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Influences on Proxemic Behaviors in Human-Robot Interaction

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Abstract— **As robots enter the everyday physical world of people, it is important that they abide by society's unspoken social rules such as respecting people's personal spaces. In this paper, we explore issues related to human personal space around robots, beginning with a review of the existing literature in human-robot interaction regarding the dimensions of people, robots, and contexts that influence human-robot interactions. We then present several research hypotheses which we tested in a controlled experiment (*N*=30). Using a 2 (robotics experience vs. none: between-participants) x 2 (robot head oriented toward a participant's face vs. legs: within-participants) mixed design experiment, we explored the factors that influence proxemic behavior around robots in several situations: (1) people approaching a robot, (2) people being approached by an autonomously moving robot, and (3) people being approached by a teleoperated robot. We found that personal experience with pets and robots decreases a person's personal space around robots. In addition, when the robot's head is oriented toward the person's face, it increases the minimum comfortable distance for women, but decreases the minimum comfortable distance for men. We also found that the personality trait of agreeableness decreases personal spaces when people approach robots, while the personality trait of neuroticism and having negative attitudes toward robots increase personal spaces when robots approach people. These results have implications for both human-robot interaction theory and design.**

I. INTRODUCTION

Simple robots such as robotic vacuum cleaners are becoming increasingly prevalent in everyday human environments, and it is only a matter of time until larger and more complex robots join them. As in human-to-human interactions, a contributing factor to human acceptance of such machines may be how well the robots obey comfortable human-robot spatial relationships. There is a wealth of information from both natural field observations and controlled laboratory experiments regarding the personal spaces of interacting people (e.g., [2][8]), but it is unclear exactly how this will inform human-robot personal spaces.

The media equation theory states that people interact with computers as they interact with people [14][16]. This may become increasingly true for human-robot interaction, where the computers that take action in the physical human environment. However, people do not always orient toward robots as they orient toward people. At times, people engage with robots in the way that they engage with tools [20], particularly when they are roboticists whose job it is to build and maintain the robot. Thus, it is necessary to gain a better understanding of which robot design decisions influence human proxemic behaviors around robots, and how human factors such as experience with robots can affect them.

By gaining a deeper understanding of the factors that most influence human-robot proxemic zones, one may gain a better sense of how to design better models of human-robot interaction, optimizing algorithms for how close robots should approach people. Indeed, using proxemic distances to alter interactive system behavior has already been effective in human-computer interactions with systems such as digital white boards [12]. Similar research is currently being done on how end-users might teach robots to engage in acceptable proxemic behaviors [13].

The goals of this study are to more thoroughly explore the human and robot factors that influence optimal proxemic behaviors in human-robot interaction and to turn those findings into implications for human-robot interaction design. As such, we first present a review of existing literature on issues of human proxemics, human dimensions of HRI proxemics, robot dimensions of HRI proxemics, and pose hypotheses to be tested by this study.

Our theoretical stance is that people will engage in proxemic behavior with robots in much the same way that they interact with other people, thereby extending the Computers as Social Actors theory [14][16] to human-robot interaction. Based on the existing empirical literature in human proxemics and HRI, we present more specific research hypotheses and test them with a controlled experiment, focusing on personal experience with pets and robots, personality characteristics, and the robot's head direction (facing the person's face vs. facing the person's legs), as they influence the personal spaces between people and robots.

II. RELATED LITERATURE

A. Human Proxemics

Fifty years ago, Edward T. Hall [8] introduced the concept of proxemics, which refers to the personal space that people maintain around themselves. Much of the research on this topic is summarized by Michael Argyle [2], who introduced an intimacy equilibrium model [1], which reasons about the interactions between mutual gaze and proxemic behavior. If a person feels that someone else is standing too close for comfort, that person will share less mutual gaze and/or lean away from the other person. As noted by Argyle [2], there are many factors that influence proxemic behaviors, including individual personalities, familiarity between people, to what degree people are interacting, the social norms of their culture, etc.

The unspoken rules of personal space tend to hold true with nonhuman agents. In virtual reality settings, people

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adjust their proxemic behaviors to virtual people (e.g., avatars and virtual agents) as they do with regular people in the physical world [3]. This is consistent with the media equation theory [14][16]. Given that people will interact with computers, on-screen characters, and virtual reality agents, it is not unreasonable to posit that such proxemic behaviors might also hold true in human-robot interaction. We explore the related works in human-robot personal spaces in the following sections.

B. Human Dimensions of HRI Proxemics

Among the many human factors that influence proxemics in HRI are a person's age, personality, familiarity with robots, and gender.

A person's age influences how close a person will stand to a robot. In controlled experiments with children and adults interacting with the mechanistic robot PeopleBot, children tended to stand further away from the robot than adults [22].

Peoples' personalities also seem to influence the distances they maintain to robots. In a laboratory experiment with robots approaching seated people, it was found that people who are highly extroverted are tolerant of personal space invasion, regardless of whether the robot approaches from the front or rear; however, people who are low on extraversion are more sensitive to robot approach directions [17]. This is consistent with previous research in human interpersonal distance that found extroverts are tolerant of closer proxemic behaviors than introverts [25]. In somewhat of a contrast, another study of standing people found that those who are more proactive (i.e., more aggressive, creative, active, excitement-seeking, dominant, impulsive, and less shy) tend to stand further away from robots [21]. Though the two studies do not tap the exact same personality construct, they pose an interesting conflict in the existing literature regarding personality and human-robot spatial relationships.

Consistent with the social science findings that people stand closer to other people with whom they are more familiar [8], people who have prior experience with a robot also tend to approach closer to it in subsequent interactions [23]. Therefore, the current study takes into account people's previous experience with the robot.

Another influence upon proxemic behavior with robots is gender. Consistent with findings that women prefer to be approached from the front than from the side and that men prefer to be approached from the side than from the front [7], an experiment on robots approaching people found that men allow robots to approach much closer from the side than from the front [18]. Gender also influences sensitivity to non-human agents such as agents and avatars in immersive virtual reality settings; in a study on proxemics in virtual reality, women were less comfortable moving close to virtual agents (supposedly controlled by software) than avatars (supposedly controlled by a person), whereas men did not differentiate between the two types of controllers [3].

C. Robot Dimensions of HRI Proxemics

Among the many robot factors that influence proxemics in HRI are a robot's voice, form, speed, and height.

In controlled experiments that manipulated robot voices, adults tended to have longer approach distances from robots with synthesized voices as opposed to approach distances from robots with high quality male as opposed to high quality female voices or no voices at all [24].

In similar experiments that manipulated robot form (mechanoid vs. humanoid PeopleBots), adults tended to have longer approach distances from humanoid robots than from mechanoid ones [19]. Similar results were found on the Nomadic Scout II [5].

People have been shown to also be sensitive to mobile robot speeds, preferring that a robot move at speeds slower than that of a walking human [5]; studies have found that having a mobile personal robot moving at approximately 1 meter per second is too fast for human comfort.

Robot height is yet another contributing factor. The study in [23] argued that actual robot height does not systematically influence comfortable approach distances across the participants, although robot appearance does. Height was a factor in overall perceptions, however, with the taller PeopleBot perceived as being more capable, authoritative and human-like than the shorter version.

D. Contextual Dimensions of HRI Proxemics

Depending upon the type of human-robot interaction activity, proxemic behaviors may vary widely. In a more dynamic interaction of people teaching robots to identify objects, adults were generally found to prefer to maintain a personal distance (i.e., 0.46 to 1.22 meters) from the robot, but this varied by the type of task (i.e., following, showing, and validating missions) [10].

E. Research Hypotheses

Based on the existing literature in human-robot interaction and proxemics, we pose four research hypotheses to be explored in this study.

1) Because experience with non-human agents might affect interactions with robots, we hypothesize that experience with owning pets will decrease the personal space that people maintain around robots.
2) Because familiarity between people decreases personal spaces between people [2] and this seems to hold true in human-robot interaction [23], we hypothesize that experience in robotics will decrease the personal space that people maintain around robots.
3) Because people have more control over their personal space when they are the ones approaching (as opposed to being approached), we hypothesize that people will maintain larger personal spaces when being approached by a robot than when they are approaching the robot.
4) Because mutual gaze increases personal spaces between people [1], we hypothesize that when the robot's head is oriented toward the individual's face, the individual will require a larger separation than when the robot's head faces the person's legs.

Each of these hypotheses hinges on the notion that robots might be treated as social actors in much the same way that computers are treated as social actors [14][16].

III. STUDY DESIGN

In order to test these research hypotheses, we conducted a 2 (robotics experience vs. none: between-participants) x 2 (robot head turned to participant's face vs. legs: within-participants) mixed design experiment. We aimed to study the factors that influence proxemic behavior around robots in several situations: (1) people approaching a robot, (2) people being approached by an autonomously moving robot, and (3) people being approached by a teleoperated robot.

A. Participants

Participants were recruited via mailing lists and online classifieds from the geographically local community in the San Francisco Bay Area of California; these results may not apply to other geographical areas. They included 30 individuals (14 women and 16 men), whose ages ranged from 19 to 55 years of age (*M*=28.9, *Standard Error*=1.5). Participants had to be at least 18 years of age and fluent in English. Ethnicities were not recorded. There was a roughly equal split between the genders of people with or without robotics experience. Among the women, six had at least one year of experience with robotics and eight did not. Among the men, eight had at least one year of experience with robotics and eight did not. Among the people with previous exposure to robots, 3 had never owned a pet while 12 had. Among those without previous exposure to robots, 2 had never owned a pet while 15 had. Their heights ranged from 1.55 to 1.88 meters (*M*=1.71, *Standard Error*=0.02).

B. Materials

The robot used in this study was the prototype version of PR2 (Personal Robot 2) in Fig. 1, which is under development at Willow Garage, Inc. PR2 is being developed as a mobile manipulation research platform for robotics researchers, however the eventual goal is for PR2 to interact with people in their everyday settings. This PR2 weighed approximately 150Kg (331lbs) and stood at its shortest height of 1.35m (4 feet 5 inches). When complete, there will be a shell covering much of the wiring and mechanisms, however the current prototype leaves the robot internals fairly exposed. The robot will also eventually have two arms, although only one was in place during our study, while the other arm position was occupied with weights to help balance the robot. In order to avoid interaction between the study participants and the arm, the arm was tucked behind the weights as in Fig. 1 and held stationary. Smooth locomotion is provided by a base with four casters, with the robot traveling at a maximum of 0.5m/s (and often slower) for our study.

The main robot sensor used for this study was the Hokuyo UTM-30LX laser range-finder positioned on the front of the robot base. An example of the 2D range data produced by this sensor can be seen in the visualization application shown in Fig. 2. Each dark red point is a return from the laser,

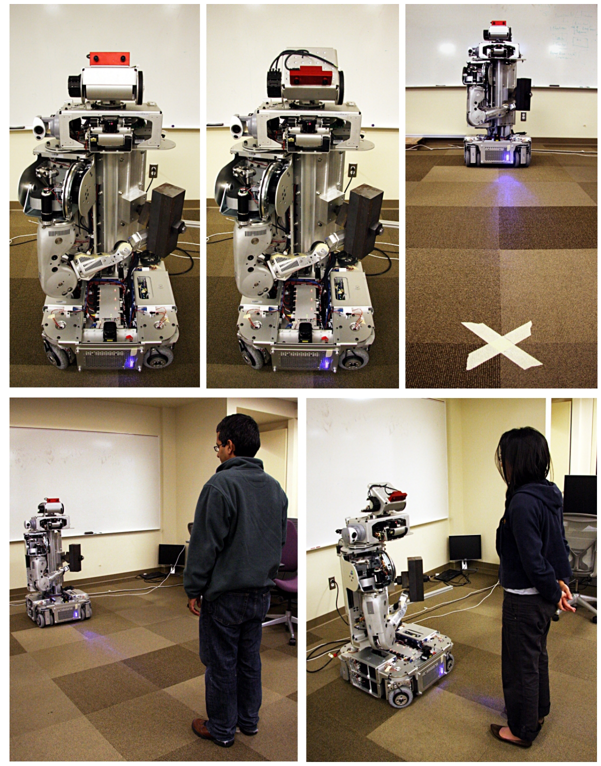

Fig. 1. PR2 up close and at different points in the study. (Top-left) PR2 up close. Note the red stereo camera unit on the head which is tilted in the direction of the subject's face. The Hokuyo range-finder is the small black box on the front of the base. (Top-center) Head tilted in the direction of the subject's feet. (Top-right) PR2 as seen from the X where the participants stood at the beginning of each study component. (Bottom-left) PR2 (head up) and participant standing on the X. (Bottom-right) PR2 (head down) and participant approaching it.

while the red and green axes show the current position of the robot's laser, with the red axis pointing forward. The range data from the Hokuyo was used both for obstacle avoidance during autonomous navigation, and for annotating the results of the study. In Fig. 2, the cursor arrow points to the leg of one of the study participants. By clicking on the leg, we were able to accurately compute the distance between the front of the robot (where the laser is mounted) and the person's shin. This method of annotation is advantageous both for its accuracy, and because it avoids instrumenting the study environment with rulers or other distance indicators.

C. Method

Each participant was welcomed to the study and informed of the overall procedures. They were explicitly informed that they could opt out of the study at anytime and that their data would be coded by a randomly assigned ID rather than an identifiable name.

If the participant chose to continue with the study they were asked the person to stand on an X marked on the floor of the lab space. The X was 2.4 meters away from the front of the robot, which was directly facing the participant, as in Fig. 1. This marked the beginning of round 1.

To counterbalance the study's design, for half of the participants the robot's head was tilted to look at their face

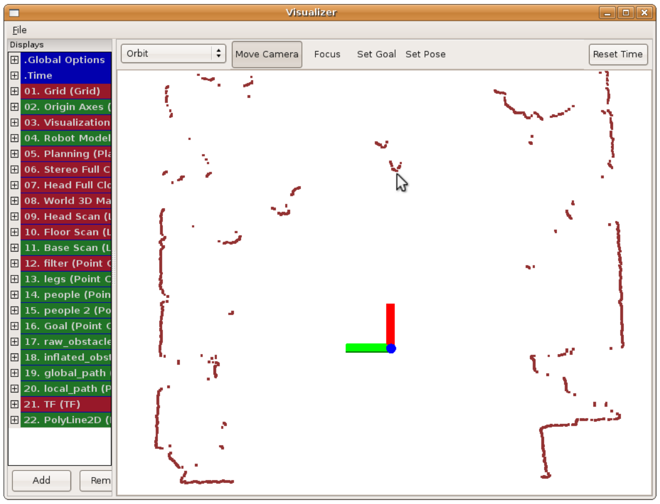

Fig. 2. Visualization of the point cloud from the 2D laser range-finder on the robot's base. The red dots represent laser returns, the green and red axes represent the laser range-finder (with red pointing forwards), and the cursor points to a subject's leg.

in round 1 and their legs in round 2; while the order was switched for the other half of the participants.

When ready, the participant was told, "The robot is going to identify you by your [face or legs]. Please move toward the robot as far as you feel comfortable to do so." Upon completion of this step, the participant was asked to repeat the action for the sake of reliability. Next the participant was told, "Now the robot will approach you. When the robot has come too close for comfort, please step to the side." Upon completion of this step, the participant was again asked to repeat the action for the sake of reliability. The robot approached the participant autonomously twice and as operated by another experimenter twice (teleoperated). The participant was told whether the robot was autonomous or being teleoperated. Once done with the behavioral part of the round, the participant filled out the brief questionnaire about perceived safety in the situation.

Next, the participant repeated these actions in the second round with the opposite robot head orientation from the first round: walking toward the robot twice, being approached by the autonomous robot twice, and being approached by the teleoperated robot twice.

Upon completion of both rounds, the participant was asked to complete the rest of the paper survey, which asked them questions about their personality and demographics. The experimenter clarified questionnaire items if the participant had trouble with the item. Once the participant completed both rounds and the final questionnaire, they were debriefed about the purposes of the study and discussed the study with the experimenters.

D. Measures

The behavioral measures in this study were the average and minimum distance that the participant reached relative to the robot's base scanner. This measurement was taken six times per round for each of the two rounds. The attitudinal measures in this study were the perceived safety measures administered at the end of each round. The personality traits (extraversion, agreeableness, conscientiousness, neuroticism, and openness), [11], need for cognition (i.e., how much one likes to think) [6], negative attitudes toward robots [15], and demographic measures were administered in the final questionnaire for the study.

E. Data Analysis

Before starting the data analysis, indices were calculated for each of the standardized questionnaires and recorded base scanner readings were watched and coded by two experimenters. The raters were blind to the experiment conditions and identified the minimum distances between the person and the robot by clicking on the person's leg scans as in Fig. 2. Interrater reliability for the distance readings was high, r=.93, $p<.001$. For each data point, we used the average of the two raters' distance selections.

In the first set of analyses, we tested the research hypotheses. We explored the main effects of personal experience with pets and robots upon proxemic behaviors around robots, using analysis of variance (ANOVA). We also investigated the effects of robot head orientation (facing the person's face vs. legs) upon proxemic behaviors, using a repeated measures ANOVA.

In the second set of analyses, we ran exploratory regression models to identify which factors would best predict variance in proxemic behaviors and perceived safety; we used forward stepwise regression because it is typically used for such exploratory analyses [9].

IV. RESULTS AND DISCUSSION

A. Effects of Personal Experience Upon Proxemic Behaviors With Robots

In support of Hypotheses 1 and 2, we found that personal experiences with pets and experience in robotics influence proxemic behaviors among the participants in this study.

In a univariate ANOVA, we found that people who had owned pets in the past were comfortable with the robot being closer (M=0.39 meters on average, *Standard Error (SE)*=0.02) than people who had never owned pets in the past (M=0.52, SE=0.07), $F(1,28)$=7.15, $p<.05$, (where there is 1 degree of freedom (df) in the numerator of the F-value and there are 28 degrees of freedom in the denominator). The mean and standard error values are depicted in Fig. 3.

Next, we examined the combined effects of who was approaching whom (person approaching robot vs. teleoperated robot approaching person), pet ownership experience, and experience with robots. In a repeated measures analysis of covariance (ANCOVA) with pet ownership experience (between-participants), experience with robots (between-participants), and person vs. teleoperated robot approaches (within-participants) predicting minimum distance between person and robot, we found that people who had at least one year of experience with robots were comfortable with being closer to the robot (M=0.25 meter minimum distance, SE=0.03, with pet ownership as a covariate) than people who

TABLE I

REPEATED MEASURES ANALYSIS OF COVARIANCE: EFFECTS OF PET OWNERSHIP, EXPERIENCE WITH ROBOTS, AND ROBOT VS. PERSON APPROACH UPON MINIMUM DISTANCE BETWEEN PERSON AND ROBOT

	Sources of Variance for Minimum Proxemic Distance	Sum of Squares	df*	Mean Square	F
within	Robot vs. person approaches	0.002	1	0.002	0.30
within	Robot vs. person approaches x Pet ownership	0.000	1	0.000	0.00
within	Robot vs. person approaches x Robot experience	0.001	1	0.001	0.13
within	Error	0.202	27	0.007	
between	Pet ownership	0.035	1	0.035	1.72
between	Robot experience	0.119	1	0.119	5.60**
between	Error	0.621	27	0.022	

* *df* = Degrees of Freedom
** $p<.05$

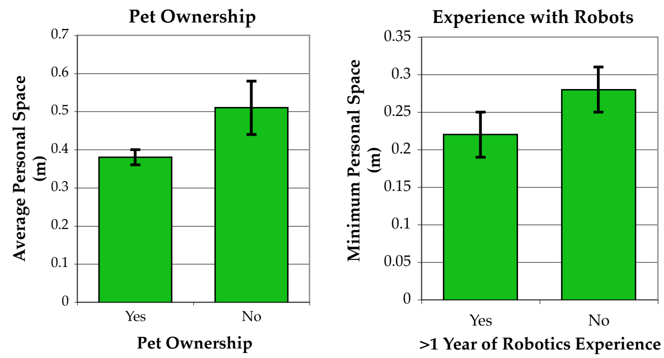

Fig. 3. Personal experience influences on proxemic behaviors with robots. The left-hand chart shows that participants who had owned a pet at some point in their lives were comfortable at closer average distances to the robot than those who had never owned a pet. The right-hand chart shows that robotics experience also correlates with smaller comfortable distances.

had less than one year of experience with robots (M=0.34, SE=0.03, with pet ownership as a covariate), $F(1,27)=4.24$, $p<.05$. The other main effects and interaction effects were not found to be significant. Thus, Hypothesis 2 was supported by this analysis, but Hypothesis 3 was not. The results of this second analysis are shown in Table I and Fig. 3.

Together, these findings provide support for Hypotheses 1 and 2, which stated that experience with pets and robots decrease personal spaces with the robot. However, these findings do not provide support for Hypothesis 3, which stated that people would allow for smaller personal distances when they were approaching the robot as opposed to when the robot was approaching them.

B. Effects of Robot Head Direction Upon Proxemic Behaviors With Robots

To examine Hypothesis 4, we ran a repeated measures ANOVA to evaluate the effects of robot head direction (facing the person's face vs. legs) upon minimum distances to the robot. Using pet ownership experience and gender as independent variables in this repeated measures ANOVA, including all main and two-way interactions, we found that pet ownership experience was a nearly significant predictor of proxemic behaviors, $F(1,28)=4.16$, $p=.05$, and that the interaction between robot head direction and gender of participant was also a significant predictor of proxemic behaviors, $F(1,27)=4.54$, $p<.05$. While both women and men generally approached the robot at the same distance when the robot's head was facing downward at their legs, women maintained a larger distance from the robot than men when the robot's head was oriented upward toward the participant's face. The mean and standard error values are depicted in Fig. 4, and full analysis results are presented in Table II.

Although this analysis did not find support for the main effect of robot head direction (Hypothesis 4), it did identify a significant interaction between gender and robot head direction such that when the robot's head is facing the person's face (as opposed to facing the person's legs), men tend to get closer to the robot than women.

C. Exploratory Analysis of Effects Upon Proxemic Behaviors With Robots in Varying Situations

Because there are so many factors that seem to influence proxemic behavior between people and robots (e.g., [10][17][23]), we decided to use exploratory regression analyses to identify which factors were more predictive of proxemic behaviors in this study. Because it is fundamentally different to approach a robot vs. be approached by a moving robot, we chose to analyze each of the three situations separately: (1) people approaching a robot, (2) people being approached by an autonomously moving robot, and (3) people being approached by a teleoperated robot. These analyses differed from the first set of analyses in that they did not look at effects upon general proxemic behavior, but rather looked at personality and personal experiences as they affect specific types of proxemic behaviors. The final analysis in this set examined what predictors best accounted for one's sense of safety in these human-robot situations.

In the first analysis of people approaching the robot, we used a forward stepwise linear regression model to see which of the following predictors would best account for minimum distance to the robot when the person approached the robot: pet ownership experience, at least one year of experience with robots, gender of participant, height of the robot, extraversion, agreeableness, conscientiousness, neuroticism, openness, need for cognition, and negative attitudes toward robots. From this analysis, we learned that the "big five" personality trait of agreeableness was the best predictor of the factors included in the model for predicting minimum distance to the robot when the person approached the robot (standardized β=-.45, t=-2.68, $p<.05$), Model R^2=.21, $F(1,28)=7.20$, $p<.05$. People who were more agreeable (as defined by the big five personality index) felt comfortable with being closer to the robot than people who were less agreeable.

In the second analysis of the teleoperated robot approaching the person, we used the same forward stepwise linear regression model to see which of those same predictors would best account for minimum distance to the robot when the

TABLE II

Repeated Measures Analysis of Covariance: Effects of Pet Ownership, Participant Gender, and Robot Head Direction Upon Minimum Distance Between Person and Robot

	Sources of Variance for Minimum Proxemic Distance	Sum of Squares	df*	Mean Square	F
within	Robot head direction	0.009	1	0.009	2.51
within	Robot head direction x Pet ownership	0.012	1	0.012	3.16
within	Robot head direction x Gender	0.016	1	0.016	4.45**
within	Error	0.098	27	0.004	
between	Pet ownership	0.100	1	0.100	4.16
between	Gender	0.006	1	0.006	0.62
between	Error	0.647	27	0.024	

* *df* = Degrees of Freedom

** $p < .05$

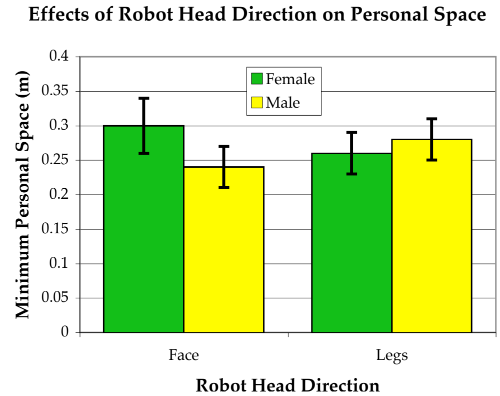

Fig. 4. Mean and standard error values for minimum personal space distances as affected by participant gender and robot head orientation, controlling for pet ownership experience=0.8

teleoperated robot approached the person. From this analysis, we learned that negative attitudes toward robots (standardized β =.42, *t*=2.58, $p<.05$) and the big five personality trait of neuroticism (standardized β=.33, *t*=2.06, $p<.05$) were the best predictors of minimum distance to the approaching teleoperated robot, Model R^2=.30, $F(2,27)$=4.25, $p<.05$. People who held more negative attitudes toward robots and were more neurotic (as defined by the big five personality index) maintained larger distances between themselves and the teleoperated robot than people who rated low on those measures.

The third analysis, looking at the autonomous robot approaching the person, had to be conducted differently. For safety reasons, if the subject did not move, the robot always stopped at a minimum of between 30-60cm from the subject's legs. Only 27 out of 120 instances of autonomous robot approaches actually resulted in people moving away from the robot. Therefore, we recoded the dependent variable as a binary value for whether or not the person ever stepped away from the robot, resulting in 12 out of 30 people actually moving away from the robot. Thus, we ran a forward stepwise binary logistic regression to see which of those same predictors would best account for whether or not the person stepped away from the autonomous robot. From this analysis, we learned that negative attitudes toward robots (β=.19, $p<.05$) and the big five personality trait of neuroticism (β=.11, p=.07) also best predicted the variance in the minimum distance to the robot when the autonomous robot approached the person, R^2=.40 (where R^2 measures the amount of variance in the minimum distance to robot that was accounted for by the model, ranging from 0 to 1). People who held more negative attitudes toward robots and were more neurotic (as defined by the big five personality index) maintained larger distances between themselves and the autonomous robot than people who rated low on those measures.

In the fourth analysis of this study, we explored the factors that most influence a person's perceived safety [4] in these interactions. We used the same forward stepwise linear regression model as the first two analyses to see which of those same predictors would best account for a person's overall perceived safety throughout the entire study. From this analysis, we learned that negative attitudes toward robots (standardized β =-.39, *t*=-2.42, $p<.05$) was the best predictor of the factors included in the model for predicting perceived safety when interacting with the robot, Model R^2=.15, $F(1,28)$=5.03, $p<.05$. People who held more negative attitudes toward robots felt less safe when interacting with the robot.

V. CONCLUSIONS AND IMPLICATIONS

A. Conclusions

In this controlled experiment, we found support for three out of four of our research hypotheses. Our data support the hypotheses that (H1) experience with owning pets decreases the personal space that people maintain around robots, (H2) experience with robots decreases the personal space that people maintain around robots, and (H4) a robot "looking" at people in the face (versus at their legs) influences proxemic behaviors. We were somewhat surprised to find that women maintain larger personal spaces from robots that are "looking" at their faces than men. We did not find support for our hypothesis that people will approach robots closer than they will let robots approach them (H3).

Through our exploratory analyses, we learned how attitudes, personal experiences, and personality factors influence proxemic behavior. We learned that people who are more agreeable (personality trait) move closer toward robots. We also learned that people who hold negative attitudes toward robots and/or are more neurotic (personality trait) stand further away from approaching robots. Finally, we learned that people who hold negative attitudes toward robots feel less comfortable in these human-robot situations. These findings regarding personality types contrast existing research that showed how proactiveness [21] and extraversion [17] were the most important influences upon proxemic behavior between people and robots. Further research is necessary to examine these differences.

B. Implications for Theory

The findings of this study mostly support the theory that people will use similar proxemic rules when interacting with robots as they do when interacting with other people in that robot head orientation, human gender, and familiarity with others (in this case, robots) influence personal spaces. Just as experience with people influences how close one would stand to one another [2], experience with robots also influences how close one would stand to this robot. Just as people maintain more distance from each other when sharing a mutual gaze [1], women in this study also stood further away from the robot when its head was facing their faces. Just as personalities influence proxemic behaviors between people [2], we found that personalities also influence proxemic behaviors between people and robots. Not all parts of human-human interaction directly translate into human-robot interaction, but we have identified several relationships that do hold true in these human-robot interaction situations.

C. Implications for Design

Based upon the results of this study, we offer several proposals for how to better design proxemic behavior into robots that interact with people. The PR2 used in this study is a prototype of a robot that will eventually be used for interacting with people in their everyday environments; as such, it is important to understand how to build robots that will follow the norms of proxemic behaviors to maintain comfort and trust levels between people and these personal robots.

The first design guideline is to use recognition of familiar people (e.g., people the robot has identified several times in the past) in deciding how close to approach people. If the person has been seen frequently over the past year, then it is reasonable to approach that person closer than one would approach a person who is not identified as being familiar. Robots that function in environments with people accustomed to their presence can be programmed to approach people more closely whereas robots that function in environments with strangers can be programmed to maintain larger proxemic distances.

The second design guideline is to include the robot's gaze behavior in deciding how close to approach people. If the robot needs to move in closer to a person, particularly a woman, the robot should direct its gaze away from the person's face. In this case, the robot could turn its head toward the ground. As robots become increasingly able to identify individuals and demographic information is increasingly available in places like the Internet, these data may better inform proper proxemic behaviors.

The third design guideline is to consider pairing person identification with personal information to better gauge the appropriate approach distances. For example, if a person is known to have negative attitudes toward robots, then it is better for the robot to maintain more distance from that individual. If a person is known to be more neurotic, then the robot should also maintain more distance from that individual. However, if the person is known to be more agreeable, then the robot should be prepared to be approached more closely by that individual. Similarly, if the personal information includes whether or not this person has ever owned pets, the robot could also know to keep more distance from those individuals who have never owned pets.

The empirical results of this study and these design guidelines are only a start to revealing the type of information that robots should take into account when calculating how close or far away to stand from people in the environment.

D. Limitations

As with any single study, there are several limitations of this experiment design that must be acknowledged. First, this study was run with only one version of one robot, PR2. Other studies have been run with robots such as the PeopleBot. It is important to test these hypotheses and theories against a wide variety of robots in order to assess whether such empirical findings generalize. Second, this study was run with only members of the local geographic community, thereby localizing its generalizeability to members of this culture. Cross-cultural issues are known to strongly affect proxemic behaviors [2][8] so it is especially important to test these hypotheses and theories in other cultural contexts with a wider demographic of people. Third, this study was only able to include a few of the many potentially important variables at play in the influences of proxemic behaviors because we could not risk participant fatigue for the sake of exhaustively manipulating and measuring every possible variable. Thus, it is important to consider the wider range of studies (such as those presented in the Introduction) when making decisions about exactly how to build proxemic behaviors into robots. Fourth, the task used in this study was very simple and not as involved as more teamwork oriented tasks between people and robots. Thus, its findings are limited in scope to simple encounters in which people approach robots and robots approach people. Future work should address how such proxemic behaviors are influenced by other contexts and activities.

VI. Future Work

This is one among many possible empirical studies regarding proxemic behaviors between people and robots. There is clearly much more research to be done in exploring the dimensions of people, robots, and their contexts. Our next step is to use these design guidelines and those from related work to inform the proxemic behaviors of PR2 when it encounters people and interacts with them.

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