body accessibility and touch apply to a robot is critical toward understanding the extent to which people treat the act of touching body regions as a sign of closeness—even if the body belongs to a robot—and is important to the field of humanoid social robotics. Thirty-one students participated in an interactive anatomy lesson with a small, humanoid robot. Participants either touched or pointed to an anatomical region of the robot in each of 26 trials while their skin conductance response was measured. Touching less accessible regions of a robot's body (e.g., its buttocks and genitals) was more physiologically arousing than touching more accessible regions (e.g., its hands and feet). No differences in physiological arousal were found when just pointing to those same anatomical regions. A social robot elicited tactile responses in human physiology, a result that signals people treat touching body parts as an act of closeness in itself that does not require a human recipient. The power of touching a humanoid body with identifiable body parts should caution mechanical and interaction designers about the positive and negative effects of human-robot interaction.

*Keywords:* human-robot interaction, touch, physiological arousal

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## 1. Introduction

Robots represent a major new type of communicative media in which devices move in shared space with people in seemingly sentient ways. Advances in robotics enable devices with mobile, humanoid bodies to perform social roles at home, at work and in public spaces. Understanding the social implications of this medium is critical to media psychology. Touch is a distinctive interaction mode of robots afforded by their physical presence (Dargahi & Najarian, 2004; Li, 2015). Natural physical contact between people and “personal service robots” (International Federation of Robotics, 2005) could be beneficial, yet it is unclear how physiological effects of interpersonal touch apply to social robots.

How will people respond to the introduction of a three-dimensional, humanoid robot that can be physically touched in public and private spaces? We know that touching is a very personal act of communication between people, and that people limit what parts of their bodies are accessible

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to others. Does this concept of “body accessibility” apply to robots as well? An experiment assessed the physiological effects of touching different regions of a humanoid robot’s body.

### 1.1. Touching Robots

The broad use of touch in social robots has emerged over the past decade. Current and potential applications of touch in robotics span the domains of medical care, telecommunications, and entertainment (Larson et al., 2016; Mittendorfer et al., 2015; Mukai et al., 2010; Nishio et al., 2007; Park et al., 2012; Robinson et al., 2015; Rus & Trolley, 2015; Stiehl et al., 2006; examples are presented in Table 1). These include elderly individuals touching a robotic pet to feel empathy and connection (Robinson et al., 2015), patients in a hospital who are lifted by a medical robot (Mukai et al., 2010), and more controversially, individuals who have intimate relationships with robots (Levy, 2007). State-of-the-art social robots increasingly feature touch-sensors (Mittendorfer et al., 2015) and materials that look and feel like human skin (Nishio et al., 2007; Park et al., 2012) or animal fur (Stiehl et al., 2006). A main hypothesis of these types of robots is that “direct” interactions in which people and robots communicate with each other may be more appropriate than “indirect” interactions in which a person controls the behavior of a robot (Thrun, 2004). In field studies with humanoid robots, both adults (Becker-Asano et al., 2010) and young children (Tanaka et al., 2007) willingly touch a robot’s hands, arms, and head. In pilot studies with animal-shaped robots, touching the robot decreased people’s heart rate (Robinson et al., 2015) and improved their evaluations of the robot (Lee et al., 2006). Human-robot collaboration, in which people work alongside robots, can be aided by brief social touch (e.g., Bevan & Stanton-Fraser, 2015). How much a person likes a robot influences how closely they approach it (Mumm & Mutlu, 2011). More generally, a large literature finds people interact with robots in a social way and that robots can be designed to make use of this fact (Breazeal, 2003). It is unknown, however, the extent to which a robot is capable of eliciting a physiological response associated with a social rule regarding touching its body.

### 1.2. Touch: The Sense of Social Closeness

What role does touch play in human communication? Compared to verbal (speech) and nonverbal communication (for example, gestures, eye gaze and posture), touch focuses more on communicating and engendering closeness between individuals than communicating informational content (Linden, 2015). Touch is used as social “glue”—a means of developing and maintaining relationships (Linden, 2015, p. 5). One way interpersonal touch does this is through evoking a variety of measurable changes in physiological arousal among people who are touching (Bautista & Lumpkin, 2011). The arousal model of intimacy states that “in a dyadic interaction, sufficient changes in the intimacy behaviors of one person will produce arousal changes in the other person” (Patterson, 1976, p. 239). In line with this theory, social touch but not self-touch results in reduced heart rate (Drescher et al., 1985). Individuals who are briefly touched by an unfamiliar person in passing experience higher skin conductance, an indicator of psychological arousal (Vrana & Rollock, 1998). Socially anxious individuals experience increased skin conductance when touched by an experimenter (Wilhelm et al., 2001). A key reason why such changes occur is that touch is a “bottom-up” sensory signal that enhances emotional processing (Schirmer et al., 2011).

Touching, in turn, influences a variety of relationship attributes, including trust, liking, prosocial behavior, and performance. A light touch on the arm during a therapy session, for instance, reduces discomfort and increases disclosure (Pattison, 1973). Holding the hand of a loved one or—to a lower extent—of a stranger, can make stressful situations easier (Coan et al., 2006). Being touched on the shoulder, upper arm or hand in a shopping mall increases prosocial behavior (Paulsell & Goldman, 1984). In professional sports, celebratory touch between players during games enhances performance by building cooperation (Kraus et al., 2010). Similarly, a habitual lack of touch can have negative side effects. Infants deprived of human touch, for example, can become depressed (Spitz, 1945).

Table 1. Proposed applications of personal robots that involve physical contact

Domain	Role of robot	Platform	Touch Use	Study results	Reference
Healthcare	Patient transfer from floor to chair	RIBA human-sized robot	Pressure applied to robot's forearm to control moving	Force touch is more suitable than length of sliding touch for input	Mukai et al., 2010; <a href="http://rtc.nagoya.riken.jp">rtc.nagoya.riken.jp</a>
	Emotional companion for general audience that expresses emotions	Haptic creature	Hugging, other pet-related touch	Back was most touched location; rump was least touched	Yohanan & MacLean, 2012
	Therapeutic animal for elderly	Paro seal robot	Stroking, patting, hugging robot's head and body	Touch decreases systolic and diastolic blood pressure	Robinson et al., 2015; <a href="http://www.paro-robots.com">www.paro-robots.com</a>
	Emotional companion that comforts hospitalized children	Probo animal robot	Touch trunk		Saldien et al., 2008
	Emotional companion that comforts and captures data from hospitalized children	Huggable teddy bear robot	Petting, scratching, rubbing, patting robot's head and body		Stiehl et al., 2006
Human replica	Conversational partner	Geminoid humanoid robot	Touching hand, head or arm	People were willing to touch the robot's hand, head or arm	Becker-Asano et al., 2010; <a href="http://www.geminoid.jp">www.geminoid.jp</a>
Telecommunications	Avatar for operator to communicate with children, which transmits how child is touching the robot to operator	Huggable teddy bear robot	Hugging and other touches from children		Stiehl et al., 2006
Customer service	Provide technical help	WowWee RoboSapien human-shaped robot	Mutual tapping, hugging, high-fiving (robot-initiated or user-initiated)	Touch decreased perceived dependability for a passive robot	Cramer et al., 2009; <a href="http://wowwee.com/robosapien-blue">wowwee.com/robosapien-blue</a>
Entertainment	Sing and dance	Sony AIBO dog robot	Head, chin and back	Touching a robot improves affective evaluation	Lee et al., 2006; <a href="http://sony-aibo.com">sony-aibo.com</a>
Early childhood education	Dancing and playing with children	Sony QRIO human-shaped robot	Touching hand, arm, head torso or legs, and hugging	Hands and arms touched more than head, torso and legs; Animate touched more than inanimate	Tanaka et al., 2007

Touching another person is clearly a powerful and meaningful act. We know based on experience that touch can evoke love, affection, anger, dislike, or a variety of other feelings among people. The same sensation of touch can therefore be perceived as pleasurable or repulsive depending on context and expectation.

### 1.3. Body Accessibility of People and Robots

A prevalent social norm in touch is that the frequency with which a person is touched depends on the location of touching. “Body accessibility” is a term introduced by Jourard (1966) to describe a person’s willingness to let others contact his body. Jourard rated body accessibility based on how frequently people reported touching or being touched by others in 24 different regions. The most accessible regions of the body were the hands, head, and arms while the least accessible region was the genitals. Does the concept of body accessibility extend to robots?

If people only treat the act of touching another person as an act of closeness, we would expect no difference in physiological response when touching one part of a robot’s body versus another part, particularly if its body is of uniform texture and material. If people treat the act of touching body regions as an act of closeness in itself, despite the body belonging to a robot, we would anticipate that touching low accessibility regions of a robot would elicit an emotional response associated with greater closeness between the person and the robot. Although there is no research that directly assesses the physiology of touching robots, there is reason to expect that the physical act of touching will work similarly for a plastic robot as it does for real humans (Reeves & Nass, 1996). That expectation is based on similar findings for primitive responses to movement, physical distance, and a range of social responses (e.g., personality, politeness, reciprocity) (Reeves & Nass, 1996).

## 2. Current Study

The present work evaluates whether the social rule of body accessibility applies to touching a small, humanoid robot. We test the effect of this social rule by measuring changes in human physiology. We hypothesize that people will be less comfortable touching a robot in areas that are not accessible, such as the buttocks, compared to areas considered highly accessible, such as the hands, and that this will result in greater epidermal perspiration during their anticipation of touching low accessible areas on a robot.

We explicitly evaluate a person touching a robot, rather than a robot touching a person, because having a robot touch a person can be unreliable and unsafe given the current state of the technology. We select an educational task, in which a person touches a robot as part of an anatomy lesson, to avoid giving away the study purpose of evaluating social rules and because it is one way to use the specific robot in this study.

## 3. Materials and Methods

### 3.1. Participants

Thirty-one right-handed participants (16 female, 15 male) affiliated with Stanford University received course credit or \$20 for their participation. Two data collection periods (one in Sept. 2015, one in July 2016) were used. Approximately half the participants were students enrolled in an undergraduate class. The remaining half were recruited through paper and online campus job postings. The Human Subjects Research Board at Stanford University approved the study.

### 3.2. Design

A 2 (*interaction condition*: touching vs. pointing)  $\times$  3 (*body accessibility rating*: low, medium, or high) within-participants study was conducted in which people viewed an interactive lesson delivered using a humanoid robot. A total of 26 trials per participant were obtained. In half the trials, the robot asked the participant to touch its body part; in the remaining half, the robot asked

the participant to point to its body part. Thirteen body parts were used, listed in Table 2. The body parts and their conditions (touch or point) were delivered in a random order that was the same across participants. The topic of anatomical terminology (the technical terms used by anatomists and scientists when referring to different anatomical locations) was selected to provide a rationale for the participant's touching of the robot's body. Pointing at the robot was selected as a contrasting activity to touching, because it activates identical muscle groups in the arm and finger but does not produce the sensation of touching the surface of the robot. Both the factors of interaction method and anatomical region were within-participant factors to give a clearer picture of treatment effects (because they address error associated with individual differences, unlike between-participant designs; Reeves & Geiger, 1994, p. 174). Within-participant designs, however, have greater risk than between-participant designs for time-based influences and the potential for participants to "figure out" the experiment (Reeves & Geiger, 1994, p. 178).

### 3.3. Procedure

The study took place in a university lab room. Prior to each session, the robot was placed in a sitting position so that its body could be easily touched. After consent was obtained, participants sat in a chair facing a small humanoid robot (Aldebaran Robotics' NAO, shown in video S1). An Affectiva Q-Sensor electrodermal sensor was placed on the fingers of the participant's non-dominant hand to measure electrodermal arousal. The experimenter explained that the sensor would measure their skin conductivity. He gave the instructions: "In this study, you will be asked to touch or point to different parts of a robot's body in an anatomy lesson. The study will begin shortly." The experimenter then left the room, after which the robot delivered the following instructions: "Hello! In this exercise we'll be talking about vocabulary for parts of the body. Sometimes I'll ask you to touch my body and sometimes I'll ask you to point to my body. When I ask you to touch me, please touch me with your dominant hand. When I ask you to point at me, please point at me with your dominant hand. Please keep your other hand on the sensor. Okay, let's get started."

Each of the 26 trials focused on a single anatomical region. In the prompt stage, the robot issued a verbal request to either touch or point to its body part (e.g., "Please touch my eye"; "Please point to my eye") using synthesized speech. In the action stage, the participant touched or pointed at the robot's body part. In the response stage, the robot verbally explained the term used to describe the body part (e.g., "This is the eye. It is referred to as the ocular region") and simultaneously executed a corresponding movement (e.g., tilting the head to display the eye, opening the legs to display the inner thigh, etc.). An example of the three stages is shown in video S1. A researcher viewing the session in an adjacent room manually initiated pre-recorded actions for the robot during the prompt and response phases. The timing of actions by the participant and robot were synchronized with readings from the electrodermal sensor by having the same researcher place markers in the sensor's data stream in real-time using the sensor's graphical software interface. The experiment lasted approximately 20 minutes.

### 3.4. Preliminary Test

A preliminary test was performed with four participants to refine the experimental method. The initial method involved having participants refer to a printed diagram of the robot with numbers marking each body part and having the robot refer to each body part by its number. This was found to be too confusing. Pre-trials also had the experimenter sitting behind the participant in the same room; this was modified so that the experimenter was in a separate room and viewed the session through an occluded window (first data collection period) and using a live camera feed (second data collection period).

### 3.5. Materials

The robot used for this study, Aldebaran Robotics' NAO, is a 25 degrees-of-freedom (DoF) programmable humanoid robot with a height of 23 inches. The robot has functional joints, limbs,

head, and hands but does not have articulated ears, nose, buttocks, or genitals. Movements for the robot were designed and recorded by a member of the research team using the robot's Choregraphe graphical user interface. During experimental sessions, these recorded movements were played back to participants.

### 3.6. Analysis

Anatomical regions were categorized by their body accessibility rating into high, medium, and low tertiles according to how frequently that region is touched in interpersonal communication (Jourard, 1966) (see Table 2). Skin conductance data were aggregated at one sample per second. Physiological arousal was defined as the change in electrodermal arousal from the prompt stage to the action stage (cf. Dawson et al., 1990, p. 214). Response time was defined as the time difference between these two stages. For the analysis of physiological arousal, two outliers among a total of 806 trials were replaced with the mean arousal from the same trial for all other participants. For the analysis of response time, one outlier was replaced with the mean response time from the same trial for all other participants.

## 4. Results

Repeated-measures ANOVA conducted in R<sup>1</sup> revealed a significant body accessibility  $\times$  condition interaction (Fig. 1A),  $F(2, 60) = 3.17, p = 0.049, \eta^2 = 0.10$ : participants experienced a larger increase in electrodermal arousal for anatomical regions with low accessibility compared to high accessibility when they touched the robot, but not when they pointed at the robot. Twenty-six of 31 participants had higher arousal for touching low accessibility compared to high accessibility regions, illustrated in Fig. 1B. Both main effects of interaction condition and body accessibility were also significant,  $F(1,30) = 11.44, p = .002, \eta^2 = 0.28$  and  $F(2,60) = 16.71, p < .001, \eta^2 = 0.36$ , respectively.

Further evidence of participants' sensitivity to touching low accessible regions of a robot emerged in an analysis of response time, which was longer for participants when touching low-accessible compared to high accessible areas. Repeated-measures ANOVA<sup>2</sup> showed a significant body accessibility main effect,  $F(2,60) = 32.5, p < 0.001, \eta^2 = 0.52$ : participants took longer to touch regions with low accessibility compared to high accessibility. Twenty-five of 31 (81%) participants had longer response times for low accessibility compared to high accessibility regions. The body accessibility  $\times$  condition interaction was not significant,  $F(2,60) = 1.26, p = 0.29, \eta^2 = 0.04$ .

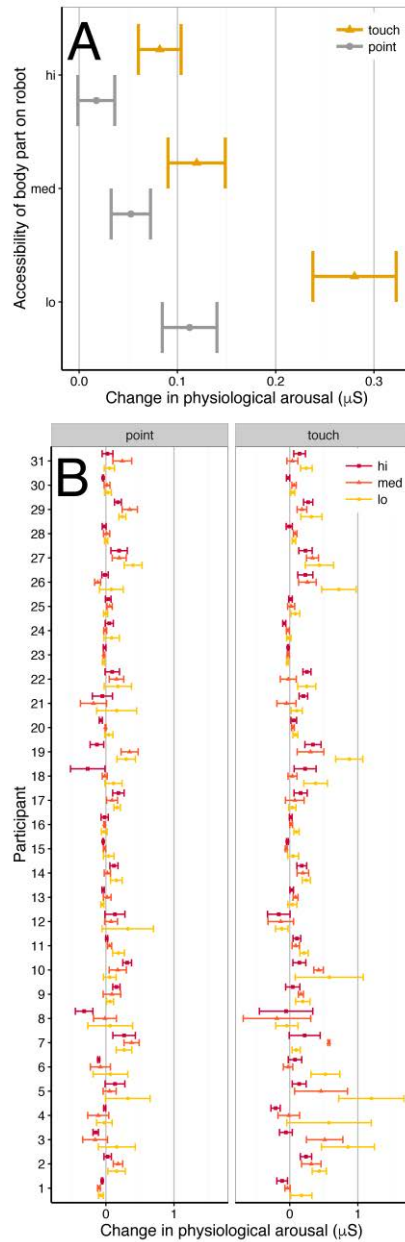
## 5. Discussion

### 5.1. Summary of Results

In a learning activity where participants either touched or pointed to different anatomical regions of a robot, physiological arousal was higher when people anticipated touching low accessible areas compared to high accessible areas, but not when they anticipated pointing to those areas. We interpret the results as meaning that people experienced a greater increase in alertness at the request of touching a robot's low accessible body parts compared to highly accessible body parts and compared to pointing. We think this alertness was due to a discomfort toward the act of touching low accessible body parts, even though the robot did not have feelings and was a machine.

<sup>1</sup> Modeled according to Larson-Hall (2016, pp. 239) as:  $\text{EDA\_change} \sim \text{body\_accessibility} * \text{condition} + \text{Error}(\text{participant} / (\text{body\_accessibility} * \text{condition}))$ . We repeated our analyses using lmer mixed effect analysis in R and obtained similar results.

<sup>2</sup> Modeled as:  $\text{response\_time} \sim \text{body\_accessibility} * \text{condition} + \text{Error}(\text{participant} / (\text{body\_accessibility} * \text{condition}))$ .



*Figure 1. (A)* Horizontal bar plot of the effect of touch on skin conductance by body accessibility rating. Physiological arousal was higher for touching (gold lines) but not pointing (silver lines) at robot body parts with low compared to high accessibility. Each point is the mean of all trials in that grouping. Error bars show variability across participants in SE. **(B)** Horizontal bar plot of the effect of body accessibility on skin conductance by participant. Change in physiological arousal per participant during point interactions is shown on the left and touch interactions on the right. Physiological arousal was higher for touching body parts with low accessibility (yellow lines) compared to high accessibility (red lines) for 26 of 31 participants (right). Each point is the mean of all trials in that grouping. Error bars show variability across body parts in SEs.

Table 2. The impact of body accessibility on interpersonal touching, pointing to a robot, and touching a robot, showing means and standard deviations.

Anatomical region	Percentage of people reporting touching or being touched by another (Jourard, 1966) <sup>†</sup>	Average change in physiological arousal for pointing to a robot ( $\mu$ S, this study) <sup>‡</sup>	Average change in physiological arousal for touching a robot ( $\mu$ S, this study) <sup>‡</sup>	Body accessibility rating (this study)
Hand	84.9	0.01 (0.16)	0.10 (0.21)	High
Arm	76.5	-0.03 (0.25)	0.01 (0.27)	High
Forehead	68.5	0.07 (0.24)	0.08 (0.27)	High
Neck	57.8	0.01 (0.17)	0.14 (0.21)	High
Back	56.3	0.08 (0.19)	0.01 (0.38)	Medium
Ear	48.8	0.04 (0.21)	0.18 (0.30)	Medium
Eye	42.3	0.07 (0.25)	0.19 (0.39)	Medium
Foot	36.9	0.03 (0.25)	0.09 (0.16)	Medium
Inner Thigh	31.3	0.15 (0.32)	0.10 (0.23)	Low
Heart	30.6	-0.01 (0.27)	0.06 (0.24)	Low
Breast	30.6	0.11 (0.25)	0.22 (0.39)	Low
Buttocks	23.6	0.02 (0.25)	0.34 (0.56)	Low
Genitals	13.8	0.29 (0.51)	0.68 (0.78)	Low

<sup>†</sup> Any number of times in the past 12 months, averaged across parents and friends as the partners of touching.

<sup>‡</sup> For reference, the increase in skin conductance for solving mental math problems is approximately 1  $\mu$ S (Lacey et al., 1963), cf. (Dawson et al., 1990); the increase due to being fully wakened after induced sleep is approximately 4  $\mu$ S (Storm et al., 2002)

## 5.2. Implications for Theory

The physiological response to a robot's request to touch its private body parts may be because the act of touching influences the participant's response more than the fact that the medium they touch is not human. How a person views their own actions with media that are "close enough" to being human could be more important than the fact that the media is not actually a real human (Reeves & Nass, 1996). This response is not simply an act of playing along—it occurs on a deeper physiological level. People are not inherently built to differentiate between technology and humans when enacting social habits. Consequently, primitive responses in human physiology to cues like movement, language, and social intent can be elicited by robots and other media just as they would by real people.

Our findings suggest that people's primitive responses can also manifest when socialized rules about body accessibility are violated, even though the robot is just a technological device governed by a computer algorithm. This result suggests that—at least from the perspective of the people doing the touching—humanoid bodies elicit social rules around touching even if the body does not belong to a human being.

According to the arousal model of intimacy, increases in relationship closeness are reflected through changes in arousal (Patterson, 1976). Since touching a robot does in fact create changes in arousal, this work provides physiological evidence that the act of touching a robot in a low accessible region is an act of closeness even though the target of the touching is a robot rather than a person. In our scenario, this closeness may have been undesirable and thus associated with a feeling of discomfort.



### 5.3. Design Implications

Robots that respond to touch have existed for over a decade. The design of these robots has acknowledged the positive impacts of touch-based interaction. Many past experiments have demonstrated the benefits of touch to aid domains of human-robot interaction. As one example, past research has shown that human-robot collaboration, in which people work alongside robots, can be aided by brief social touch (e.g., Bevan & Stanton-Fraser, 2015). This work provides empirical evidence of the influence of touch, which is an interaction modality that can be used by designers to capture people's attention and keep them alert. This work also illustrates the potential downside to touching a humanoid robot, in that it can make people uncomfortable when used in socially inappropriate ways. The finding that social rules regarding body accessibility apply to social touch means that socially appropriate design of touch is important for designers to account for.

### 5.4. Practical Applications

Perhaps most importantly, responses to physical contact with a robot can be reliably measured in human physiology. Past work (e.g., Lu & Hsu, 2015) has measured participants' physiological responses to interactions with robots but has not focused on touch and has not identified trends connecting physiological arousal with touching a robot, perhaps due to smaller sample sizes or taking an average of the participants' arousal across an entire minute-long interaction. Our work presents a controlled experiment which specifically looks at the physiological effects of touching a robot. This methodology can be used to test the influence of specific robot-related stimuli in the timescale of seconds on motivational responses important for attention, memory, and behavior change.

### 5.5. Limitations and Future Work

A limitation of this work is that we selected one specific medium: a small, humanoid robot. We purposely selected a robot for this study because its specific set of multimodal behaviors (including gesture, verbal speech, and a non-virtual body collocated with the participant) are becoming more common in modern consumer technology. We anticipate our result to extend to other media that have bodies with identifiable body parts in varying degrees. Dolls, stuffed animals, mannequins, or virtual people may elicit body accessibility response in human physiology to a greater or lesser degree found with the robot in the current study. Since evaluation of multiple media was outside the scope of this study, it is left as future work.

A second limitation is that we selected one specific context: an anatomy lesson. We anticipate body accessibility to extend to touching a robot's body in some—but not all—other contexts. For example, a person who anticipates touching the buttocks of the robot used in this work (in addition to other areas of its body) as part of carrying the robot to another location would be unlikely to become physiologically aroused due to discomfort in anticipation of the touch. However, we do anticipate similar results for touching robots in contexts where an interpersonal social rule would apply to touching a person instead of a robot. For example, a robot that acts as a sales assistant in a department store could elicit physiologically arousing feelings of discomfort in a person if it asks the person to touch its body, because this is a socially inappropriate action for a human sales assistant. This is in spite of the fact that a robot may have a valid reason to do so that a human would not (for instance, the practical reason of a robot asking a person to select the type of clothing he would like to purchase on its touch-sensitive body, and the person wanting to purchase underwear). It would be interesting to evaluate how different social roles or social contexts influence responses to touch.

A third limitation is that we did not explicitly interrogate the reasons for our result, but we can speculate on three contributing study variables here. Why is touching low accessible body parts of a robot more physiologically arousing than highly accessible body parts? First, our result could be

because hearing the combined verbalization of the words “touch” and “my buttocks” is itself physiologically arousing, regardless of what the participant does or what communicates the words. Second, the actual act of touching (i.e., reaching out and feeling) a low accessible region of the robot could have led to increased physiological arousal. With these study variables, it is the anticipation or act of touching, respectively, which causes an increase in physiological arousal, rather than the robot’s body itself. We did not run controls for each of the above possibilities, which is left as future work. Of course, a third contributing study variable could have been the robot itself: the fact that the robot has a physically collocated body, moves autonomously, and supports speech, gesture, and collocated touch. These properties of the robot may have given participants a sense that the robot had its “own” body that prompted people to adhere to social norms of body accessibility. We did not evaluate the effect of the autonomy or motion of the robot in this preliminary work. Finally, we exclude the physical sensation of feeling the material of the robot itself as resulting in increased physiological arousal from touching low versus high accessible regions, since the robot had a uniform plastic covering across all body parts.

Our results are further limited by the sample population studied and future work could explore the correlates of physiological response to touch, which include individual characteristics such as gender, age and culture (Remland et al., 1995).

Future work is needed on robots that are designed for situations of low body accessibility. This work begs the question about designing robots for situations in which touching robots in low accessible regions is socially acceptable. Given the well-documented presence of sexual themes in video games, movies, and virtual worlds (Ivory, 2006), “intimacy” robots (Levy, 2007; Young et al., 2009) could eventually be used as a means of entertainment. Given the increasing prevalence of long-distance relationships and the importance of relatedness to humans (cf. Hassenzahl et al., 2012), interacting with romantic partners using a telepresence robot is another application that could develop. These applications raise important questions about gender equality, robot ethics, and social connection that are beyond the scope of this work. Our work only demonstrates that people view the act of touching an artificial agent’s body as following social conventions of body accessibility that can be both designed for and violated.

## 6. Conclusion

Touching low accessible body parts elicits changes in human physiology, even when the target of the touching is a robot. This suggests that people apply a social rule about body accessibility to a humanoid robot.

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## References

- Bautista, D., & Lumpkin, E. (2011). Probing mammalian touch transduction. *Journal of General Physiology*, 138(3), 291-301. doi:10.1085/jgp.201110637
- Becker-Asano, C., Ogawa, K., Nishio, S., & Ishiguro, H. (2010). Exploring the uncanny valley with Geminoid HI-1 in a real-world application. In *Proceedings of IADIS International Conference Interfaces and Human Computer Interaction*. (pp. 121-128). IADIS Press.
- Bevan, C., & Stanton Fraser, D. (2015, March). Shaking hands and cooperation in tele-present human-robot negotiation. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction* (pp. 247-254). ACM. doi:10.1145/2696454.2696490

- Breazeal, C. (2003). Emotion and sociable humanoid robots. *International Journal of Human-Computer Studies*, 59(1-2), 119-155. doi:10.1016/S1071-5819(03)00018-1
- Coan, J. A., Schaefer, H. S., & Davidson, R. J. (2006). Lending a hand: Social regulation of the neural response to threat. *Psychological Science*, 17(12), 1032-1039. doi:10.1111/j.1467-9280.2006.01832.x
- Cramer, H., Kemper, N., Amin, A., & Evers, V. (2009, March). The effects of robot touch and proactive behaviour on perceptions of human-robot interactions. In *Proceedings of the 4th ACM/IEEE International Conference on Human-Robot Interaction*. (pp. 275-276). IEEE. doi:10.1145/1514095.1514173
- Dargahi, J., & Najarian, S. (2004). Human tactile perception as a standard for artificial tactile sensing—A review. *International Journal of Medical Robotics and Computer Assisted Surgery*, 1, 23-35. doi:10.1002/rcs.3
- Dawson, M. E., Schell, A. M., & Fillion, D. L. (2000). The electrodermal system. In J. T. Cacioppo, L. G. Tassinary and G. G. Berntson (Eds.). *Handbook of psychophysiology* (2nd ed.) (pp. 200-223). New York, NY: Cambridge University Press.
- Drescher, V. M., Whitehead, W. E., Morrill-Corbin, E. D., & Cataldo, M. F. (1985). Physiological and subjective reactions to being touched. *Psychophysiology*, 22(1), 96-100. doi:10.1111/j.1469-8986.1985.tb01565.x
- Hassenzahl, M., Heidecker, S., Eckoldt, K., Diefenbach, S., & Hillmann, U. (2012). All you need is love: Current strategies of mediating intimate relationships through technology. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 19(4), 30. doi:10.1145/2395131.2395137
- International Federation of Robotics (2005). *World robotics 2005*. New York, NY: United Nations Publications.
- Ivory, J. D. (2006). Still a man's game: Gender representation in online reviews of video games. *Mass Communication & Society*, 9(1), 103-114. doi:10.1207/s15327825mcs0901\_6
- Jourard, S. M. (1966). An exploratory study of body-accessibility. *British Journal of Clinical Psychology*, 5(3), 221-231. doi:10.1111/j.2044-8260.1966.tb00978.x
- Kraus, M. W., Huang, C., & Keltner, D. (2010). Tactile communication, cooperation, and performance: An ethological study of the NBA. *Emotion*, 10(5), 745. doi:10.1037/a0019382
- Lacey, J. I., Kagan, J., Lacey, B. C., & Moss, H. A. (1963). The visceral level: Situational determinants and behavioral correlates of autonomic response patterns. In P. H. Knapp (Ed.). *Expression of the emotions in man* (pp. 161-196). New York, NY: International Universities Press.
- Larson, C., Peele, B., Li, S., Robinson, S., Totaro, M., Beccai, L., Mazzolai, B., & Shepherd, R. (2016). Highly stretchable electroluminescent skin for optical signaling and tactile sensing. *Science*, 351, 1071-1074. doi:10.1126/science.aac5082
- Larson-Hall, J. (2016). *A guide to doing statistics in second language research using SPSS and R* (2nd ed.). New York, NY: Routledge.
- Lee, K. M., Jung, Y., Kim, J., & Kim, S. R. (2006). Are physically embodied social agents better than disembodied social agents? The effects of physical embodiment, tactile interaction, and people's loneliness in human-robot interaction. *International Journal of Human-Computer Studies*, 64(10), 962-973. doi:10.1016/j.ijhcs.2006.05.002
- Levy, D. (2007). *Love and sex with robots: The evolution of human-robot relationships*. New York, NY: Harper.

- Li, J. (2015). The benefit of being physically present: A survey of experimental works comparing copresent robots, telepresent robots and virtual agents. *International Journal of Human-Computer Studies*, 77, 23-37. doi:10.1016/j.ijhcs.2015.01.001
- Linden, D. (2015). *Touch: The science of hand, heart and mind*. New York, NY: Penguin.
- Lu, J. M., & Hsu, Y. L. (2015). The use of psychophysiological methods in the evaluation of mental commitment robots for elderly care. *Journal of Industrial and Production Engineering*, 32(7), 449-456. doi:10.1080/21681015.2015.1078420
- Mittendorfer, P., Yoshida, E., & Cheng, G. (2015). Realizing whole-body tactile interactions with a self-organizing, multi-modal artificial skin on a humanoid robot. *Advanced Robotics*, 29(1), 51-67. doi:10.1080/01691864.2014.952493
- Mukai, T., Hirano, S., Nakashima, H., Kato, Y., Sakaida, Y., Guo, S., & Hosoe, S. (2010, October). Development of a nursing-care assistant robot RIBA that can lift a human in its arms. In *Proceedings of the 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*. (pp. 5996-6001). IEEE. doi:10.1109/IROS.2010.5651735
- Mumm, J., & Mutlu, B. (2011, March) Human-robot proxemics: Physical and psychological distancing in human-robot interaction. In *Proceedings of the 6th International Conference on Human-Robot Interaction*. (pp. 331-338). ACM. doi:10.1145/1957656.1957786
- Nishio, S., Ishiguro, H., & Hagita, N. (2007). Geminoid: Teleoperated android of an existing person. In A.C. de Pina Filho (Ed.). *Humanoid robots: New developments* (pp. 343-352). Vienna, Austria: I-Tech.
- Park, Y. L., Chen, B. R., & Wood, R. J. (2012). Design and fabrication of soft artificial skin using embedded microchannels and liquid conductors. *IEEE Sensors Journal*, 12(8), 2711-2718. doi:10.1109/JSEN.2012.2200790
- Patterson, M. (1976). An arousal model of interpersonal intimacy. *Psychological Review*, 83(3), 235-245. doi:10.1037/0033-295X.83.3.235
- Pattison, J. E. (1973). Effects of touch on self-exploration and the therapeutic relationship. *Journal of Consulting and Clinical Psychology*, 40(2), 170-175. doi:10.1037/h0034573
- Paulsell, S., & Goldman, M. (1984). The effect of touching different body areas on prosocial behavior. *Journal of Social Psychology*, 122(2), 269-273. doi:10.1080/00224545.1984.9713489
- Reeves, B., & Geiger, S. (1994). Designing experiments that assess psychological responses to media messages. In A. Lang (Ed.). *Measuring psychological responses to media messages* (pp. 165-180). Hillsdale, NJ: Lawrence Erlbaum.
- Reeves, B., & Nass, C. (1996). *The media equation: How people treat computers, television, and new media like real people and places*. New York, NY: Cambridge University Press.
- Remland, M. S., Jones, T. S., & Brinkman, H. (1995). Interpersonal distance, body orientation, and touch: Effects of culture, gender, and age. *The Journal of Social Psychology*, 135(3), 281-297. doi:10.1080/00224545.1995.9713958
- Robinson, H., MacDonald, B., & Broadbent, E. (2015). Physiological effects of a companion robot on blood pressure of older people in residential care facility: A pilot study. *Australasian Journal on Ageing*, 34(1), 27-32. doi:10.1111/ajag.12099
- Rus, D., & Tolley, M. (2015). Design, fabrication and control of soft robots. *Nature*, 521, 467-475. doi:10.1038/nature14543
- Saldien, J., Goris, K., Vanderborght, B., & Lefeber, D. (2008, April). On the design of an emotional interface for the huggable robot probot. In *Proceedings of the AISB 2008*

*Symposium on the Reign of Catz & Dogz: The second AISB symposium on the role of virtual creatures in a computerized society.* (pp. 1-6). The Society for the Study of Artificial Intelligence and Simulation of Behaviour. Aberdeen, Scotland, UK.

- Schirmer, A., Teh, K. S., Wang, S., Vijayakumar, R., Ching, A., Nithianantham, D., . . . Cheok, A. D. (2011). Squeeze me, but don't tease me: Human and mechanical touch enhance visual attention and emotion discrimination. *Social Neuroscience*, 6(3), 219-230. doi:10.1080/17470919.2010.507958
- Spitz, R. A. (1945). Hospitalism: An inquiry into the genesis of psychiatric conditions in early childhood. *The Psychoanalytic Study of the Child*, 1(1), 53-74. doi:10.1080/00797308.1945.11823126
- Stiehl, W. D., Breazeal, C., Han, K. H., Lieberman, J., Lalla, L., Maymin, A., . . . Kishore, A. (2006, July). The huggable: A therapeutic robotic companion for relational, affective touch. In *Proceedings of the Special Interest Group on Computer Graphics and Interactive Techniques Conference (SIGGRAPH)*. (pp. 15). ACM. doi:10.1145/1179133.1179149
- Storm, H., Myre, K., Rostrup, M., Stokland, O., Lien, M. D., & Raeder, J. C. (2002). Skin conductance correlates with perioperative stress. *Acta Anaesthesiologica Scandinavica*, 46(7), 887-895. doi:10.1034/j.1399-6576.2002.460721.x
- Tanaka, F., Cicourel, A., & Movellan, J. R. (2007). Socialization between toddlers and robots at an early childhood education center. *Proceedings of the National Academy of Sciences*, 104(46), 17954-17958. doi:10.1073/pnas.0707769104
- Thrun, S. (2004). Toward a framework for human-robot interaction. *Human-Computer Interaction*, 19(1-2), 9-24. doi:10.1080/07370024.2004.9667338
- Vrana, S. R., & Rollock, D. (1998). Physiological response to a minimal social encounter: Effects of gender, ethnicity, and social context. *Psychophysiology*, 35(4), 462-469.
- Wilhelm, F. H., Kochar, A. S., Roth, W. T., & Gross, J. J. (2001). Social anxiety and response to touch: Incongruence between self-evaluative and physiological reactions. *Biological Psychology*, 58(3), 181-202. doi:10.1016/S0301-0511(01)00113-2
- Yohanan, S., & MacLean, K. E. (2012). The role of affective touch in human-robot interaction: Human intent and expectations in touching the haptic creature. *International Journal of Social Robotics*, 4(2), 163-180. doi:10.1007/s12369-011-0126-7
- Young, J. E., Hawkins, R., Sharlin, E., & Igarashi, T. (2009). Toward acceptable domestic robots: Applying insights from social psychology. *International Journal of Social Robotics*, 1(1), 95-108. doi:10.1007/s12369-008-0006-y

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Jamy Jue Li, Department of Human-Media Interaction, University of Twente, Enschede, Netherlands. Email: j.j.li@utwente.nl; Wendy Ju, Center for Design Research, Stanford University, Stanford, USA. Email: wendyju@stanford.edu; Byron Reeves, Department of Communication, Stanford University, Stanford, USA. Email: reeves@stanford.edu