Touching a Mechanical Body: Tactile Contact with Intimate Parts of a Humanoid Robot is Physiologically Arousing

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Abstract

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 human-robot interaction. Ten 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 the robot (e.g., buttocks and genitals) was more physiologically arousing than touching more accessible regions (e.g., hands and feet). No differences in physiological arousal were found when just pointing to those same anatomical regions. Social robots can elicit tactile responses in human physiology, a result that signals the power of robots, and should caution mechanical and interaction designers about positive and negative effects of human-robot interactions.

Keywords

Body Accessibility, Physiological Experiment, Human-Robot Interaction

Introduction

Robots represent a major new type of communicative media in which devices move in shared space with people in seemingly sentient ways. Understanding the social implications of this medium is critical to technology development and media theory. Advances in robotics enable devices with mobile, humanoid bodies to perform social roles at home, at work and in public spaces. 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" (U.N. and I.F.R.R, 2002, p. 11) could be beneficial, yet it is unclear how principles of interpersonal touch apply to social robots.

How will people respond to the introduction of three-dimensional, humanoid bodies that can be physically touched in public 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 to others. Does this concept of "body accessibility" apply to robots as well? An exploratory study assessed the physiological effects of touching different regions of a humanoid robot's body.

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 (examples are presented in Table 1). These include elderly individuals touching a robotic pet to feel empathy and connection (Robinson et al., 2013), 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, 2009). State-of-the-art social robots increasingly feature touch-sensors (such as (Mittendorfer, Yoshida, & Cheng, 2015)) and materials that look and feel like human skin (Ishiguro & Minato, 2005) and animal fur (Stiehl, Lalla, & Breazeal, 2004). 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). Indeed, in pilot studies with animal-shaped robots, touching the robot decreased people’s heart rate (Robinson, MacDonald, & Broadbent, 2015) and improved their evaluations of the robot (Lee, Jung, Kim, & Kim, 2006). In field studies, both adults (Becker-Asano, Ogawa, Nishio, & Ishiguro, 2010) and young children (Tanaka, Cicourel, & Movellan, 2007) willingly touch a robot’s hands, arms and head. More generally, a large literature finds people interact with robots in a social way and that robots can be designed which make use of this fact (Breazeal, 2003). It is unknown, however, what effect touching a humanoid robot has on human physiology, and hence on motivational responses important for attention, memory and behavior change.

(Table 1 about here)

Touch: The Sense of Social Intimacy

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 intimacy between individuals than communicating informational content. Touch is used as social “glue” – a means of developing and maintaining relationships. One way interpersonal touch does this is through evoking a variety of measurable changes in physiological arousal among people who are touching. 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, Whitehead, Morrill-Corbin, & Cataldo, 1985). Individuals who are briefly touched by an unfamiliar person in passing experience higher skin conductance (an indicator of psychological arousal; Vrana and Rollock, 1998). Socially anxious individuals experience increased skin conductance when touched by an experimenter (Wilhelm, Kochar, Roth, & Gross, 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, Schaefer, & Davidson, 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, Huang, & Keltner, 2010). Similarly, a habitual lack of touch can have negative side effects. Infants deprived of human touch, for example, exhibit poor development and depression (Spitz, 1945).

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.

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 perceive a robot as simply being a device that can be touched, we would expect no difference in response when touching one part of its body versus another, particularly if its body is of uniform texture and material. If people perceive a robot using a social lens, we would anticipate that touching low accessibility regions would elicit an emotional response associated with greater intimacy 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).

Current study

The present work evaluates whether touching a small, human-like robot affects human physiology. We hypothesize that if it does, 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. Touch behavior is evaluated empirically using a novel design in which participants either moved their dominant hand to touch or point to a region of the robot's body.

Method

Participants. Ten right-handed students (4 female, 6 male) enrolled in an undergraduate communication class at Stanford University participated in a randomized fully crossed experiment where they touched a small humanoid robot. They received course credit for the study, which was approved by the Human Subjects Research Board at Stanford University.

Design. A 2 (*interaction condition*: touching vs. pointing) x 13 (*anatomical region*: repetitions) 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 Appendix A. The topic of anatomical terminology (the technical terms used by anatomists and scientists when referring to different anatomical locations) was selected to provide 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. Trials were delivered in random order, although the order was the same for all participants.

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 Figure 1). An Affectiva Q-Sensor was placed on the fingers of the participant's non-dominant hand to measure skin conductance, a measure of physiological arousal. The robot then 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 would issue a request to either touch or point at its body part (e.g., "Please touch my eye.") using synthesized speech and lights to indicate speech activity; no movement was used. 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 Figure 1. A researcher viewing the session through an occluded window 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 data stream in real-time. The experiment lasted approximately 20 minutes.

(Figure 1 about here)

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.

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.

Data analysis. Anatomical regions were categorized by their body accessibility rating ("bar") into high, medium and low tertiles according to how frequently that region is touched in interpersonal communication (based on Jourard, 1966). Skin conductance data were aggregated at one sample per second. Physiological arousal was defined as the change in skin conductance from the prompt stage to the action stage. Response time was defined as the time difference between these two stages. For the analysis of physiological arousal, one outlier among a total of 260 trials was 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.

Results

In a learning activity where participants either touched or pointed to different anatomical regions of a robot, physiological arousal was higher when people touched low-accessible areas compared to high-accessible areas, but not when they pointed to those areas. Repeated-measures ANOVA conducted in R[1] revealed a significant body accessibility × condition interaction (Figure 2), $F(2, 18) = 4.42$, $p = 0.027$, $\eta^2 = 0.33$: 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. Nine of ten participants had higher arousal for low accessibility compared to high accessibility regions, illustrated in Figure 3. Both main effects of interaction condition and body accessibility were also significant, $F(1,9) = 10.91$, $p = .009$, $\eta^2 = 0.55$ and $F(2,18) = 8.44$, $p = .003$, $\eta^2 = 0.48$, respectively.

(Figure 2 about here)

(Figure 3 about here)

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 who touched low-accessible but not high-accessible areas. Repeated-measures ANOVA[2] showed a marginally significant body accessibility × condition interaction (Figure 4), $F(2,18) = 3.25$, $p = 0.062$, $\eta^2 =$

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[1] Modeled according to (Larson-Hall, 2015, p. 239) as: EDA_change ~ bar * condition + Error(participant / (bar * condition))

[2] Modeled as: response_time ~ bar * condition + Error(participant / (bar * condition))

0.27: participants took longer to touch regions with low accessibility compared to high accessibility, but not to point at those regions. Eight of ten participants had longer response times for low accessibility compared to high accessibility regions, illustrated in Figure 5. The main effect of body accessibility was also significant, $F(2,18) = 5.70$, $p = 0.012$, $\eta^2 = 0.39$.

(Figure 4 about here)

(Figure 5 about here)

Discussion

Robots that respond to touch have been in development for over a decade. The finding that tactile sensation with a robot affects human physiology lends merit to the idea that robots can elicit powerful social responses from people. These responses arise from an inherent tendency for people to treat media that are “close enough” to being human like real people (Reeves & Nass, 1996). These responses are not simply an act of playing along – they occur on a deeper physiological level. People are not inherently built to differentiate between technology and humans. Consequently, primitive responses in human physiology to cues like movement, language and social intent can be elicited by robots just as they would by real people.

This has implications for both robot design and theory of artificial systems. Human-robot collaboration, in which people work alongside robots, could be aided by brief social touch. Robots that perform social roles such as emotional companionship could appear more persuasive and friendly with occasional, mutual touch. Future teleoperation robots could serve as mobile “avatars” of real people that are capable of receiving touch from coworkers or family members. Regardless of whether you feel happy or horrified at the prospect of your spouse, for example, touching your robot stand-in, new robotic media enable this type of interaction. Perhaps most important, responses to physical contact with a robot can be reliably measured in human physiology. In practice, most people will not touch humanoid robots in regions that have low accessibility, with the possible exception of robots designed for romantic or sexual companionship. Nevertheless, human-robot touch as an interaction mode may be more important than previously thought.

Why is touching body parts of a robot physiologically arousing? This work did not explicitly interrogate the reasons for increased physiological arousal when touching, but we can speculate on some possibilities here. The physical bodies of robots and the autonomous movement of those bodies in space can intensify the perception that the robot has a lifelike body. Sensations on the skin during touch also reinforce the perception that the robot's body is its own. A robot with a human shape may therefore prompt people to adhere to social norms that are associated with interpersonal relationships, such as body accessibility, despite the fact that the robot does not have highly articulated body parts and is clearly not a human. When asked to touch the buttocks or genitals of a robot, people could feel discomfort toward the social context of touching the robot (more so than pointing to the robot), toward the increased intimacy associated with such an act, toward the robot's request to be touched or toward the actual physical sensation of touching the robot. The body of the robot used in this study had a relatively uniform plastic covering for its body, so there was little textural or temperature difference between different parts of the robot. Thus, we would expect a change in physiological arousal to be present for all instances of touch if it were due to physical sensation alone; in fact, physiological response was only higher for body parts with low accessibility.

In terms of societal implications, the result that touching a robot is a powerfully arousing action shows that – at least in theory – intimate relationships with robots are possible. According to the arousal model of intimacy, increases in relationship intimacy are reflected through changes in arousal. Since touching a robot does in fact create changes in arousal, this work provides physiological evidence that touching a robot increases intimacy between a person and a robot. The application of this finding could mean that “intimacy” or “sex” robots that have been forecasted by pundits (e.g., Levy, 2009) and academic scholars (e.g., Young et al., 2009) alike could be particularly potent. Given the well-documented presence of sexual themes in video games, movies and virtual worlds (e.g., Ivory, 2006), robots could eventually be used as a means of sexual 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. Such use, however, raises important societal questions about sex roles, gender equality, robot ethics and human social connection that are beyond the scope of this work. Our work only demonstrates that human relations with artificial bodies follow social conventions that can be both designed for and violated.

An additional limitation to our work is that we chose a task in which the robot played the role of a teacher in an educational activity. It would be interesting to evaluate how different social roles for a robot (such as conversational partner) or different social contexts influence responses to touch. 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, Jones, & Brinkman, 1995). Finally, we conducted the experiment using only a single robot, which resembled a child or toy in its size and voice. We would anticipate that these results would be transferable to similar robot platforms that are small and human-shaped but not necessarily to robots that more closely resemble people (e.g., have a gender, hair and human-colored skin) or that are not human-shaped (e.g., are shaped like a car).

Conclusion

Tactile contact with a robot elicited changes in human physiology in a study of ten participants who each touched thirteen different body parts on a human-shaped robot. Physiological arousal was higher when participants touched the robot on inaccessible parts of its body compared to when they touched accessible parts. In the future, robots with human forms may assist us in personal and public spaces. While they are clearly not human, social conventions such as body accessibility may apply to robots as well. Touching robots is therefore a powerful mode of interaction.

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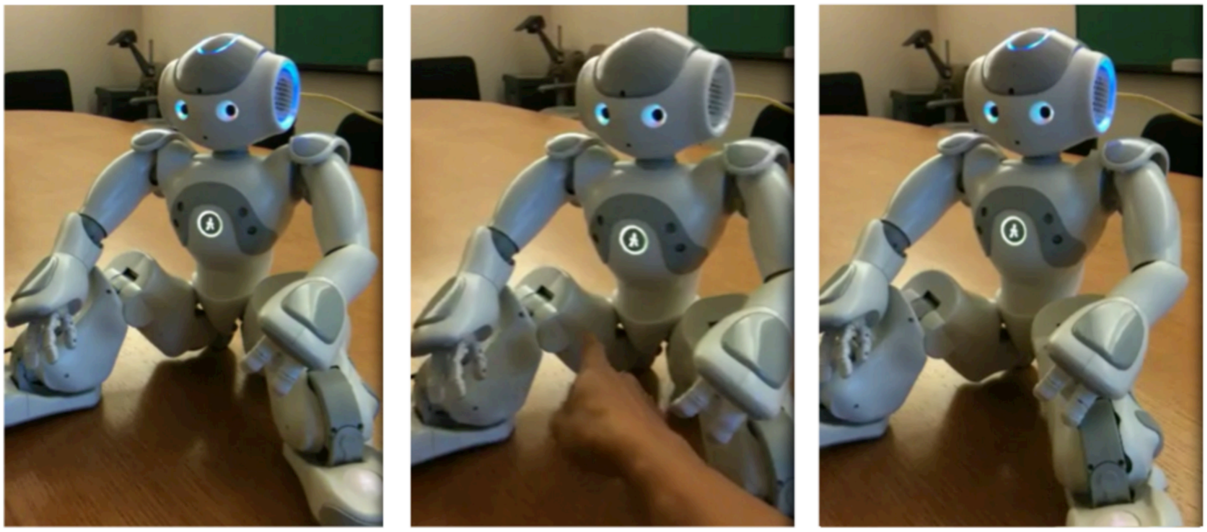
Figure 1: Participant's first-person view of the robot during a single trial of an interactive lesson on anatomical regions of the body.



A) Robot prompts participant: "Please touch my thigh."

B) Participant touches robot.

C) Robot responds to participant's touch: "This is the thigh. It is referred to as the femoral region." [robot moves thigh]

Figure 2: Horizontal bar plot of the effect of touch on skin conductance by body accessibility rating. Physiological arousal was higher for touching (dotted lines) but not pointing (solid 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.

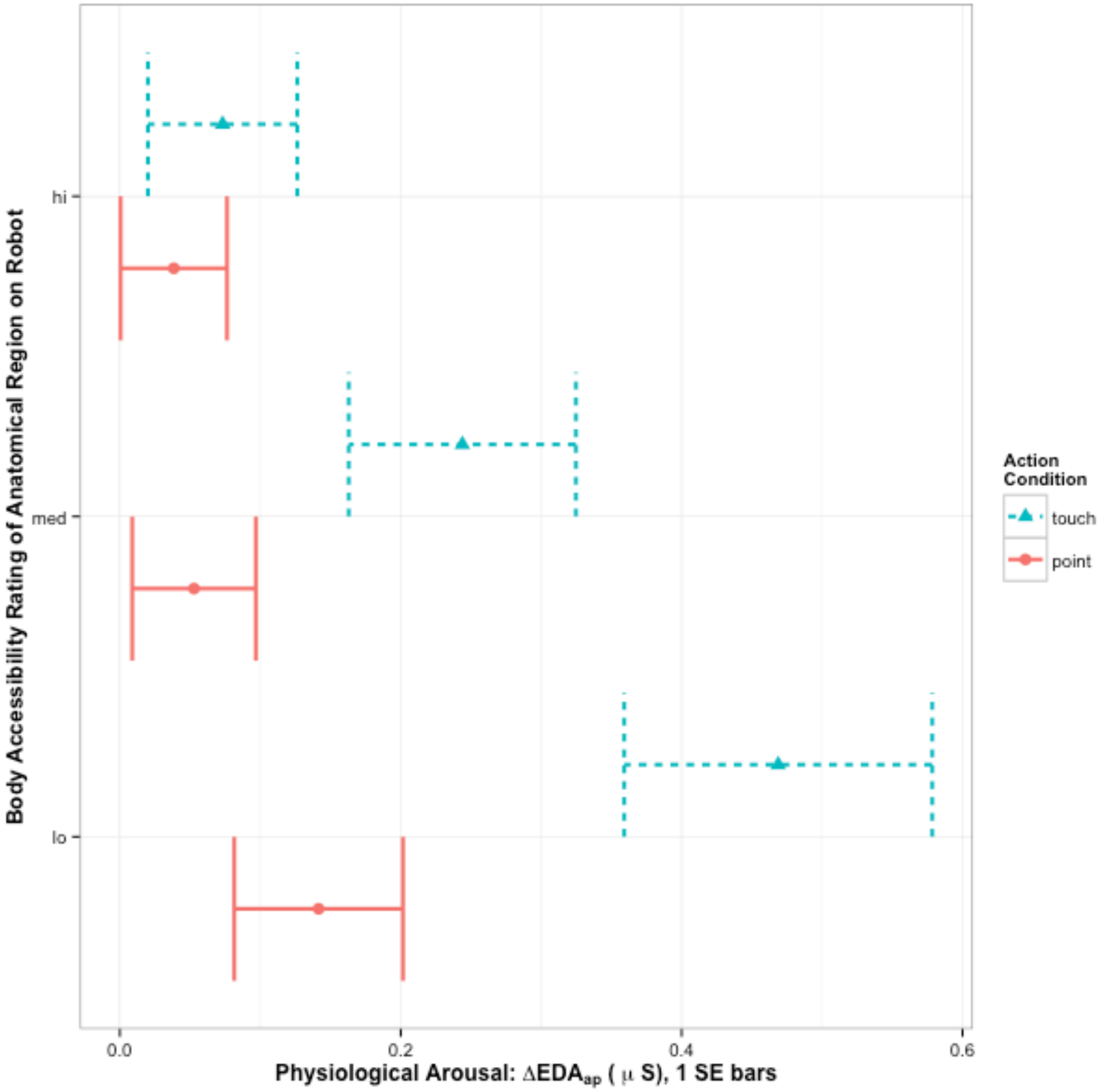


Figure 3: Horizontal bar plot of the effect of body accessibility on skin conductance by participant. Physiological arousal was higher for body parts with low accessibility (red lines) compared to high accessibility (blue lines) for nine of ten participants. Each point is the mean of all trials in that grouping. Error bars show variability across body parts in SEs.

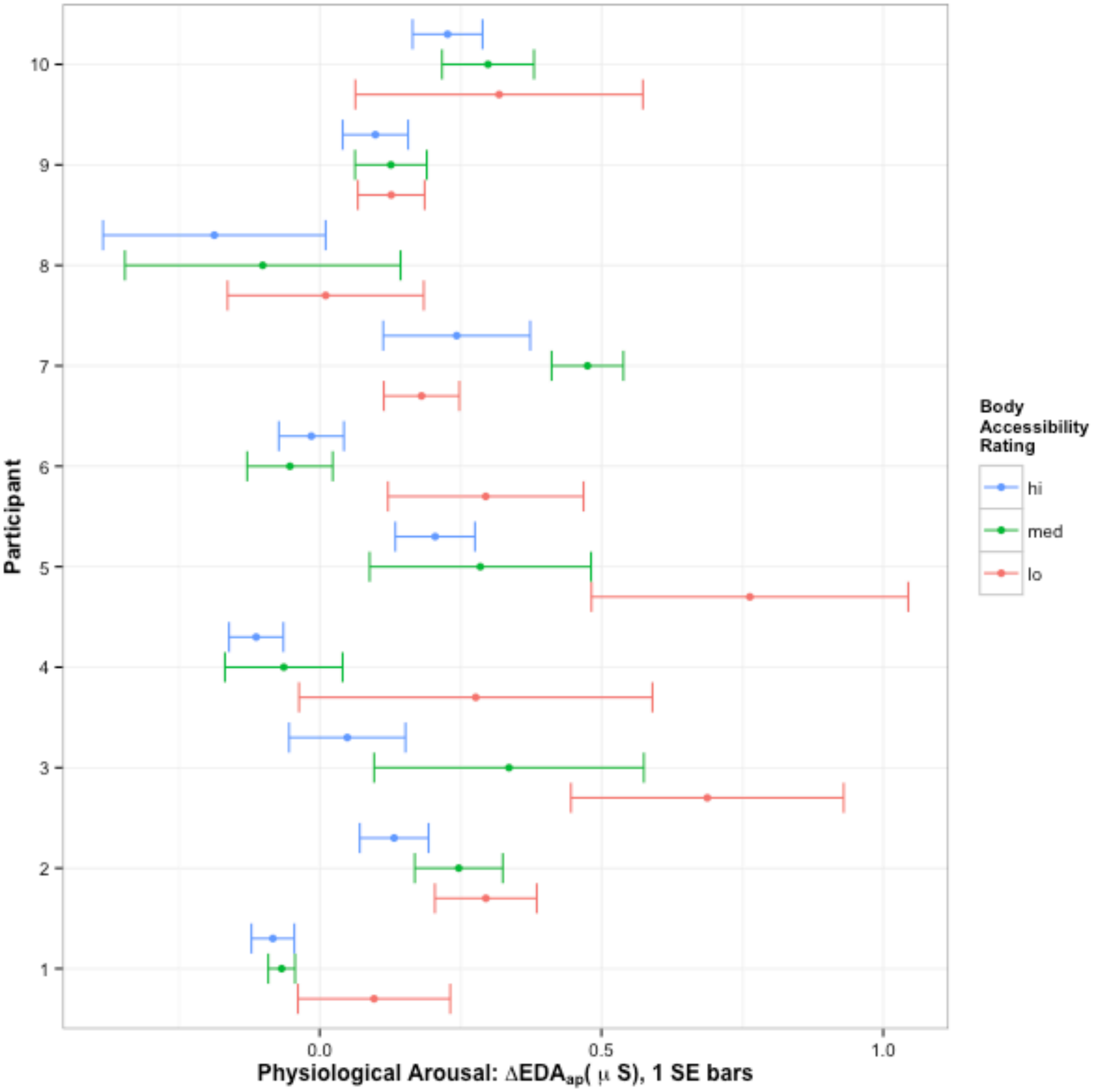


Figure 4: Horizontal bar plot of the effect of touch on response time by body accessibility. Response time was longer for touching (dotted lines) but not pointing (solid lines) at robot body parts with low compared to high accessibility. Each point is the mean of all trials in that grouping. Error bars show variability across participants in SE.

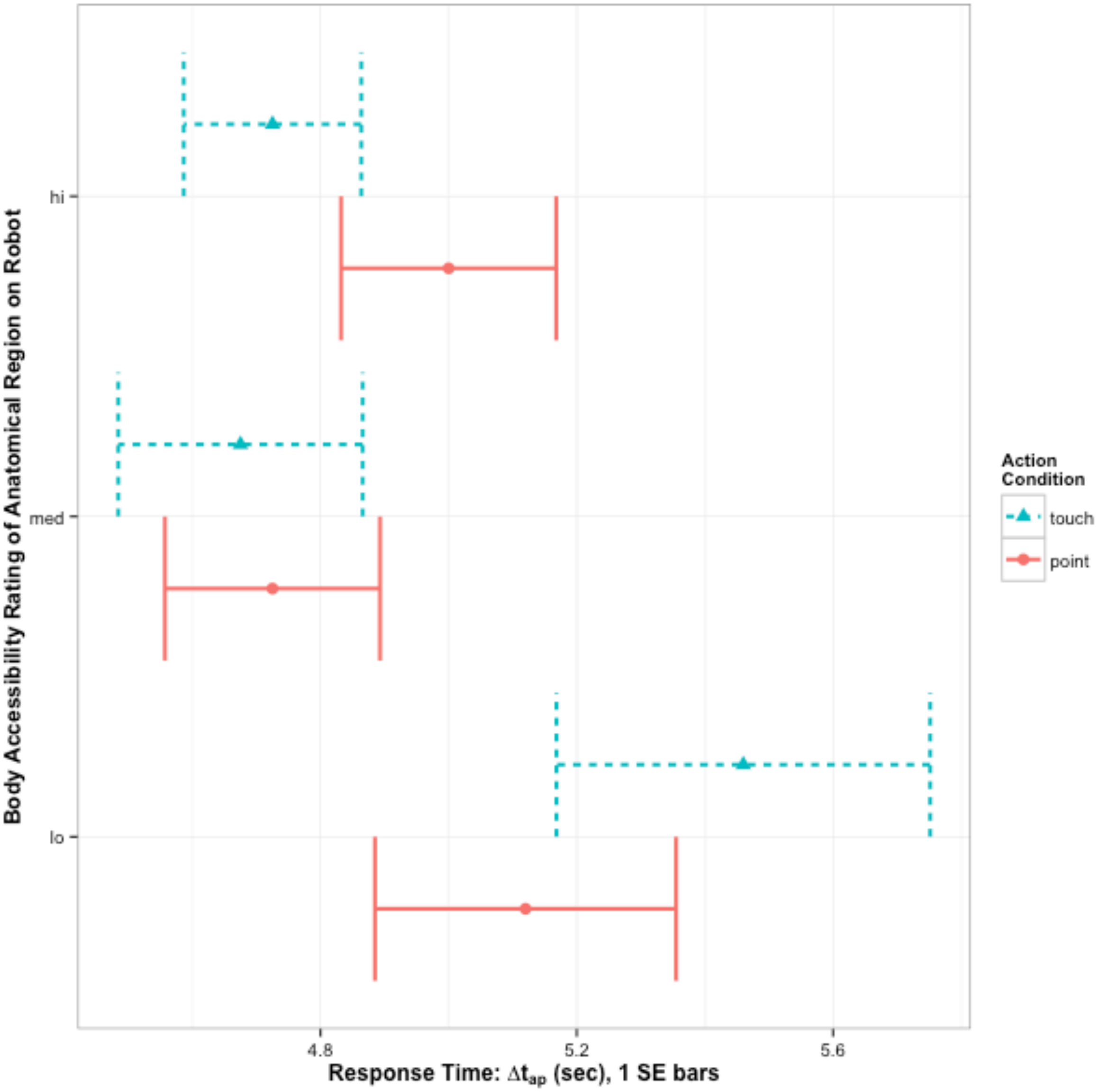


Figure 5: Horizontal bar plot of the effect of body accessibility on response time by participant. Response time was longer for body parts with low accessibility (red lines) compared to high accessibility (blue lines) for eight of ten participants. Each point is the mean of all trials in that grouping. Error bars show variability across body parts in SEs.

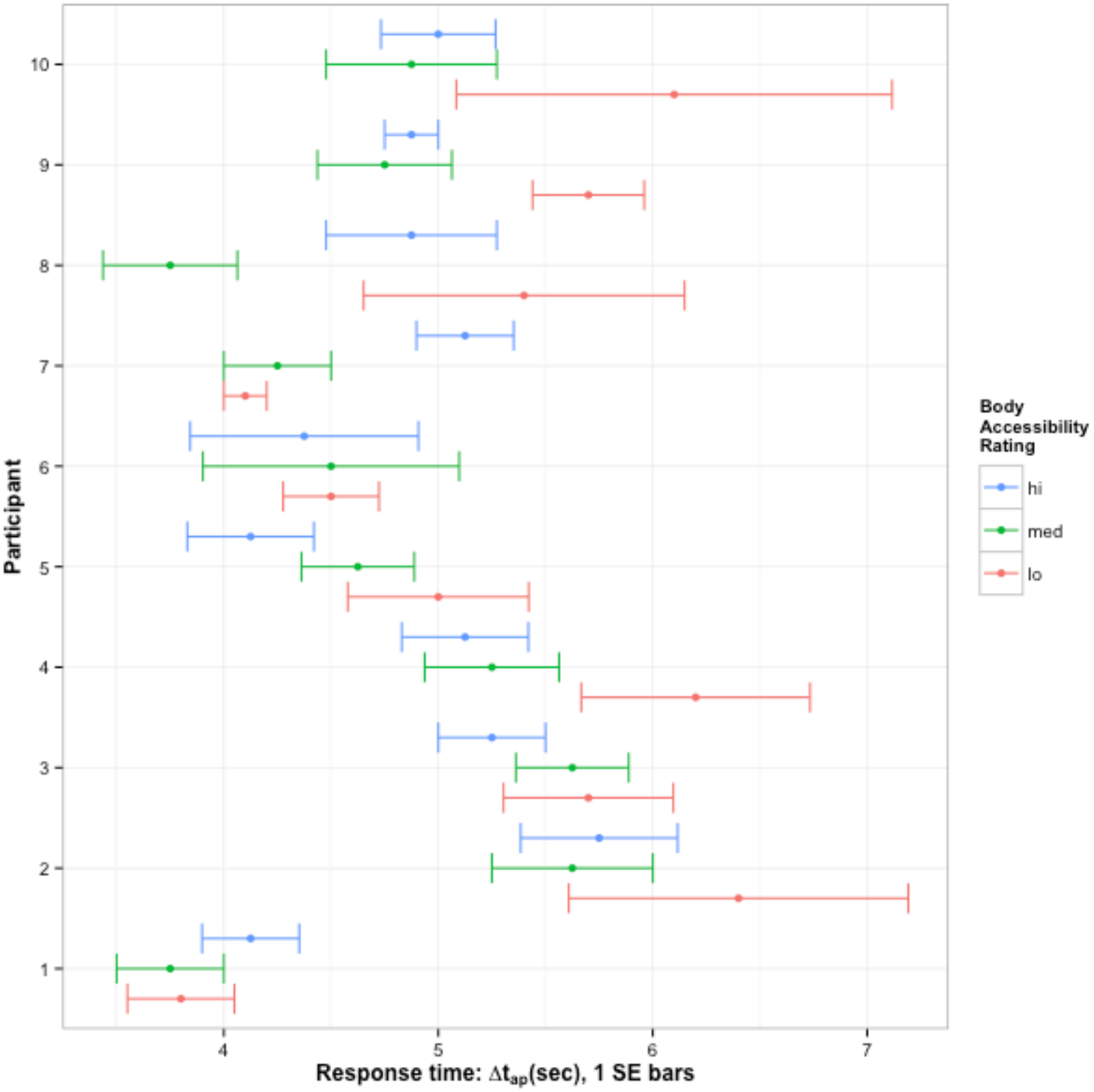


Table 1: Proposed applications of personal robots that involve physical contact.

Domain	Application or role of robot	Platform	Touch Use	Study results (if available)	Citation; More information
Medical care - general	Patient transfer from floor to chair	RIBA human-size robot	Pressure applied to robot's forearm to control movement	Force touch is more suitable than length of sliding touch for input	(Mukai et al., 2010); rtc.nagoya.riken.jp
	Emotional companion for general audience / Express emotions to user	Haptic creature	Hugging, other pet-related touch	Back was most touched location; rump was least touched	(Yohanan & MacLean, 2012)
Medical care - elderly	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); www.parorobots.com
Medical care - children	Emotional companion for hospitalized children / Comfort user	Probo animal robot	Touch trunk		(Saldien, Goris, Vanderborght, & Lefeber, 2008)
	Emotional companion for hospitalized children / Comfort user; capture data for nurses to view	Huggable 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); www.geminoid.jp
Telecommunication	Social communication avatar for operator to communicate with children; communication how child is touching the robot to the operator	Huggable teddy bear robot	Hugging and other touches from children		(Stiehl et al., 2006)
Technical service	Provide technical help	WowWee RoboSapien	Mutual tapping,	Touch decreased	(Cramer, Kemper, Amin, & Evers, 2009);

		human-shaped robot *	hugging, high-fiving (robot-initiated or user-initiated)	perceived dependability for a passive robot	wowwee.com/robosapien-blue
Entertainment	Sing and dance	Sony AIBO dog robot	Head, chin and back	Touching a robot improves affective evaluation	(Lee et al., 2006); sony-aibo.com
Early childhood education	Dancing and playing with children	Sony QRIO human-shaped robot	Touching hand, arm, head torso or legs; Hugging robot	Hands and arms touched more than head, torso and legs; Animate robot was touched more than an inanimate robot	(Tanaka et al., 2007)

* Commercially available robot at time of writing

Appendix A: Means and standard deviations for anatomical region data.

Anatomical region	Percentage of people reporting touching or being touched by another (Jourard, 1966) †	Average change in physiological arousal for touching a robot (this study) ‡	Average change in physiological arousal for pointing to a robot (this study) ‡	Body accessibility rating (this study)
Hand	84.9	0.01 (0.19)	0.00 (0.27)	High
Arm	76.5	-0.04 (0.41)	-0.02(0.22)	High
Forehead	68.5	0.17 (0.38)	0.12 (0.27)	High
Neck	57.8	0.15 (0.32)	0.06 (0.21)	High
Back	56.3	0.03 (0.72)	0.12 (0.22)	Medium
Ear	48.8	0.43 (0.37)	0.09 (0.30)	Medium
Eye	42.3	0.39 (0.54)	0.05 (0.28)	Medium
Foot	36.9	0.11 (0.23)	-0.04 (0.32)	Medium
Inner Thigh	31.3	0.09 (0.44)	0.20 (0.52)	Low
Breast	30.6	0.37 (0.33)	-0.04 (0.34)	Low
Heart	30.6	-0.02 (0.40)	0.20 (0.31)	Low
Buttocks	23.6	0.63 (0.85)	0.01 (0.23)	Low
Genitals	13.8	1.23 (0.98)	0.34 (0.58)	Low

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

‡ For reference, the increase in skin conductance for solving mental math problems is approximately 1 μS (Lacey, 1963; c.f., Dawson et al., 2007); the increase due to being fully wakened after induced sleep is approximately 4 μS (Storm et al., 2002).