Human-robot proxemics: Physical and psychological distancing in human-robot interaction

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2 authors:

Jonathan Mumm

Bilge Mutlu

University of Wisconsin–Madison

Human-Robot Proxemics: Physical and Psychological Distancing in Human-Robot Interaction

Jonathan Mumm
Department of Computer Sciences
University of Wisconsin–Madison
1210 W. Dayton St., Madison, WI 53706, USA
mumm@cs.wisc.edu

Bilge Mutlu
Department of Computer Sciences
University of Wisconsin–Madison
1210 W. Dayton St., Madison, WI 53706, USA
bilge@cs.wisc.edu

ABSTRACT
To seamlessly integrate into the human physical and social environment, robots must display appropriate proxemic behavior—that is, follow societal norms in establishing their physical and psychological distancing with people. Social-scientific theories suggest competing models of human proxemic behavior, but all conclude that individuals' proxemic behavior is shaped by the proxemic behavior of others and the individual's psychological closeness to them. The present study explores whether these models can also explain how people physically and psychologically distance themselves from robots and suggest guidelines for future design of proxemic behaviors for robots. In a controlled laboratory experiment, participants interacted with Wakamaru to perform two tasks that examined physical and psychological distancing of the participants. We manipulated the likeability (likeable/dislikeable) and gaze behavior (mutual gaze/averted gaze) of the robot. Our results on physical distancing showed that participants who disliked the robot compensated for the increase in the robot's gaze by maintaining a greater physical distance from the robot, while participants who liked the robot did not differ in their distancing from the robot across gaze conditions. The results on psychological distancing suggest that those who disliked the robot also disclosed less to the robot. Our results offer guidelines for the design of appropriate proxemic behaviors for robots so as to facilitate effective human-robot interaction.

Categories and Subject Descriptors
H.1.2 [**Models and Principles**]: User/Machine Systems – *human factors.* H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *evaluation/methodology, user-centered design*.

General Terms
Design, Experimentation, Human Factors.

Keywords
Human-robot interaction, humanlike robots, proxemics, distancing, gaze, proximity, disclosure, Wakamaru.

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Figure 1. The robot maintaining mutual gaze (left) and avoiding gaze (right) with a participant.

1. INTRODUCTION
Robots promise widespread integration into the human social and physical environment in such domains as healthcare, education, and public services. A key consideration for the design of such robots is *proxemics*—physical and psychological distancing from others [11]. People might perceive robots that do not show appropriate distancing behavior as threatening and disruptive to their social environments and work practices [20]. On the other hand, carefully designed proxemic behaviors in robots might foster closer human-robot relationships and enable widespread acceptance of robots, contributing to their seamless integration into society.

The key to designing proxemic behaviors that follow societal norms into robots is to first gain an understanding of how people distance themselves from others, particularly the cues that help individuals maintain appropriate social distances and the social and cognitive outcomes of interpersonal distancing. Research in human communication has extensively studied human proxemic behavior and developed a number of models that integrate proxemic cues and predict how these cues might affect human communication [3,9,10,11,16,21]. These models have formulated physical and psychological distancing in terms of the amount of mutual gaze, physical proximity, initial attraction, and other interpersonal factors such as the topic of a conversation, the amount of smiling, and gender, age, and ethnic configuration of the individuals [11,13]. Four prominent models—*compensation* [3], *reciprocity* [10,14], *attraction-mediation* [9,16], and *attraction-transformation* [21]—offer competing predictions on how individuals respond to attempts by others to change distancing.

While a small number of studies in human-robot interaction have explored physical distancing [22,24], we lack a comprehensive model of how people distance themselves from robots and the role of verbal and nonverbal cues in this process. In this paper, we investigate which of the four prominent models of interpersonal distancing (illustrated in Figure 2) might best explain human-robot proxemics and suggest guidelines for the design of robots that effectively use verbal and nonverbal cues to establish closer relationships with people.

The next section introduces these models, reviews related work in human-computer interaction and human-robot interaction research, and presents our hypotheses. In the remainder of the paper, we describe our methodology, present our results, and discuss the implications of our findings for the design of robot proxemic behavior.

2. BACKGROUND

Anthropologists, sociologists, and psychologists have extensively studied human proxemic behavior—physical and psychological interpersonal distancing—since the 1920s. Bogardus [7] observed that people maintained certain "social distances" from members of other ethnic groups. Moreno [17,18] formulated that the distance between groups depended on the amount of attraction between the groups. Hall [11] further detailed these observations and described the different distances individuals maintained between themselves, the factors that affected interpersonal distancing, and the differences in distancing behavior across cultures. These initial descriptions of proxemic behavior led to the development of a number of theoretical models that have attempted to explain interpersonal distancing. In this section, we describe four such models (also illustrated in Figure 2), discuss the foundations and predictions of each model, and provide an overview of prior work on proxemics in human-computer interaction and human-robot interaction research.

The Compensation (or Equilibrium) Model

Argyle and Dean [3] developed a model of interpersonal distancing that suggested an *equilibrium* in the distance between two individuals. Based on this model, when individuals increase their closeness (or decrease distance) with their partners, their partners *compensate* for this increase by decreasing closeness with them. This model formulated distancing in terms of eye contact, physical proximity, intimacy of topic, the amount of smiling, and so on and argued that compensation could manifest itself in any of these components. For instance, the equilibrium models suggests that if an individual maintains a high amount of eye contact, her partner might compensate for this increase in closeness by decreasing her amount of gaze or by physically distancing herself further from her partner. To illustrate the equilibrium model, Argyle and Dean [3] conducted an experiment in which they manipulated a confederate's distance from the participants. Their results showed for all gender combinations a compensatory effect; participants maintained less eye contact when their proximity to the experimenter increased.

The Reciprocity Model

The first model, suggested by clinical-psychological research on disclosure processes, focused on psychological distancing and how interpersonal distancing affects how much people disclose with each other. This second model suggests that, in dyadic interaction, when one increases closeness (or decreases distancing), the other *reciprocates* and increases closeness to the other person [10,14]. Jourard and Friedman [14] observed a linear increase in participants' self-disclosure when the experimenter increased disclosure by means of verbal disclosure touching.

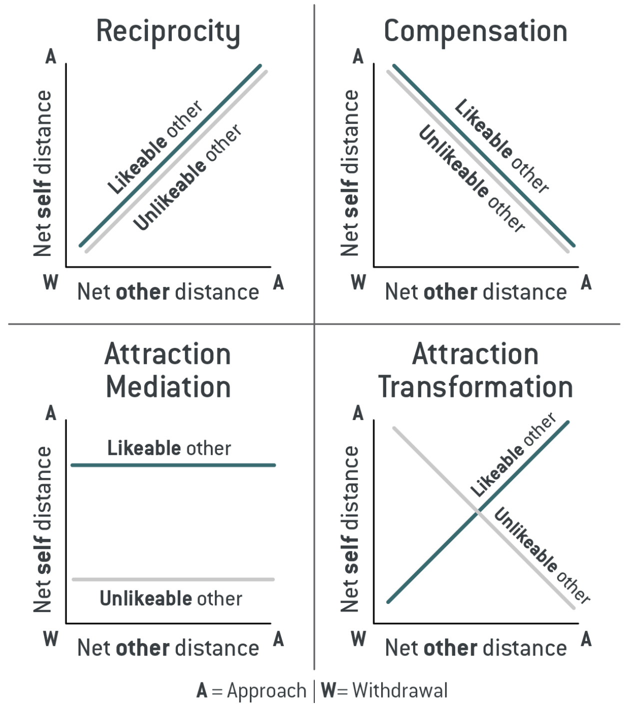

Figure 2. The four models of interpersonal distancing (adapted from Kaplan et al. [15]).

A critical review of the compensation and reciprocity models shows that these two models originate from distinct theoretical orientations and predict incompatible outcomes [9]. The compensation model has its origins in research on nonverbal communication that examines such cues as eye contact, body orientation, and posture to study social processes. The reciprocity model stems from research on the verbal aspects of interpersonal communication such as speech fluency, latency, and breadth and depth of disclosure. These distinct theoretical orientations and incompatible predictions have led researchers to develop models that bridge these competing explanations of distancing behavior. The most prominent two such models are the *attraction-mediation* and *attraction-transformation*.

The Attraction-Mediation Model

Firestone [9] and Kaplan [16] argue that the level of *attraction* between the individuals (can also be formulated as liking, closeness, or rapport) at the onset of the interaction determines the distancing behavior. The model suggests that individuals with high levels of attraction between them will maintain high levels of closeness independent from changes in their partners' distancing. Individuals with low levels of attraction, however, will maintain low levels of closeness regardless of changes in their partners' distancing behavior.

The Attraction-Transformation Model

A fourth model, developed by Patterson [21], incorporated the reciprocity and compensation models and suggested that the level of attraction between individuals at the onset of the interaction affects whether individuals compensate or reciprocate. This model suggests that if two individuals initiate interaction at a positive footing that increases mutual attraction, an attempt by one of the individuals to increase closeness will be reciprocated by the other individual. On the other hand, the other individual will compensate for the attempt, if two individuals have a low level of initial mutual attraction.

Kaplan and his colleagues [15] compared these four models and found that the reciprocity model best predicted how much participants verbally disclosed to the experimenter and the attraction-transformation model explained how much participants' maintained eye contact with the experimenter. More specifically, when the confederate disclosed more information about herself, the participant reciprocated, both liked and disliked confederates, by disclosing more information about herself. Participants' nonverbal behavior showed a different pattern; they *reciprocated* the liked confederate's disclosure by increasing the amount of gaze and *compensated* for the disliked confederate's attempt for increasing closeness by reducing it.

Other Factors that Affect Interpersonal Distancing

While the four models we present here consider two main effects on distancing behavior, increased closeness by the other party (by means of increased gaze, proximity, disclosure, etc.) and interpersonal attraction or liking, research in proxemics suggests that interpersonal distancing is also affected by such factors as cultural background [11], ethnic group [6], gender [2,6,23], age [6], physical attractiveness [15], and body orientation [4,13]. Hall [11] observed significant differences in distancing behaviors across cultures. For instance, an acceptable distance between individuals in the Middle East might be unacceptable and anxiety arousing for Northern Europeans. Baxter [6] found in a study he conducted in the United States significant differences among three ethnic groups in physical distancing behavior. A number of studies revealed significant differences in distancing behavior between men and women. Overall, women maintain less physical distance between themselves and others [1,2] and tolerate and more favorably react to gaze cues [23] than men do. Finally, people maintain greater distances between themselves and others when they are facing the front of another person than when they are facing the back [4,13]. While we expect these factors to have a significant effect on how people distance themselves from robots, the present work does not consider them.

Studies of Distancing in Human-Computer Interaction

Only a small number of studies have explored proxemics behavior in human-computer interaction. In the most notable of such studies, Bailenson and his colleagues [5] studied physical distancing between participants and a virtual agent in an immersive virtual environment. They manipulated the agent's "realism" incrementally from an inanimate cylinder to an agent that maintained mutual gaze with the participants. Their results showed that participants maintained more distance from the agent than from the inanimate cylinder. They also found that female participants maintained more space between themselves and the agent that maintained mutual gaze them than between themselves and the agent that did not maintain mutual gaze, showing a compensatory effect of gaze on distancing. Their results showed no differences in male participants' distancing behavior across different levels of realism.

Studies of Distancing in Human-Robot Interaction

A small but promising number of studies in human-robot interaction have explored proxemic behavior. Walters and his colleagues [24] studied whether participants conformed to the proxemic zones that Hall [11] identified for human social interaction (close intimate, intimate, personal, social, and public zones). Their results showed that 60% of their participants conformed to these zones, while 40% of them stood too close to the robot, suggesting that they did not perceive the robot as a social actor. They also found that participants' personality affected their distance from the robot; those who were more proactive maintained a larger distance between themselves and the robot. Takayama and Pantofaru [22] studied how a robot's gaze behavior and participant characteristics affected how comfortable participants rated the distance the robot maintained with them. Their results showed an interaction between participant gender and the effect of robot's gaze in participants' distance from the robot. Females were comfortable with a larger distance when the robot looked toward their faces then they were when the robot looked toward their legs, while males rated a smaller distance as comfortable when the robot looked toward their faces then they did when it looked at their legs. They also found that participants who had prior experience with robots and those who owned pets were more comfortable with smaller distances than others.

While these studies show promising evidence that people express proxemic preferences when they are interacting with robots, a comprehensive theoretical model of physical and psychological distancing is needed to guide the design of proxemic behaviors for robots.

2.1 Hypotheses

We formed a number of hypotheses for human-robot proxemics based on the models we presented earlier and findings from human-computer and human-robot interaction studies.

Hypothesis 1. Following the *compensation* model, derived from nonverbal research, participants will maintain a greater distance with the robot when the robot maintains eye contact with them than they do when it avoids gaze.

Hypothesis 2. Following the *attraction-transformation* model, which has been proposed as a bridge to explain verbal and nonverbal cues, how much participants like the robot will affect their distancing behavior with the robot; they will maintain a greater distance with the disliked robot when the robot maintains eye contact with them than they do when it avoids gaze, while maintaining a smaller distance with the liked robot when the robot maintains eye contact with them than they do when it avoids gaze.

Hypothesis 3. Following the *compensation* model participants will disclose less to the robot when the robot maintains eye contact with them than they do when it avoids gaze.

In the next section, we describe a controlled laboratory experiment in which we seek to evaluate these competing models in a human-robot interaction scenario.

3. METHOD

We conducted a laboratory experiment to explore which of the four models of interpersonal distancing best explains proxemic behavior in human-robot interaction. Experimental design, procedure, measurement, and participant information for the experiment are discussed hereafter.

3.1 Experimental Design

We conducted a two-by-two, between-participants study in which we manipulated Wakamaru's *likeability* and *gaze behavior* and measured how these manipulations might affect how much *physical* and *psychological distance* participants maintained with the robot. We introduced the manipulation for the *likeability* of the robot prior to starting either task. At the beginning of the experiment, the robot greeted the participant and gave a twenty-second verbal introduction of the task using a pre-recorded human voice. The manipulation involved changing which monologue was played during the introduction. In the *unlikeable* condition, the robot's monologue was rude, selfish, and urged the participant to not "fool around or waste time". Conversely in the *likeable* condition, the robot was kind, pleasant, and empathetic. A pilot study was conducted to develop and test the effectiveness of this manipulation prior to running the experiment.

We also manipulated the *gaze behavior* of the robot. In the "mutual gaze" condition, the robot *looked toward* the participant as the participant moved around the room; the robot's eyes appeared locked to the direction of the participant's face (while the participant may or may not maintain eye contact with the robot). Alternatively, in the "averted gaze" condition, the robot *looked away* from the participant, as the participant moved across the room; the robot's head looked down and away from the direction of the participant.

In the experiment, participants performed two tasks: the first to examine *physical distancing* and the second to examine *psychological distancing*. Figure 3 illustrates the experimental setup for both tasks.

Physical Distancing Task — Following the introduction of the likeability manipulation, participants were instructed to begin the *physical distancing task* (shown in Figure 3). This task, an adaptation of the task Bailenson and his colleagues [5] used to study distancing in immersive virtual environments, measured the "personal space" that participants place between themselves and the robot as they approach it. The task involved the following:

The experiment software showed participants a number from one to ten and asked them to retrieve the word that corresponded to this number from a piece of paper that we placed at the back of the robot. Participants approached the robot to identify the word and returned to their original location to type it in into the computer. After they entered the word, the software displayed another number and asked them to retrieve the word that corresponded this new number from the back of the robot. We repeated this process five times.

Psychological Distancing Task — The second task involved the robot interviewing participants and measured the amount of information that the participants were willing to disclose to the robot. The task involved the following:

Near the end of the experiment, participants were told by the computer that the robot wanted to ask them some personal questions in order to get to know them better. Participants sat at a computer screen while the robot asked them 17 personal questions (i.e., "How often do you lose your temper?," "Have you ever stolen anything?," "Have you ever cheated on a romantic partner?"). When the robot asked each question, five multiple-choice answers, which the participant could select, appeared on the screen. Four of the five answers were designed to cover the possible range of responses for that particular question and the fifth answer was "I do not feel comfortable sharing this information with the robot."

3.2 Experimental Procedure

The experiment was conducted in a closed room with controlled lighting and no outside distraction. Only the robot and one participant were present in the room throughout duration of the experiment. Participants were brought in to the experiment room

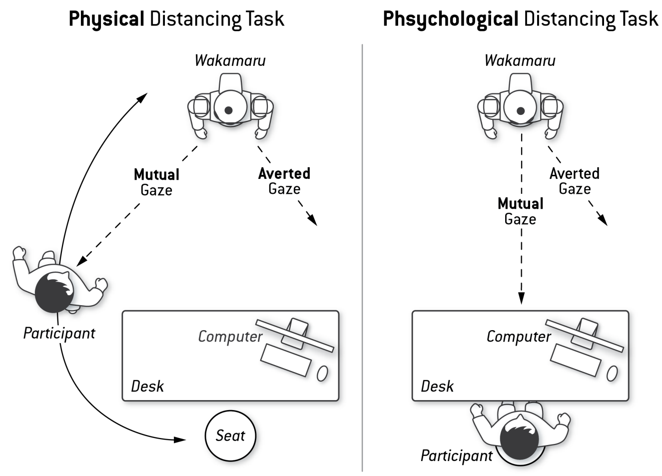

Figure 3. In the physical distancing task, participants walked behind the robot to read a word from the list on its back. In the psychological distancing task, participants sat at a computer desk while the robot asked them seventeen personal questions.

and were asked to sit at a table with a computer screen, keyboard, and mouse. We then gave participants a brief description of what they would be asked to do in the experiment and then asked them to review and sign a consent form. The experimenter told the participants that they were going to play a game with the robot. After consenting, participants were asked to direct their attention to the computer screen, which provided the instructions for the remainder of the experiment. The experimenter then told participants that they could press the start button on the screen after he left the room. Upon pressing start, the robot began introducing itself. Following the introduction, the robot told participants to read the instructions on the computer screen for the *physical distancing task*. After indicating that they understood the instructions, the computer lead participants through the physical distancing task. Upon completing the physical distancing task, participants answered the questionnaire and then were asked to perform the *psychological distancing task*.

To ensure consistency across participants and to avoid human error, the robot's gaze behavior was controlled autonomously using real-time video processing. A high definition camera located behind the robot sent video frames to a server in which we processed and extracted the participant's position in the room. Using this position, we calculated the appropriate angle for the robot's gaze and sent updates to the robot to adjust its gaze at an approximate rate of 30 times per second.

Following the final task, the researcher re-entered the room and debriefed participants on the purpose of the experiment. The total experiment time was approximately 12 minutes. Participants were paid $5 for their participation.

3.3 Measurement

Our experiment involved two independent manipulated variables, (1) *likeability* of the robot, and (2) *gaze behavior* of the robot. Both independent variables were manipulated between-participants. The dependent variables involved *objective* measurements for evaluating *physical* and *psychological distancing* and *subjective* measurements for checking whether our manipulations were effective.

Physical Distance — Our physical distance measure captured the amount of personal space that the participants placed between themselves and the robot as they approached it during the *physical distancing task*. Following previous studies in proxemics [12], we used the *minimum distance* between the participant and the robot for this measure. As pointed out by Bailenson and his colleagues [5], minimum distance is preferred over average distance for two reasons: (1) minimum distance is a more accurate measure of how close participants were willing to get and (2) participants spend an unequal amount of time at specific distances due to the nature of the task, which would lead to inconsistent results when calculating the average distance.

Physical distancing data was gathered using a high-definition camera mounted in the ceiling for capturing videos. The camera was positioned at a right angle directly over the head of the robot. Videos were post-processed using motion capture to calculate the minimum distance between the mid-point of the robot and the mid-point of the participant.

To calculate relative distance between the participant and the robot, in each frame of the video we needed to locate, (1) the absolute position of the robot and, (2) the absolute position of the participant. First, the absolute position of the robot was located manually by examining the frame and selecting the robot's mid-point coordinate. Because both the robot and camera were stationary, this only had to be done once and was consistent throughout all videos. Second, the mid-point of the participant was located by finding the *difference image* between each frame in the video and the base background frame (the frame of just the room with no participant in it). The difference image is a representation of the movement in a given frame. After getting the difference image, we apply erosion and threshold filters to eliminate any noise resulting from the video. We also "block out" the robot so that the movement of the robot's head would not be a part of the difference image. After these filters are applied, the result is a binary image, where white pixels represent movement and black pixels represent no movement. Because the experiment took place in an isolated room with controlled lighting, we can conclude that any movement in the resulting image is solely that of the participant. We then calculate the mid-point of all the white pixels in the image, and the result is the absolute position of the participant. Now having both the position of the robot and the participant, we calculate the relative distance between the two in each frame. We calculated distance at a rate of ten times per second.

Given that people distance themselves differently depending on whether they are in front of or behind the other person [4,13], we determined both *back minimum distance* and *front minimum distance*. We achieved this calculation by evaluating which side the mid-point of the participant lied on relative to the mid-point of the robot. Each participant approached the robot five times, and thus a total of ten measures for each participant were examined—five front distances and five back distances.

Finally, because distance data was calculated using digital video, pixels were the unit of measurement we initially used. We then converted pixels to centimeters by approximating the real-world size of a pixel in our video. However, it should be noted that these conversions are only approximations and should not be considered to be exact real-world distances.

Psychological Distance — Our psychological distance measure captured the amount of personal information that participants disclosed to the robot during the *psychological distancing task*. The robot asked participants 17 personal questions. The experiment software provided participants with the option to decline responding to the questions that they felt uncomfortable answering. The number of questions that the participants did answer was used as the measure of psychological distancing from the robot.

Manipulation Checks — Our experiment manipulated the robot's *likeability* and *gaze behavior*. Following the *physical distancing task* we asked participants to answer a post-experiment questionnaire, which primarily served to check that our manipulations were effective and to gather demographic information. We used seven-point rating scales anchored by "Strongly Disagree" and "Strongly Agree" for all subjective questionnaire items. To assess whether the *likeability* manipulation was effective, the questionnaire included the Interpersonal Judgment Scale [8] adapted for the robot, which measures interpersonal social attraction. We asked participants how much the robot maintained eye contact with them as they approached it in order to assess whether the gaze manipulation was effective.

3.4 Participation

A total of 60 participants (30 males and 30 females) took part in the experiment. All participants were native English speakers and were recruited on the University of Wisconsin–Madison campus. The ages of the participants varied between 18 and 67 (M = 24.4, SD = 10.5). The computer use among participants was very high (M = 6.8, SD = 0.54) on a scale from one to seven. Using the same scale, their video game use was moderate (M = 4.03, SD = 1.76) and their familiarity with robots was relatively low (M = 3.0, SD = 1.81). Of the 60 participants, 42 reported that they interacted with pets on a regular basis.

4. RESULTS

Our analysis of the data started with manipulation checks for the likability of the robot and the robot's gaze behavior using analysis of variance (ANOVA). Results confirmed that the likability manipulation had a significant effect on how much participants liked the robot, $F(1,58) = 7.28$, $p < .01$. Participants also rated how much the robot maintained eye contact with them significantly more in the mutual gaze condition than they did in the averted gaze condition, $F(1,58) = 157.40$, $p < .001$, confirming that our gaze manipulation was also successful.

Before analyzing our results, we first look at our measurements in the context of each of the four models of interpersonal distancing:

The *reciprocity model* predicts that people meet *increased* closeness by *increasing* closeness with them. For physical distancing to follow this model, increased gaze from the robot should lead to a decrease in the physical distance participants place between themselves and the robot. For this model to predict participants' psychological distancing, increased gaze from the robot should lead to an increase in self-disclosure from participants.

The *compensatory model* predicts that people meet *increased* closeness by others by *decreasing* closeness with them. This model's prediction for physical distancing would suggest that increased gaze from the robot should lead to an increase in physical distance between participants and the robot. For

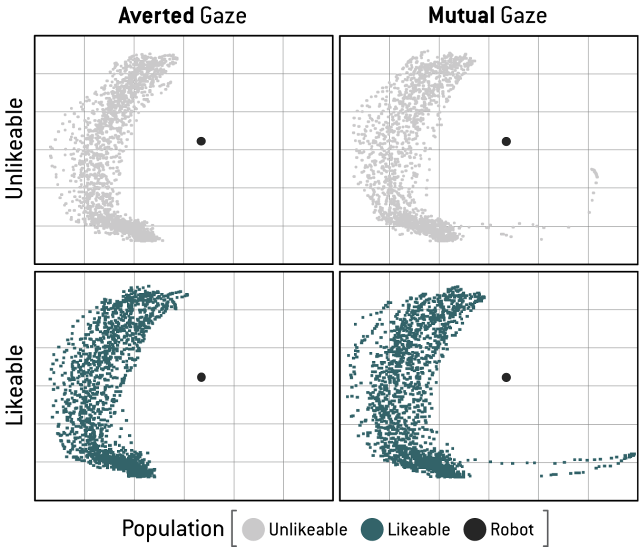

Figure 4. All position data collected from participants in the physical distancing task in each of the four conditions.

psychological distancing to follow this model, increased gaze from the robot should lead to a decrease in self-disclosure from participants.

The *attraction-mediation model* predicts that people maintain less distance between themselves and a *likeable* partner and more distance between themselves and a *dislikeable* partner and, therefore, that increased closeness by others does not affect their distancing behavior. If participants' physical distancing behavior followed this model, a likeable robot, regardless of gaze behavior, should lead to a decrease in personal space. For this model to explain participants' psychological distancing, a likeable robot, regardless of gaze behavior, should lead to an increase in self-disclosure from participants.

Finally, the *attraction-transformation* model predicts that people reciprocate an attempt to increase closeness by a *likeable* partner and compensate for such an attempt by a *dislikeable* partner. For participants' physical distancing behavior to follow this model, increased gaze from a likeable robot should lead to a decrease in personal space and increased gaze from a dislikeable robot should lead to an increase in personal space. This model's predictions for psychological distancing would suggest that increased gaze from a likeable robot should lead to an increase in self-disclosure and increased gaze from a dislikeable robot should lead to a decrease in self-disclosure.

We analyzed our data to test which model best fits for both physical and psychological distancing. We analyzed physical distance using a mixed-effects repeated measures ANOVA using participant IDs, trial IDs, and approach orientations (front or back) as random effects and gaze and likeability conditions as fixed effects. We analyzed psychological distance using a fixed-effects ANOVA. Both analyses also included two measured independent variables, participant gender and pet ownership, as fixed effects.

Physical Distance — In the physical distancing task, we asked participants to walk behind the robot as part of a game and used the actual distance participants placed between themselves and the robot when they approached it as the measure of physical distancing. The physical distance data included 600 total distance measurements: minimum front and back distances in each of the 5 trials for all 60 participants. Of the 600 measurements, 12 measurements were excluded from the analysis. In these trials, participants accidentally hit the "Back" button located on the side of the multimedia mouse attached to the experiment computer, which reset the experiment software and caused a loss of data. Figure 4 illustrates the data points collected from all 60 participants in the four unique experimental conditions.

Our analysis showed that gaze behavior had a significant effect on physical distance (shown in Figure 5a). When the robot increased its amount of gaze (the "mutual gaze" condition), participants significantly increased the distance they placed between themselves and the robot, $F(1,584) = 13.66$, $p < .001$. Our analysis also found a significant interaction between likeability and gaze behavior, $F(2,584) = 7.95$, $p < .01$. Participants who disliked the robot distanced themselves significantly further when the robot increased its amount of gaze, a compensatory effect, $F(1,584) = 20.75$, $p < .001$. However, participants who liked the robot did *not* change how they distanced themselves as the robot increased its gaze, $F(1,584) = 0.41$, p = ns. This result best fits the *attraction-transformation* model. We discuss this result further in the Discussion section.

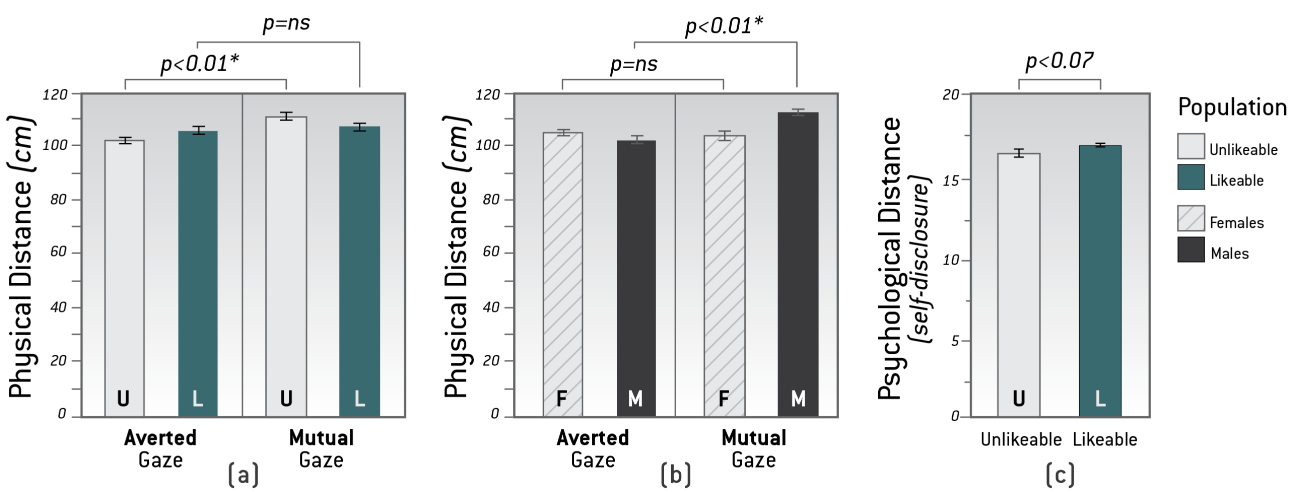

Figure 5. Results on physical and psychological distance: (a) the interaction between gaze behavior and likeability on physical distance, (b) the interaction between gaze behavior and participant gender on physical distance, and (c) the effect of likeability on psychological distance.

Our analysis showed a main effect of gender on physical distancing (shown in Figure 5b). Males distanced themselves significantly further than females, $F(1,586) = 6.87$, $p < .01$. Our analysis also found a significant interaction between gaze behavior and participant gender. Consistent with prior work that suggests that females tend to tolerate and react more favorable to gaze than males [23], our analysis shows that females did *not* change how they distanced themselves as the robot increased its gaze, $F(1,584) = 0.46$, p = ns. Males, however, distanced themselves significantly further when the robot increased its amount of gaze, $F(1,584) = 28.16$, $p < .01$.

Our analysis showed a main effect of pet ownership on physical distancing. Pet owners distanced themselves significantly further than non-pet owners, $F(1,586) = 8.13$, $p < .01$. Our analysis also found a significant triple interaction between pet ownership, gaze behavior, and likeability, $F(3,580) = 4.30$, $p < .04$. Space constraints do not permit extended discussion on this analysis.

Consistent with past distancing research [4,12], our analysis showed that participants distanced themselves differently depending on whether they were in front of or behind the robot. Participants distanced themselves significantly further from the robot when they were in front of it compared to when they were behind it, $F(1,292) = 474.80$, $p < .001$.

Psychological Distance — In the psychological distance task, the robot asked participants 17 personal questions. We provided participants with the option to answer or skip the question if they did not feel comfortable sharing that information with the robot. Psychological distance, a measure of self-disclosure, is the number of questions participants were willing to answer.

Our analysis showed a marginal main-effect of robot *likeability* on psychological distance (shown in Figure 5c). Participants disclosed marginally more information with a likeable robot compared to an unlikeable robot, $F(1,58) = 3.45$, $p < .07$. Our analysis further showed that gaze behavior of the robot had no effect on psychological distance, $F(1,58) = 0.36$, p = ns. No other significant interactions were found. This result suggests that the *attraction-mediation* model best explains human-robot psychological distancing. We discuss this result further in the Discussion section.

5. DISCUSSION

Our results on physical distancing showed strong support for our first hypothesis; participants maintained a greater distance with the robot when it established mutual gaze with them, following the *compensation* model of interpersonal distancing. However, our results also showed partial support for the competing *attraction-transformation* model; participants' compensatory distancing behavior was affected by how much they liked the robot. Specifically, participants compensated for increased closeness by a robot they disliked by maintaining a greater distance with the robot. On the other hand, increased closeness by a robot they liked did not affect their distancing behavior. Results on psychological distancing did not confirm our hypothesis, instead providing partial support for the *attraction-mediation* model. Participants disclosed more to the robot they liked than they did to the disliked robot, while the increased closeness by the robot did not affect their disclosure. These two models for physical and psychological human-robot distancing are represented in Figure 6.

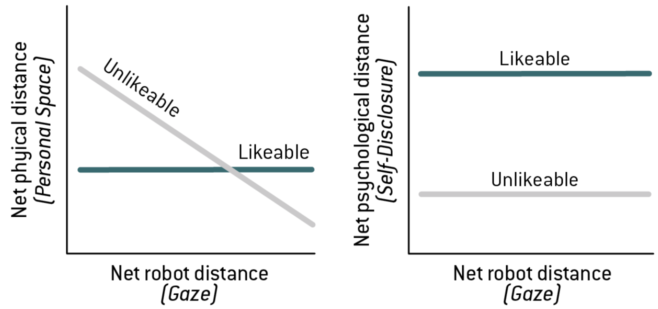

Figure 6. Models of human-robot distancing. Participants who disliked the robot compensated for increased gaze by distancing themselves further from it, while those who liked the robot were not affected by increased gaze (left). Participants who liked the robot disclosed more with the robot than participants who disliked the robot (right).

Our analysis also showed that participants' gender and pet ownership affected their distancing behavior. Overall, men maintained a greater distance from the robot than women did. They also compensated for increased closeness by the robot by increasing their distance, while increased gaze by the robot did not affect the women's distancing from the robot, consistently with the finding that women tolerate and react more positively toward gaze cues [23]. Pet owners also maintained an overall greater distance from the robot than others did, following the finding that pet owners might be more sensitive to social cues presented by robots [19].

Design Implications — Our findings offer three significant implications for the design of proxemic behavior for robots. First, robots need to be designed to initially establish a certain level of likeability or rapport with people before seeking physical and psychological closeness with them. Failure to do so might cause people to physically distance themselves from robots, avoid disclosing personal information, or ceasing to interact with the robot altogether. Second, robots that are designed to function in situations that do not allow them to establish rapport with people (e.g., public spaces) need to be mindful of how they employ cues that might increase closeness in their interactions with people. Under low levels of rapport, people might compensate for the robot's attempts to increase closeness by withdrawing themselves from it. Finally, robots need to be designed to consider individual characteristics—such as gender and pet ownership—when they establish their distancing with people. For instance, seeking to increase closeness by maintaining more eye contact with both genders equally might cause males to compensate for this increase and distance themselves from the robot.

Limitations — The results presented here have a number of limitations. First, Wakamaru's design might have affected participants' perceptions of its gaze cues and likability. While our manipulation checks showed strong effects of the gaze and likability manipulations, that the robot does not have articulate eyes and its nonthreatening design in terms of size and physical features might have prevented even stronger effects. Second, because we focused on understanding people's distancing behavior with robots and how robot gaze and likability affected this behavior, we limited the robot's behaviors to speech and gaze. Therefore, we do not know the generalizability of our results to situations in which robots use a wider range of behavioral cues. Lastly, we used gaze cues to manipulate the robot's distancing from people, while alternative behaviors exist such as increasing or decreasing physical proximity. We plan to conduct future studies that explore how a mobile robot that adjusts its physical proximity might affect people's distancing from it.

6. CONCLUSION

Robots must be designed to follow societal norms of physical and psychological distancing in order to seamlessly integrate them into the human physical and psychological environment. People might perceive robots that do not follow these norms as disruptive and threatening and, eventually, consider them as obstacles rather than assets. On the other hand, establishing and maintaining appropriate physical and psychological distances might allow robots to offer smoother and more comfortable interactions.

In this paper, we explored whether existing models of proxemics might explain how people physically and psychologically distance themselves from robots and suggest guidelines for the design of proxemic behaviors for robots. In a laboratory experiment with 60 participants, we evaluated how manipulations in the likeability of the robot and gaze behavior affected participants' physical distance from the robot and disclosure of personal information. Our results showed that participants who disliked the robot compensated for the increase in the robot's gaze by maintaining a greater physical distance from the robot, while participants who liked the robot did not differ in their distancing from the robot across gaze conditions. We also found that participants who disliked the robot disclosed less personal information to the robot.

These results provide us with a comprehensive theoretical model of human-robot proxemics that will inform the design of proxemic behaviors for robots. However, further work is required to understand to what extent these results generalize to other situations, behavioral cues, and robot designs.

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