Touched By a Robot: An Investigation of Subjective Responses to Robot-initiated Touch

Tiffany L. Chen
Georgia Tech
tiffany.chen@gatech.edu

Chih-Hung King
Georgia Tech
aaking@hsi.gatech.edu

Andrea L. Thomaz
Georgia Tech
athomaz@cc.gatech.edu

Charles C. Kemp
Georgia Tech
charlie.kemp@bme.gatech.edu

ABSTRACT

By initiating physical contact with people, robots can be more useful. For example, a robotic caregiver might make contact to provide physical assistance or facilitate communication. So as to better understand how people respond to robot-initiated touch, we conducted a 2x2 between-subjects experiment with 56 people in which a robotic nurse autonomously touched and wiped the subject's forearm. Our independent variables were whether or not the robot verbally *warned* the person before contact, and whether the robot verbally indicated that the touch was intended to clean the person's skin (*instrumental touch*) or to provide comfort (*affective touch*). On average, regardless of the treatment, participants had a generally positive subjective response. However, with instrumental touch people responded significantly more favorably. Since the physical behavior of the robot was the same for all trials, our results demonstrate that the perceived intent of the robot can significantly influence a person's subjective response to robot-initiated touch. Our results suggest that roboticists should consider this factor in addition to the mechanics of physical interaction. Unexpectedly, we found that participants tended to respond more favorably without a verbal warning. Although inconclusive, our results suggest that verbal warnings prior to contact should be carefully designed, if used at all.

Categories and Subject Descriptors

J.3 [**Life and Medical Sciences**]: Health; J.4 [**Social and Behavioral Sciences**]: Psychology

General Terms

Human Factors, Experimentation

Keywords

Human-Robot Interaction; Haptics; Healthcare

Figure 1: The robot Cody touches a subject during our experiment.

1. INTRODUCTION

Humans initiate contact with one another to achieve a variety of goals, such as facilitating communication and providing physical assistance. Robots have the potential to achieve similar goals by initiating physical contact with people, but this type of interaction is fraught with both physical and psychological implications. For example, human skin is an especially important channel for social communication [14], and robot-initiated contact implies that the robot will enter into the person's intimate space [7].

While substantial research has studied how robots can safely operate around people and handle unintended collisions [6], little is known about how a person will subjectively respond when a robot intentionally makes contact with the person's body. This type of interaction is especially relevant to healthcare, since caregiving frequently requires that the caregiver initiate contact with the care receiver's body. For example, studies of nurse-patient interactions have observed that nurses frequently initiate contact with patients, both to perform tasks that require contact, such as cleaning a person's skin, and to communicate with patients, such as when providing emotional support [4].

So as to better understand how people respond to robot-initiated touch, we designed and conducted a 2x2 between-subjects experiment with 56 people (14 people per treatment) in which a robotic nurse autonomously reached out, touched the participant's arm, moved across their arm, and then retracted. Depending on the treatment, the robot verbally indicated before the physical interaction (*warning*) or after (*no warning*) that it was performing this action to clean the participant's arm (*instrumental touch*) or to provide comfort (*affective touch*). In order to assess participants' subjective responses, we administered post-task questionnaires, including the Self-Assessment Manikin (SAM), the Positive and Negative Affect Schedule (PANAS), and a number of Likert-scale questions related to their experience.

In agreement with our first hypothesis, we found that participants responded more favorably to the *instrumental touch* than to the *affective touch* conditions. Nonetheless, even with the *affective touch* conditions, participants let the robot touch them again. Since the physical behavior of the robot was the same for all trials, our results also demonstrate that the perceived intent of robot-initiated touch can significantly influence a person's subjective response. As such, our results suggest that roboticists should consider this factor in addition to the mechanics of physical interaction.

In contradiction to our second hypothesis, we found that participants tended to respond more favorably to *no warning* than to *warning* conditions. This result is inconclusive and merits further investigation. It suggests that verbal warnings prior to contact should be carefully designed, if used at all.

2. RELATED WORK

Within this section, we review related literature from studies of nurse-patient interactions and human-robot interaction (HRI).

2.1 Nurse-Patient Interaction

Nurse-patient interaction serves as an important source of inspiration for our experiment. It both serves as a motivating application for robots that initiate touch, and as a well-studied example of the role of touch in human-human interaction.

Caris-Verhallen et al. observed two types of touch between nurses and patients that they defined as follows: *instrumental touch*, which is "deliberate physical contact" that is necessary in performing a task such as wound dressing; and *affective touch*, which is "relatively spontaneous" and "not necessary for the completion of a task" [4]. In an accompanying study of 165 nurse-patient interactions, researchers observed affective touch in 42% of the interactions and instrumental touch in 78% of the interactions [4]. McCann and McKenna report on observations of touching interactions between nurses and older adults in hospice [13]. Most of the observed nurse-initiated touches were on the extremities (arm, hand, leg, foot), and most touches (95.3%) were instrumental. Touches from nurses on the face, leg, and shoulders were perceived as uncomfortable by patients. Only instrumental touches on the shoulder and arm by a nurse were viewed as comfortable. The authors suggest that misinterpretation of a nurse's intention may have contributed to patient discomfort during some touches.

In our experiment, we make the same distinction between instrumental and affective touch. By using a robot, we have the distinct advantage of being able to control the physical interaction, and thereby investigate the role of perceived intent through a controlled-laboratory experiment.

2.2 Human-Robot Touch

We classify haptic interactions between a human and a robot into three categories: robot-initiated touch, human-initiated touch, and cooperative touch. We define robot-initiated touch as a haptic interaction that the robot initiates by making physical contact with the human. Similarly, we define human-initiated touch as a haptic interaction that the human initiates by making physical contact with the robot. We also assume that the initiator of contact plays an active role during the interaction episode, while the other entity plays a primarily passive role. We define cooperative touch as being a haptic interaction for which the initiator, or the active and passive roles, are ambiguous or unmatched.

Shaking hands [17] is an example of cooperative touch, since both the human and robot can actively move toward each other and shaking is cooperative. When people pet robots, such as Paro [8], it is an example of human-initiated touch, since the person actively moves toward a robot and makes physical contact with the robot's body.

Within this paper we focus on robot-initiated touch. Various robotic systems for healthcare involve robot-initiated touch, including facial massage [11], skin care [18], patient transfer [15], surgery [10], and hygiene [9].

There has been some prior work on studying people's responses to robot-initiated touch. For example, Bickmore has studied users' perceptions of and responses to affective touch performed by a virtual agent. The virtual agent included a robotic component capable of pneumatically applying pressure to the user's hand. The user placed his hand in the robotic device and held it there. The pressure was initiated by the virtual character to help convey empathy and comfort [2]. There has also been a video study that looked at the effect of robot touch on people's perceptions of a small humanoid robot's machine-likeness and dependability [5]. However, there is a dearth of research on people's responses when a robot touches them in both an instrumental and affective manner, or when a robot actively moves toward them in order to make contact. We are also unaware of previous research that has directly investigated how the perceived intent of a robot influences a human's subjective response to robot-initiated touch. Furthermore, there has been little work on determining cues robots can use to improve subjective responses to robot-initiated touch.

3. IMPLEMENTATION

In this section, we describe the robot we used in our experiment and the algorithm for the robot to safely make physical contact with a human participant's arm.

3.1 The Robot

The robot Cody, shown in Figure 1,[1] is a statically stable mobile manipulator. The components of the robot follow: two arms from MEKA Robotics (MEKA A1), a Segway omnidirectional base (RMP 50 Omni), and a 1 degree-of-freedom (DoF) Festo linear actuator. The arms are anthropomorphic with series elastic actuators (SEAs) at each of their 7 joints, which enables low-stiffness actuation. The robot's wrists are equipped with 6-axis force/torque sensors (ATI Mini40). For this study, we used a custom 3D-printed, spatula-like end effector (7.8 cm x 12.5 cm) which resembles an extended human hand [9]. We cut a towel to fit the shape of the end effector and attached it to the bottom of the end effector. In our experiments, this towel makes contact with

[1]We obtained IRB approval and participant permission for all of the photos in this paper.

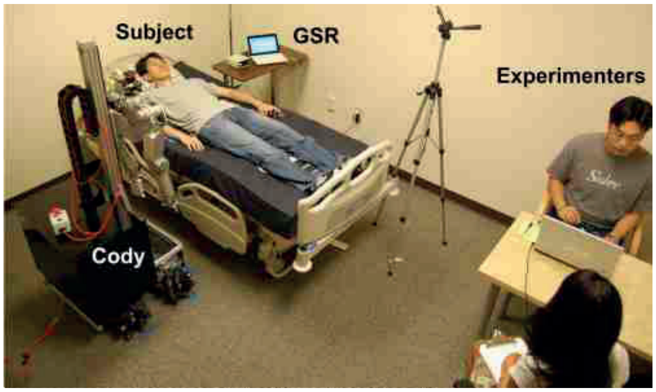

Figure 2: Experimental setup with a lab member in the patient bed. The two experimenters are shown seated in the bottom-right corner of the image.

the participants' forearms. The towel's material can be interpreted as a cleaning surface and a compliant exterior for the robot's end effector.

3.2 Touching behavior implementation

For implementation details of the touching behavior, please refer to our previous work [9]. For this paper, we attempted to make the touching behavior consistent with both cleaning a person's forearm and providing comfort, so that there would be ambiguity about the purpose of the behavior. When the robot is in its standby position, its arms and end effectors are pointing down toward the floor. The touching behavior begins by executing what we refer to as the "*Initial*" action. During this action, the robot uses a preprogrammed joint trajectory that moves the left arm to a position where the end effector is 15.4 cm above the mattress surface and directly above the participant's forearm. The robot then immediately moves its end effector downward until the force sensor on the wrist measures a force magnitude ≥ 2 N, indicating the end effector has made contact with the arm. We designed the arm trajectory so that the "*Initial*" action completed within approximately 7 seconds when tested on a lab member's arm. During the experiment, we recorded the time it took for the robot to perform the "*Initial*" action. The overall mean time for the robot to complete the action across all participants was 6.91 seconds (SD=0.10 sec).

After making contact, the robot performs what we refer to as the "*Along*" action. During this action, the arm moves the Cartesian equilibrium point (CEP) of the end effector at approximately 4 cm/s. We designed the CEP to travel 14 cm to the left, and then 14 cm to the right along the participant's arm. A bang-bang controller attempts to keep the force magnitude measured by the force sensor on the wrist between 1 and 3 N. As a safety precaution, the robot terminates the touching behavior if the force magnitude exceeds 30 N. During the "*Along*" action, the robot exerted an overall mean force magnitude of 2.44 N (SD=0.18N), where we computed the mean across all participants. We also designed this trajectory to complete within approximately 7 seconds. The overall mean time of the "*Along*" action across all participants was 6.92 seconds (SD=0.02 sec), and the mean distance the end effector traveled to the left and right was 13.71 cm (SD=0.07 cm) and 13.61 cm (SD= 0.02 cm), respectively.

To complete the touching behavior, the robot performs what we refer to as the "*Away*" action. During this action, the robot lifts its end effector upward, so that it moves away from the person's forearm. The robot then moves its arm back to the standby position. We designed this action to take approximately 7 seconds. The overall mean time for the robot to complete this action across all participants was 6.83 seconds (SD=0.08 sec).

3.3 Safety

Ensuring the safety of a person while interacting with a robot is important during any human-robot interaction scenario. Studies in which a robot makes physical contact with a human require special care. We took several precautions when designing the robot's behavior and conducting the study to reduce the chance of injury. First, during the study an experimenter was always prepared to operate a run-stop button if undesirable contact with the robot were observed or anticipated. Second, the robot's arm operated with low joint stiffness and low joint velocities. Third, the robot attempted to keep the magnitude of the force against the participant's arm lower than 3 N. For comparison, Tsumaki et al. reported that people experienced no pain when a skin care robot applied a downward force of 10 N [18]. Other researchers used a force magnitude threshold of 39.2 N with an oral rehabilitation robot [11]. Various factors could influence the force range that a person would find comfortable, including the contact surface over which the applied force is distributed, and the part of the person's body with which contact has been made. As such, we only note these values for qualitative comparison with the forces we used.

During the debriefing, participants generally reported that the force the robot applied was comfortable. No participants indicated any pain or discomfort during the interaction.

4. METHODOLOGY

4.1 Experimental Design

		Warning Type	
		Warning	*No Warning*
Touch Type	*Instrumental*	7 men, 7 women	7 men, 7 women
	Affective	7 men, 7 women	7 men, 7 women

Figure 3: Experimental design.

We conducted a gender-balanced, 2x2 between-subjects experiment (see Figure 3). We designed the experiment to investigate the following two hypotheses about people's subjective responses to robot-initiated touch:

- **Hypothesis 1**: Participants will find robot-initiated touch more favorable when it is perceived to be instrumental versus affective.
- **Hypothesis 2**: Participants will find robot-initiated touch more favorable when given a verbal warning prior to contact versus no verbal warning.

To test these hypotheses, we defined two independent variables: (1) the type of touch the robot executed (*instrumental*

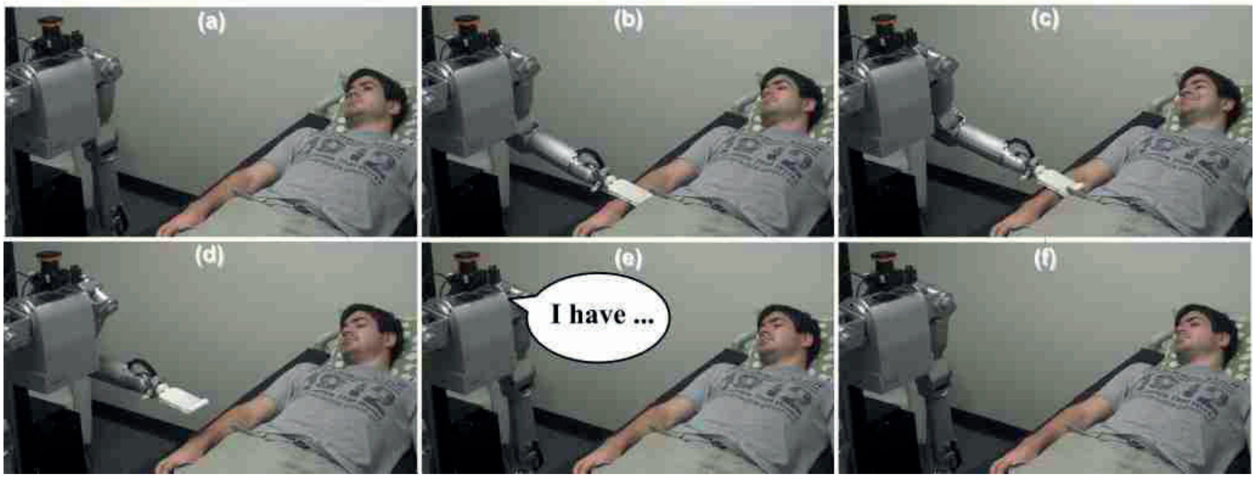

Figure 4: Cody touches a participant in the *instrumental, no warning* treatment. (a) Baseline. (b) *Initial* contact. (c) Moving *Along* the participant's arm. (d) Lifting *Away* from the participant. (e) The robot *Speak*s to the participant. (f) Baseline.

vs. *affective*) and (2) the warning condition (*warning* vs. *no warning*).

In each of the four treatment conditions, the robot executed the same touching behavior described in Section 3.2. The only change between the *instrumental* and *affective* treatment conditions was what the robot said to the participant. The robot used the following two utterances:

- *Instrumental utterance*: "I am going to rub your arm. I am going to clean you. The doctor will be with you shortly."

- *Affective utterance*: "Everything will be all right, you are doing well. The doctor will be with you shortly."

With this design, each participant experienced very similar physical interaction, but associated different intentions with this interaction, depending upon what the robot said. As we describe in detail in Section 4.3.3, we asked questions in order to exclude participants who did not interpret the robot's intentions correctly. We also controlled the length of time the robot spoke to be approximately 7 seconds for both conditions.

Warning	Baseline	Speak	Initial	Along	Away	Baseline
No Warning	Baseline	Initial	Along	Away	Speak	Baseline
	2 min	7 sec	7 sec	7 sec	7 sec	2 min

Figure 5: Timing for *warning* vs. *no warning*.

Similarly, between the *warning* and *no warning* treatment conditions we only changed when the robot made the utterances. For *warning*, the robot spoke before it touched the participant's arm. For *no warning*, the robot touched the participant's arm and spoke after the haptic interaction was over (i.e., once it was no longer in contact with the participant's body). We changed the grammatical construction of the utterances to be appropriate for these two cases. Figure 5 illustrates the ordering and timing of the robot's action and speech in the *warning* and *no warning* conditions.

Our experimental design ensures the following: (1) the same touching behavior is performed on each participant across all four treatment conditions; (2) the content of speech is the same for either of the warning conditions; (3) the length of time the robot speaks is controlled across all four treatment conditions; and (4) the interaction is plausible for a robotic nurse.

4.2 Procedure

We recruited 63 students from the Georgia Tech campus through various student email lists, flyers, and word of mouth. We required participants to be at least 18 years of age, a United States citizen, and to speak English as their native language. We excluded six participants because they did not correctly interpret the robot's intentions (see Section 4.3.3) and one participant due to a software malfunction while collecting his survey data. We assigned participants to each of the four treatment groups on a rolling basis, according to gender.

In total, we included the data from 56 of the participants (28 males and 28 females) in the analysis for this paper, ranging in age from 18-29 years (M=22.7, SD=2.7). The self-reported ethnicity of these participants was White (31), Asian (19), African American (2), Hispanic (2), Native Amer. / Pac. Islander (1), and Other (1). 87.5% of the participants were engineering students.

We performed our experiment in the Healthcare Robotics Lab in a 4.3m x 3.7m, climate-controlled simulated hospital room (see Figure 2). We placed a fully functional Hill-Rom 1000 patient bed, an I.V. pole, an overbed table, a living room chair, and a side table in the room. Participants filled out all paperwork and surveys within the simulated hospital room. We placed the robot 17 cm away from the edge of the patient bed. Two experimenters (the first and second authors of this paper) conducted all of the trials and remained in the room throughout the experiment to ensure the participant's safety. One experimenter proctored the experiment by reading a script. The participant was first welcomed to the lab and introduced to the experimenters. Then the participant was asked to sign a consent form, fill out a demographic survey, and fill out a pre-task questionnaire.

Afterward, the experimenter explained that the robot was capable of performing several different simulated nursing duties, and that the robot would mimic doing so by gesturing with its arms and end effectors. It is important to note that the participants were unaware that the robot would reach out and make contact with them. Then, the experimenter asked the participant to lay down on the patient bed, and if a female participant were wearing a skirt, we offered her a blanket to cover her legs. We then asked the participant to place his right arm between two lines of tape marked on the mattress and to place his elbow directly on top of a third line of tape on the mattress. This arm placement ensured that the robot would make contact with the person's forearm. If the participant were wearing a long-sleeve shirt or sweater, we asked him to roll up his sleeve past his elbow or to remove the sweater, if possible. We asked the participant to place his left arm on the mattress and affixed a galvanic skin response (GSR) sensor to his fingers. We collected one minute of baseline data from this sensor and then asked the participant to fill out a survey while laying on the bed (measures are detailed in Section 4.3).

We then asked the participant to keep his head facing a camera during the experiment. After which, we collected 2 additional minutes of baseline data, initiated the robot interaction (described in Section 4.1), and then collected another 2 minutes of baseline data. We then asked the participant to get off the bed and fill out the post-task questionnaire. Then, we performed a repeated trial of the same interaction they had just experienced. Note that, although each participant interacted with the robot twice, we only analyze the results from the first trial in this paper. Since all of the dependent measures we analyze in this paper were collected prior to the second trial, the part of the experiment we analyze is equivalent to a single trial study.

4.3 Measured Variables

We measured several variables both before and after the participant interacted with the robot by administering a pre- and post-task questionnaire, respectively. This paper represents our initial inquiry into this data and focuses on people's response to the interaction as a whole. As such, in this paper we do not analyze a variety of data that we collected including GSR data, video of the subjects, the results of surveys administered before the start of the experiment, and survey questions referring to specific times during the interaction, rather than the interaction as a whole. We leave this follow-up analysis as future work. In this section, we describe the measured variables we use in this paper.

4.3.1 Emotional State

We measured the emotional state of the participants using the Self-Assessment Manikin (SAM) and the Positive and Negative Affect Schedule (PANAS). SAM comprises three 9-point scales which measure arousal, valence, and dominance (also referred to as level of control) using pictorial representations of these dimensions as described in [3, 12]. The Positive and Negative Affect Schedule (PANAS) comprises two 10-word mood scales, where each word is measured on a 5-point scale [19]. Individually, the two scales measure Negative Affect (NA) and Positive Affect (PA), where the lowest possible individual NA or PA score is 10 and the highest is 50. Both SAM and PANAS have been used extensively in psychology and human-robot interaction research to measure emotional state [16, 1].

We adapted the text from [3] and [19] for the SAM and PANAS questionnaires we administered. We administered the SAM survey prefaced with the text, "Use these panels to rate your personal reaction OVERALL after the robot finished interacting with you:". Similarly, we administered the PANAS survey prefaced with the text, "Indicate to what extent you felt the following way OVERALL after the robot finished interacting with you:".

4.3.2 Custom Likert-scale Questionnaire

In addition to assessing the participants' emotional response, we asked general questions about their experience using 7-point Likert scale questions where 1 = "Strongly Disagree," 4 = "Neutral," and 7 = "Strongly Agree". We asked the following questions pertaining to our two hypotheses:

- LQ1 I was confused as to why the robot was touching my arm.
- LQ2 It was enjoyable when the robot was touching my arm.
- LQ3 I was scared when the robot was touching my arm.
- LQ4 I felt reassured when the robot was touching my arm.
- LQ5 It was necessary for the robot to touch my arm.
- LQ6 I would let the robot touch me again.
- LQ7 I would have preferred that the robot did not touch my arm.

The questionnaire included additional questions unrelated to these hypotheses. For completeness, these questions can be found in Figure 8.

4.3.3 Manipulation Check

We designed the first two questions of the post-task questionnaire to assess whether or not our manipulation was successful. Specifically, we asked these questions in order to exclude participants from our analysis who did not interpret the robot's intentions correctly. First, we asked the participant to write down what the robot said to determine if the person correctly heard the robot's speech. Second, we asked the participant to write down why the robot was touching his forearm to determine if the person correctly understood the robot's stated intention. If a participant did not pass these manipulation checks, we did not use his data in the analysis.

4.4 Expected Outcomes

Within this section, we describe the outcomes we would expect if our hypotheses were true.

4.4.1 Hypothesis 1: Instrumental vs. Affective Touch

Overall, we expect participants to have a stronger preference for the robot not to touch them if the touch were affective as opposed to instrumental (LQ7). This is based primarily on the nursing findings described in Sec. 2.1. We also expect participants to experience lower arousal, higher valence, and higher dominance when the robot performs an instrumental touch compared with when it performs an affective touch. Additionally, we expect participants to have higher feelings of positive affect and lower feelings of negative affect when the touch is instrumental. We expect that they would enjoy the touching interaction more (LQ2), feel that the touch is more necessary (LQ5), and would be more willing to let the robot touch them again when the touch is

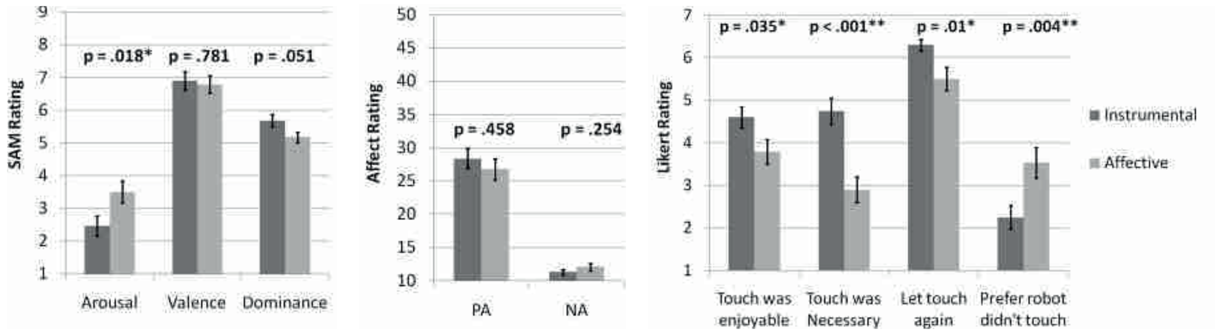

Figure 6: Main Effects of Touch Type: Participants' subjective responses according to SAM (left), PANAS (middle), and 7-point Likert scale questions (right). (p <.0055, *p <.05, Standard error bars shown)**

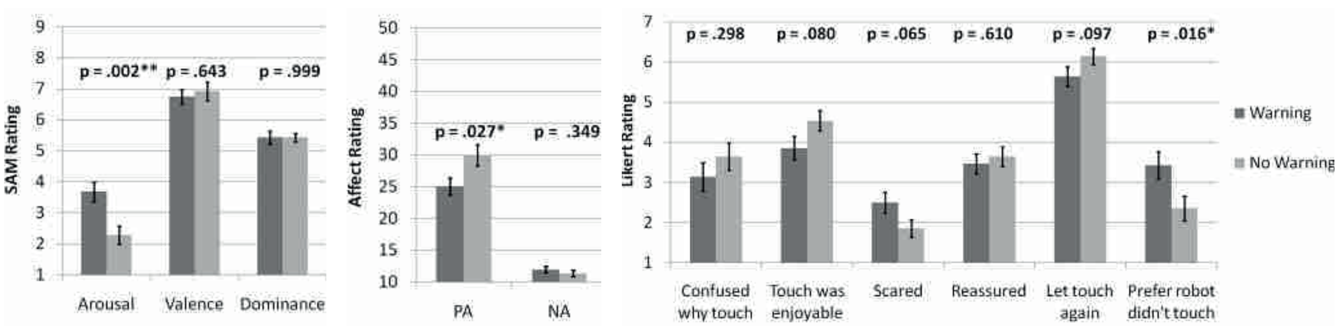

Figure 7: Main Effects of Warning Type: Participants' subjective responses according to SAM (left), PANAS (middle), and 7-point Likert scale questions (right). (p <.0045, *p <.05, Standard error bars shown)**

instrumental (LQ6). These expected outcomes correspond with 9 dependent measures.

4.4.2 Hypothesis 2: Warning vs. No Warning

We expect participants to experience lower arousal, higher valence, and higher dominance when they receive a warning from the robot before it touches them, compared with when the robot touches them before speaking. We also expect participants to have higher feelings of positive affect and lower feelings of negative affect when they receive a warning. We expect participants to enjoy the interaction more (LQ2), to be less scared (LQ3), to feel more reassured (LQ4), and to be more willing to let the robot touch them again (LQ6) with a warning. We also expect participants would be less confused as to why the robot was touching their arm (LQ1), and would be less inclined to prefer that the robot had not touched them (LQ7) with a warning. These expected outcomes correspond with 11 dependent measures.

5. RESULTS

We conducted a two-way, between-subjects analysis of variance (ANOVA) on the data and found no significant interactions between the independent variables of *touch type* and *warning type*. Thus, we will discuss the main effects of the independent variables.

Figure 6 shows the main effects of *touch type* on the 9 dependent measures relevant to Hypothesis 1. We denote dependent measures that were significant with α=.05 using (*). We denote dependent measures that were significant with the more conservative Bonferroni adjusted α=.0055 (.05/9) using (**). The Bonferroni correction reduces the risk of finding significance by chance due to the multiple dependent measures associated with Hypothesis 1 (i.e., Type I errors - false positives).

Similarly, Figure 7 shows the main effects of *warning type* on the 11 dependent measures relevant to Hypothesis 2. We denote dependent measures that were significant with α=.05 using (*). We denote measures that were significant with the more conservative Bonferroni adjusted α=.0045 (.05/11) using (**).

For completeness, Figure 8 shows the main effects for all other Likert-scale questions from the post-task questionnaire. There were no significant interactions between the independent variables for these responses. Furthermore, none of these measures were significant with α=.05.

5.1 Hypothesis 1

With respect to the expected outcomes discussed in Section 4.4.1, the results are consistent and in support of Hypothesis 1. All 9 dependent measures changed in the anticipated directions, although the changes associated with four of the dependent measures were not statistically significant.

Two dependent measures were significant with the Bonferroni corrected α=.0055. Most importantly, participants significantly preferred that the robot not touch them when the touch was affective ($F(1,52)=9.01$, $p=.004$). This clearly supports Hypothesis 1. Participants also felt that the instrumental touch was significantly more necessary than the affective touch ($F(1,52) = 18.29$, $p<.001$). Participants viewed the instrumental touch as slightly necessary with a mean score of 4.8, and viewed the affective touch as slightly unnecessary with a mean score of 2.9.

Three other dependent measures were only significant with α=.05. Participants were less aroused during the experiment when the robot performed an instrumental touch compared with when it performed an affective touch (F(1,52) = 5.92, p=.018). They also enjoyed the touch more (F(1,52) = 4.68, p=.035) and would be more willing to let the robot touch them again when the touch was instrumental as opposed to affective (F(1,52) = 7.05, p=.01). These results are also consistent with Hypothesis 1.

In addition, according to Figure 6, participants reported that on average they would let the robot touch them again, regardless of the touch type. Their average Likert scale responses were greater than a score of 5="Slightly Agree" across both types of touch. When asked whether they would prefer that the robot not touch them, participants similarly reported average Likert scale responses less than a score of 4="Neutral" across both types of touch. Thus, participants were generally open to allowing the robot to interact with them and touch them again, regardless of the type of touch. Moreover, although we do not report detailed results from the second trial, all 56 participants allowed the robot to touch them in the second trial.

5.2 Hypothesis 2

Surprisingly, with respect to the expected outcomes discussed in Section 4.4.2, the results support the contrary assertion that *no warning* results in more favorable subjective responses. 9 out of the 11 dependent measures relevant to Hypothesis 2 changed in the opposite direction from what we anticipated, although the changes associated with six of these dependent measures were not statistically significant. Only the mean confusion changed in the anticipated direction, since people tended to be more confused in the no warning case, albeit not significantly. The average dominance was identical for the *warning* and *no warning* conditions.

Only one dependent measure was significant with the Bonferroni corrected α=.0045. Participants were significantly more aroused when the robot warned them prior to contact (F(1,52) = 10.71, p=.002), which is in contradiction to Hypothesis 2.

Two other dependent measures were only significant with α=.05. Participants had a higher positive affect rating when the robot did *not* warn them (F(1,52) = 5.19, p=.027). When the robot warned them, subjects had a greater preference for the robot not to touch them (F(1,52) = 6.26, p=.016). These results are in opposition to Hypothesis 2.

6. DISCUSSION AND CONCLUSION

We have presented results from our study in which a human-scale robot using a compliant arm autonomously made contact with the forearms of 56 human participants without incident or reported discomfort. On average, regardless of the treatment, participants had a generally positive subjective experience as indicated by measures such as valence, positive affect, and negative affect, as well as Likert-scale questions about perceived safety, fear of the robot, and willingness to have the robot touch them again. In general, these results suggest that robot-initiated touch can be a successful form of human-robot interaction.

More specifically, in this study we investigated how two factors influence the subjective response of subjects to robot-initiated touch. We selected these factors based on their relevance to human-human interaction in the context of nursing. Our results suggest that when a human-scale robotic nurse initiates physical contact with a person's body, the person will tend to have a more favorable subjective response when the touch is perceived to be instrumental instead of affective. This matches results from studies that have observed interactions between human nurses and human patients. In our study, the robot touched a relatively innocuous location on the participant's body. We would anticipate a much stronger effect size if the robot were touching a more sensitive part of the body, such as during a full bed bath.

We believe an important general result from our study is that perceived intent can significantly influence a person's subjective response to robot-initiated touch. For all trials, the robot executed the same behavior, which resulted in consistent physical interaction with the participants. Significant variation in responses resulted not from differences in the physical interaction, but from the participants' perception of the robot's intent. This suggests that even if roboticists choose to focus on instrumental touch, they should carefully consider how people will interpret the robot's actions. Exploring ways to reinforce desired interpretations of robot-initiated touch could be a worthwhile direction for future research. This could potentially be even more important when working with particular user populations, such as older adults. In our study, we used the robot's speech, the actions of its arm, and the nursing scenario to convey intent. Many other contextual cues, both implicit and explicit, could plausibly be used to influence perceived intent.

We found that participants tended to respond more favorably when no verbal warning was given by the robot prior to contact. However, these results lack clear statistical significance. As such, our results with respect to verbal warnings prior to contact are suggestive, but inconclusive. The trends in our results, and the significance of some measures without Bonferroni correction, suggest that verbal warnings prior to contact should be carefully designed, if used at all.

In open-ended survey responses from our study, 11 of the 28 participants from the *no warning* treatment indicated that they would have liked the robot to warn them before it touched their arm. However, 3 of the 28 participants from the *warning* treatment noted that when the robot warned them, its voice startled them. One person specifically mentioned that the speech was surprising, since the robot had been silent, while another person noted that the robot's voice seemed very loud. Being startled by the robot's voice may have contributed to the participants' higher arousal ratings and our unexpected results. Interestingly, this may indicate that the robot's unexpected physical movement *and contact with the person* after a long period of stillness was less jarring than the robot's unexpected speech after a long period of silence. It seems likely that factors such as the velocity of the movement and the loudness of the speech would play a role in this type of interaction. Having the robot speak to the person ahead of time in a more natural manner, or otherwise reducing surprise, might lead to different results. Similarly, the slow motion of the robot's arm prior to touching the person may have reduced the surprise of contact.

One potential limitation of our experiment is that the utterances associated with the instrumental and affective touch conditions differ in their explicitness. The instrumen-

Likert-scale Question	Touch Type	Warning Type
The robot was easy to understand.	M_1=5.7 M_2=5.9 p=0.66	M_3=5.7 M_4=5.9 p=0.51
I was confused as to why the robot was touching my arm.	M_1=3.0 M_2=3.8 p=0.08	(in bar chart)
I was scared when the robot was touching my arm.	M_1=2.0 M_2=2.4 p=0.30	(in bar chart)
I felt reassured when the robot was touching my arm.	M_1=3.6 M_2=3.5 p=0.61	(in bar chart)
It was necessary for the robot to touch my arm.	(in bar chart)	M_3=3.9 M_4=3.8 p=0.87
The robot cares about me.	M_1=3.2 M_2=2.9 p=0.45	M_3=2.8 M_4=3.3 p=0.27
The robot was entertaining.	M_1=5.4 M_2=6.0 p=0.16	M_3=5.7 M_4=5.7 p=0.99
When I first saw the robot, I thought it would hurt when it touched me.	M_1=1.9 M_2=2.5 p=0.14	M_3=2.3 M_4=2.1 p=0.58
The robot looks very strong.	M_1=4.8 M_2=4.8 p=0.99	M_3=5.1 M_4=4.4 p=0.12
The robot looks friendly.	M_1=3.2 M_2=2.9 p=0.36	M_3=3.0 M_4=3.0 p=0.99
Interacting with the robot would be more enjoyable if it looked more human-like.	M_1=4.9 M_2=5.0 p=0.87	M_3=5.0 M_4=4.8 p=0.63

Mean Responses: M_1 = Instrumental Touch, M_2 = Affective Touch, M_3=Warning, M_4=No Warning

Figure 8: Main Effects of Touch Type and Warning Type on Likert-scale questions unrelated to Hypothesis 1 and Hypothesis 2.

tal touch utterance explicitly indicates that the robot will touch the person, while the affective touch utterance is more implicit, which conveys less information about the robot's impending action.

Further research will be required to determine the generality of our results. We carefully controlled factors such as the robot's appearance, the robot's motions, where contact was made on the person's body, and the person's posture. Any one of these or other factors, such as long-term interaction with the robot or the person's culture, could potentially have a significant influence on a person's subjective response. We look forward to investigating these and other factors in future research.

In conclusion, we believe that robot-initiated touch represents a distinct form of HRI with important real-world implications. Through our experiment, we have begun to investigate factors that influence this promising form of interaction. We hope that our results will be of benefit to both researchers and practitioners in this exciting new area.

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