University of Nevada, Reno

FACTORS INFLUENCING THE HUMAN PREFERRED INTERACTION DISTANCE

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Computer Science and Engineering

by

Vineeth Rajamohan

Dr. David Feil-Seifer/ Thesis Advisor

May 2020

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

Vineeth Rajamohan

entitled

Factors Influencing The Human Preferred Interaction Distance

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Dr. David Feil-Seifer
Advisor

Dr. Sergiu Dascalu
Committee Member

Dr. Hanif Livani
Graduate School Representative

David W. Zeh, Ph.D., Dean
Graduate School

May, 2020

Abstract

Nonverbal interactions are a key component of human communication. Since robots have become significant by trying to get close to human beings, it is important that they follow social rules governing the use of space. Prior research has conceptualized personal space as physical zones which are based on static distances. This work examined how preferred interaction distance can change given different interaction scenarios. We conducted a user study using three different robot heights. We also examined the difference in preferred interaction distance when a robot approaches a human and, conversely, when a human approaches a robot. Factors included in quantitative analysis are the participants' gender, robot's height, and method of approach. Subjective measures included human comfort and perceived safety. The results obtained through this study shows that robot height, participant gender and method of approach were significant factors influencing measured proxemic zones and accordingly participant comfort. Subjective data showed that experiment respondents regarded robots in a more favorable light following their participation in this study. Furthermore, the NAO was perceived most positively by respondents according to various metrics and the PR2 Tall, most negatively.

A follow up study involved finding out if there is any correlation between the robot's height and the method of approach focus across each proxemic zone based on the results obtained from our prior work. In addition, we conducted an user study to understand how interaction distance between a human and a robot changes with the change in the robot's physical configuration such as arm position (extended versus tucked in) and gaze (robot directly looking at the participant versus robot being distracted reading a newspaper). Data collected from this experiment was used to study the relationship between the physical configuration of the robot and preferred interaction distance. Subjective measures included human comfort and perceived safety. The results obtained through this study shows that robot's arm position and gaze behavior did have a significant effect in influencing measured proxemic zones. Subjective data showed that the experiment did have a short-term impact on the participants' opinion on the robot.

Acknowledgments

First and foremost, I would like to thank my research supervisor, Dr. David Feil-Seifer and committee member, Dr. Sergiu Dascalu. Without their assistance and dedicated involvement in every step throughout the process, this thesis would have never been accomplished. I would like to thank them very much for their support and understanding over these past years. I would like to express my sincere gratitude to graduate school representative, Dr. Hanif Livani. Last but not least, I would like to thank my friends for their support and my parents for their spiritual and emotional support throughout my life.

This material is based in part upon work supported by the National Science Foundation under grant number (IIS-1719027). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Chapter 1

Introduction

Verbal and nonverbal communication go hand in hand in our day to day life. Nonverbal communication is defined as conveying of feelings, emotions, and messages through expressions and actions rather than words [14]. Human-human interpersonal navigation behavior is governed by social rules, both written and unwritten. Field research with robots has demonstrated the importance placed on robots obeying these rules as well [21]. While automated systems can be created to obey social norms [9], such systems may utilize features of the robot itself in its model of appropriate navigation behavior [2]. An important question is, *at what distance does a person feel comfortable and safe when interacting with a robot?* In order to enhance the quality of communication between humans and robots, a robot should be able to autonomously position itself in a social setting in order to make interaction as comfortable as possible.

Proxemics in the study of nonverbal communication include body movement, touch, verbal, etc. is defined as the study of human use of space [24], establishes rules for both stationary and moving agents. Personal space is the distance between two people such that they both feel comfortable when interacting [16]. For example, authority can be communicated by the height from which one person interacts with another. If one stands while the other sits, the person standing has placed himself or herself in a position of authority. Also, in western countries eye contact is an important part of respectful communication, especially when in a professional work environment. This concept of personal space has been defined as "proxemic zones," which define how people interact with each other namely as shown in Figure 1.1, public (>3.6m), social (1.2m - 3.6m), personal (0.45m - 1.2m), and intimate zone (<0.45m) [13]. These zones are only defined in static distances that don't take into account an agent's motion at all.

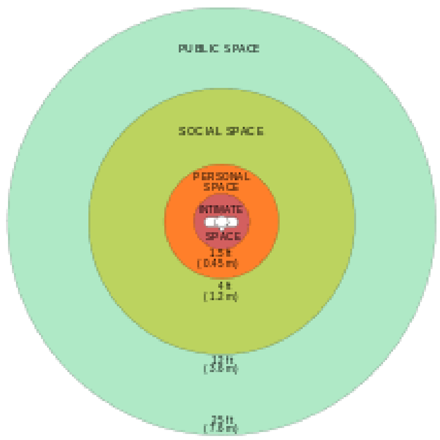

Figure 1.1: Proxemic zones

By contrast, this work examines factors that influence a person's preferred interaction distance beyond just interpersonal distance. In a human-human interaction, moving closer often signals familiarity and greater comfort whereas moving farther often signals strangeness and discomfort. Argyle *et al.* [1] mentioned in his book that factors such as familiarity between people, cultural norms, individual personalities, etc. play a huge role in proxemic behavior. While it is likely that these proxemic zones also exist in human robot interaction scenarios [21], it is also likely that these zones can be different based on features of the robot, user preferences, and relative motion of the two agents. The main goal of this study is to detail more accurately at what physical distance each zone exists when a person is approaching and being approached by a robot. For example, a robot that serves as a caregiver might need to interact with a human in his/her intimate or personal zone whereas an interaction with a robot that provides information in shopping mall needs interact within a person's social zone. We also want to determine if the height of a humanoid robot has a direct effect on the preferred interpersonal distance.

In an follow up study we focused on finding out if the robot's height played a significant role in influencing the size of the human's personal space. In addition, we are interested in knowing the significance of physical distance across all four proxemic zones when a person approached the robot as well as when the robot approached the human. Also, for the experiment we considered how interaction distance between a human and a robot changes with the change in the robot's physical configuration such as arm (extended versus tucked in) and gaze (robot making eye contact with the participant versus robot distracted such as reading a newspaper). Subjective analysis involves human comfort and perceived safety.

The goals of this study are to explore the human and robot factors that influence proxemic behaviors in human-robot interaction and to turn those findings into implications for human-robot interaction design. Through our works one can gain information on factors that have an effect on proxemic zones and apply that knowledge to design and develop better models and optimizing algorithms for human-robot interaction. Human-computer interactions have already started to make use of proxemic distances to alter interactive system behavior [17]. We believe that our work can help researchers to take into account of person's preferred interaction distance in order to create a safe and comfortable interaction.

The following Chapter 2 explores the related works in human-robot personal spaces. Chapter 3 describes individually about experiment design, hardware platform, procedure, conditions, hypothesis, and participant recruitment. Chapter 4 discusses on results followed by Chapter 5 discussion.

Chapter 2

Background

Since early 1920s many psychologists, anthropologists have studied and conducted experiments on proxemic behavior. Proxemics is defined as the study of our perception and structuring of interpersonal and environmental space. The term proxemics was first introduced by an anthropologist Edward T.Hall [13]. Based on extensive observation of humans' use of space Hall developed a notation system of personal space which is used as a measurement in proxemics. The term interpersonal distances is described as the relative distances between people is divided into four distinct zones intimate space, personal space, social space, and public space [12]. The above mentioned zones do not consider the agent's motion and are only defined in static distances. In this section, we outline prior work for both human-human and human-robot proxemic interaction.

2.1 Human-Human Nonverbal Behavior

Studies on interpersonal movement confirmed that males preferred to be approached from the sides whereas females preferred to be approached from the front at the time of interaction [8]. This experiment conducted in Purdue University library had participants being approached from different spatial positions. A feelings scale previously established as a self-report measure of affect developed by Byrne and Clore [5] was used as an indicator of affect. Attraction toward the invader was measured by means of the Interpersonal Judgment Scale [4]. The authors concluded that male and female differences should be taken into account in arranging spatial configurations in public settings.

Walters *et al.* conducted two experiments to study human-robot interaction in the context of an initial encounter with the PeopleBot robot [32]. One study involved 24 groups of 10 children playing an interactive game with the robot and the other study included adults to interactive with the robot in a simulated living room setup. Data obtained from video recordings was used for analysis. The authors concluded that even though children showed more acceptance of the robot compared to adults, they maintained a larger distance compared to adults when interacting with the robot. Similarly in another study [31] their research group claimed that people who had prior experience with the robot preferred a closer interaction distance compared to people who did not have any prior experience with robot's. In order to remove any such bias we made sure that no participant in our study had any prior interaction with robot.

The stop-distance technique is a well-used technique to examine the interpersonal distance at which a person is comfortable [18]. In this technique, one agent is approaches another; a person will say "stop" when s/he feels uncomfortable with the interpersonal distance. This work has shown that some participants required a larger personal space when compared to other participants, especially when approached from a rear angle. Our experiment leverages this stop distance technique to examine preferred interpersonal distance.

Experiments have shown that the size of person's personal space can be influenced by the height of the person who approaches. Human-human proxemics research suggests that people require more space when interacting with a taller agent when compared to smaller agents [6]. An experiment conducted by Hartnett [15] used two experimenters of different height (1.9m and 1.6m) in order to examine the human's personal space distance. In the study the participant was asked to use the stop distance technique by approaching the experimenter. The results obtained show that the height and pose action of the experimenters played a significant role.

2.2 Human-Robot Proxemics

One way people get the attention of another human is by making eye contact or gazing at them to get their attention and let them know they want to interact. If robots are to become part of our lives, we anticipate that the same social norms apply to robots. As a result, gaze may be a very important attribute in gaining the attention of and interacting with a person.

An agent can control the user's impression through parameters that control how it looks at them [10]. The authors developed a gaze movement model and gaze parameters that allows robots to convey different impressions to participants. They concluded that gaze parameters can induce impressions reliably. A robot's actions, such as making eye contact and following a person's gaze, play an important role in the ability to transfer knowledge [27] and also can be an indicator in the trust of a robot [25].

Mumm and Mutlu [21] study manipulated gaze behavior and likeability of a Wakamaru robot. The results showed that participants' who did not like the robot maintained a higher personal space when the robot avoided the gaze. For the participants' who liked the robot their physical distance from the robot remained the same across the gaze behavior. In addition, the authors mentioned that men maintained a greater distance from the robot than women did. However, in our study we are interested in studying the effect of gaze behavior in each proxemic zone. In addition, they used videos captured from the camera to obtain physical distance. At times data obtained from videos do not translate well. To avoid such, in our study we physically measure the distance between the robot and the participant using a measuring tape.

Experimental research work examined whether age and gender has any influence on human preferred distance in human robot interaction by directly considering the height of the robot. Oosterhout and Visser work provided a subjective preferred distance for male and female adults while interacting with a tall and short robot [22]. Results showed that age and gender are a significant factor in determining the preferred interaction distance. This experiment had a variety in age and gender among the participants and used two different robots to study proxemic behavior. However, this experiment only used a visual method for measuring the interaction distance. Participants were not asked to fill out any subjective questionnaires which makes it difficult to get a participant's perspective. Our study makes use of three different robot heights in a laboratory setting. In addition, Walters *et al*. [31] work argued that robot's height was a factor in overall perception, however it did not have any effect on humans proxemic behavior.

Takayama and Pantofaru [30] studied if the method of appraoch i.e., whether robot is being approached by the human or the human being approached affects the human's personal space. Data was collected based of laser scanner reading and later translated for analysis. The authors concluded that the method of approach did not have any significant effect on human's personal space.

Another work involved evaluating the social distance for passage in a corridor environment based on the proxemic rules [23]. Results indicated that entering the intimate sphere of people is less comfortable. This is one of the experiments that considered a very common place of interaction i.e, corridors to study proxemic behavior. On the other hand, this study did not include any factors like participant's age, gender, etc. which play an important role in proxemic behavior. In our study we included participant's gender to investigate if gender play a crucial role in preferred human distance from a robot. Duncan and Murphy [7] studied the comfortable approach distance and height for human interaction using a small unmanned aerial vehicle (sUAV). The sUAV approached a human at above head height and below head height, but was unable to find any conclusive comfort difference.

Studies have shown that human factors such as gender [8], age [32], robot familiarity [31] are among the factors that influence proxemic behavior. Similarly factors such as robot's gaze [10, 27, 25], method of approach [30], height [22] are few of the factors have also been studied to understand their effect during a human-robot interaction. The information provided from these studies can help gain a deep understanding of the factors that most influence human-robot proxemic zones, but a question that still remains unanswered is *at what distance does a person feel comfortable and safe when interacting with a robot?*. To provide a solution, our work examines factors such as participants gender, robot's height, method of approach, robot's gaze and arm positions that influence a person's preferred interaction distance beyond just interpersonal distance. In addition, we also provide values of human's preferred interaction distance so that the robots can engage in acceptable proxemic behaviors.

Chapter 3

Methodology

This chapter is divided into Study 1 and Study 2. An initial experiment referred as *Study 1* is the study that was conducted to investigate if factors such as participants' gender, robot's height, and method of approach have any effect on human personal space. A follow up study referred as *Study 2* investigated the effect of factors such as robot's arm position and robot's gaze behavior on proxemic behavior. This chapter explains in detail on study design, hardware platforms, experiment procedure, experiment conditions, hypothesis, and participant recruitment for both Study 1 and Study 2.

3.1 Study 1: Factors influencing human proxemic behavior

The main purpose of this user study is to investigate the factors influencing preferred interaction distance from a robot considering the robot's height, participant's gender, and method of approach. The objective measure evaluated was the approved physical distance between the robot and human. Subjective analysis includes human comfort and perceived safety.

We designed our study to examine the effects of approach type (robot approaching human or human approaching robot), participant gender, and robot height in a controlled experimental setting, which could be replicated outside the lab in the future. We employed the stop-distance technique in order to obtain an objective measure of where each participant's comfortable interpersonal distance was, given the experimental conditions. We also used subjective measures of the participants' experience to provide further detail about a participant's comfort with the robot's interpersonal behavior.

3.1.1 Experiment Design

We designed a within-participants 2x3x4 experiment with three factors: methods of approach, robot height, proxemic zones. Methods of approach had two levels, human approaching robot and robot approaching human. Robot height had three levels: short, medium, tall. Proxemic zones had four levels: public, social, personal, and intimate. With 40 participants, this results in 960 different data points gathered as data. This will investigate factors affecting the dimensions of personal space for each proxemic zone when a human is interacting with a robot.

Independent variables in our study include the gender of the participant, three different robot heights, two methods of approach. Dependent variables are the size of intimate zone, personal zone, social zone, and public zone. For the three different robot heights we used two different robots as mentioned in Section 3.1.2. Two methods of approach were used in the study. One method of approach is when the participant approaches the robot and the second method is when the robot approaches the participant. Our conditions were tested in a laboratory setting and all participants approach or be approached while standing. The study was conducted inside a laboratory on the University of Nevada, Reno campus.

3.1.2 Hardware Platforms

We used two different robots with three different heights which are described in detail below. These robots were used to change and test the effect if the height of the robot play a role in the size of each proxemic zone. ROS and Choregraphe software allowed us to control the movement of each robot. A robot's movement had to be manually controlled to either stop movement or move it forward. For other materials we used a tape to mark the position of the robot and the participant. The distance between the participant's marked position and the robot's marked position was measured using a measuring tape. The different types of robot and the software that were used in the study are discussed below:

3.1.2.1 Nao

Nao [11] as shown in Figure 3.1 below is an autonomous, programmable humanoid robot developed by Aldebaran Robotics. Nao robots have been used for research, health care, and education purposes in numerous institutions worldwide. The robot is 58cm tall that can move, talk, and is capable of speech and face recognition. NAO contains several sensors, motors, and software driven by NAOqi and also has a dedicated operating system. In addition, the NAO has 25 degrees of freedom for movement, two cameras to visualize its surroundings, an inertial measurement unit that allows the robot to detect if it is upright or sitting down, touch, and four directional microphones.

3.1.2.2 PR2 and PR2 Tall

The PR2 [19] (Personal Robot 2) is an open and robust robot platform designed from the ground up by Willow Garage for software developers and researchers. The PR2 robot is

Figure 3.1: The NAO robot

fully integrated with ROS and allows software experts to immediately create new functionality on the robot. The PR2 robot has backdriveable arms, spring counterbalance, wrist, and gripper for manipulation. The telescoping spine and an omnidirectional base allows for better mobility. Since the spine of the PR2 robot can be adjusted, its height ranges between 133cm (referred as PR2) as shown in Figure 3.2 and 164.5cm (referred as PR2 Tall) as shown in Figure 3.3.

Figure 3.2: PR2 robot with height set at 133cm

3.1.3 Study Procedure

Once the participant had agreed to take part in the study only then s/he was invited to enter the laboratory room along with the researchers. The participants were asked to place any of their personal belongings such as a backpack, water bottle, notebooks, and etc. in one corner of the room so they can freely perform the task. Next, a consent form was provided to the participant to fill out prior to the start of the experiment. Prior to data collection, participants were asked to fill a pre-experiment questionnaire regarding their attitude towards situations and interactions with robots [29].

A demo of the task was then shown prior to any task performed so that participants could get more familiar with the procedure. No training or practice was given to the participants since it may allow familiarity with a particular robot compared to the others. This in turn could skew resulting data. Participants were asked to stand at a marked position referred to as the starting point facing straight towards the robot. The distance between the robot and the starting point was set to 8m. Next, the experimenter briefly explained about each of the four proxemic zones to the participants [12]. The participants were allowed to

Figure 3.3: PR2 robot with height set as 164.5cm referred as PR2 Tall

ask questions to clarify any details that they needed.

One of the three robots as mentioned before was randomly chosen. The participants were asked to perform a task, described in Section 3.1.4. Once the participant completed both tasks for a particular robot, they were given an in-experiment questionnaire [3] asking their impression about the robot. A small 15 seconds break was given to the participants while the experimenters switched to a different robot. The entire process was performed with the other two robots, one after the other in a randomized order. Once the task was completed, the participants were provided with the post-experiment questionnaire, the same as the pre-experiment questionnaire in order to determine any significant changes regarding their attitude towards situations and interactions with robots [29]. In addition the post questionnaire also included details involving demographic data. The entire process for each participant was complete in 18-25 minutes.

Questionnaires were given to the participants towards the end of the study which served as qualitative data for us to examine. Factors that were considered for quantitative data include the distance between the participant and the robot, method of approach, and participant's gender.

3.1.4 Experiment Conditions

There were two movement tasks in this experiment. One task required the participant to move towards a stationary robot and the other task involved the robot to approach a stationary participant. Each of the task are discussed in detail below.

First, an experimenter told the participant which proxemic zone was currently being tested. The proxemic zone was chosen at random in order to avoid any pattern displayed by the participant when approaching the robot. The participant then walked slowly from the starting point towards a robot and stopped when he/she felt that they reached the edge of the indicated proxemic zone as shown in Figure 3.4. After stopping, the researcher recorded the position of both the participant and the robot. Next, the participant was asked to move back to the starting point. The researcher then let the participant know the next proxemic zone being tested. The previous steps were repeated for all four proxemic zones. Once all four proxemic zones were tested, the participants were asked to repeat the entire procedure for the other two remaining robots. Throughout the task the robots remained stationary. After all four proxemic zones for each of the three robots were tested the participant was then asked to perform the second task.

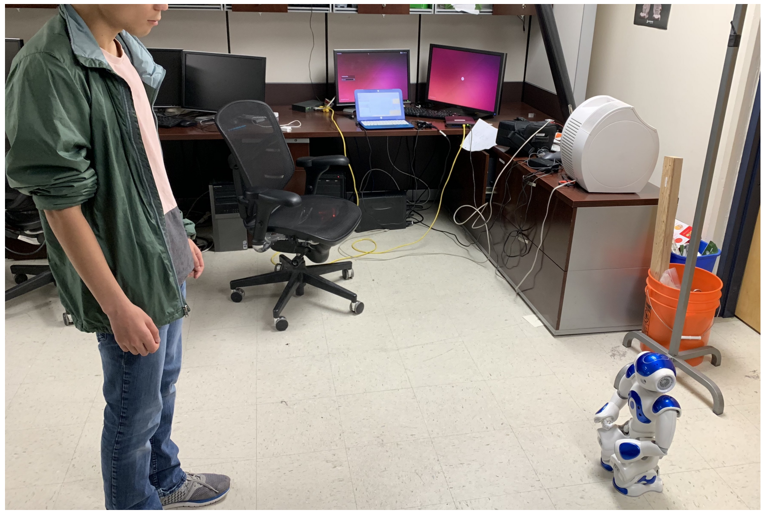

Figure 3.4: Task 1 being performed with the NAO robot in which the participant was asked to approach the personal zone

In the second task the participants were asked to remain standing stationary in the starting point. The robot was placed at a 8m distance from the participant and slowly approached the participant approximately 0.1 m/s. The participants were asked to raise their hand and also say the word “stop" when the robot reached the specified zone. Once a researcher received a stopping signal he stopped the robot as seen in Figure 3.5. The position of the robot was marked and recorded in order to measure the preferred distance between the robot and the participant. Then the robot was moved back to the initial position and the same method were repeated until each of the four proxemic zones were covered. Afterwards, the entire procedure was repeated for the other two remaining robots.

3.1.5 Experiment Hypotheses

Based on our literature review, we constructed hypotheses:

- **H1**: The size of each proxemic zone will differ based on the situation of whether a human is approaching a robot or when a robot is approaching a human.

Figure 3.5: Task 2 being performed with the PR2 robot in which the robot approached the social zone

- **H2**: The size of each proxemic zone will be smaller when men approach the robot or is approached by a robot compared to women.

- **H3**: The size of each proxemic zone is directly proportional to the height of the robot.

3.1.6 Participant Recruitment

We recruited a total number of 40 participants for our study (50% male/50% female) from college students at the University of Nevada, Reno. None of the participants chosen knew about the robots nor they had any prior interaction with a robot. Recruitment occurred through word of mouth. Participants were given snacks for participating in the study.

3.2 Study 2: Robot's gaze and arm position's influence on human proxemic behavior

The main aim of this study was to investigate if the robot's height and the method of approach played a significant role in influencing the size of the human's personal space across all four proxemics zones based of the data collected from our prior work [26]. We also consider how interaction distance between a person and a robot changes depending on the robot's physical configuration such as arm (extended versus tucked in) and gaze (robot making eye contact with the participant versus robot distracted such as reading a newspaper). We employed the stop-distance technique in order to obtain an objective measure of where each participant's comfortable interpersonal distance was, given the experimental conditions. We also use subjective measures of the participants' experience to provide further detail about a participant's comfort with the robot's interpersonal behavior.

3.2.1 Height and Approach

In our prior work we predicted that the size of each proxemic zone will differ based on the method of approach and the height of the robot [26]. After analysing the data, explained in detail in Chapter 4, we found that both the height of the robot as well as the method of approach had a minimal effect across all four proxemic zones in both male and female. To further investigate, we wish to see if there is a correlation between robot's height and preferred interaction distance as well as method of approach and preferred interaction distance in each proxemic zone. We hypothesize that in each proxemic zone for both male and female a positive correlation will be found between robot's height and preferred interaction distance also method of approach and preferred interaction distance. A Pearson's test was conducted to validate our hypothesis.

The Pearson's correlation coefficient *r* is the measure of the strength of a linear association between two variables. The coefficient *r* value ranges from $+1$ to -1. A positive association is denoted for a value greater than 0. This means that the value of one variable increases with the increase in value of other variable. A value less than 0 denotes a negative association meaning that as the value of one variable increases, the value of other variable decreases.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

In this equation *r* represents Pearson's *r* correlation coefficient between x and y. Number of observations is represented by n and x_i and y_i represents the value of x and y for ith observation.

The below Table 3.1 and 3.2 shows the Pearson's *r* coefficient values for both male and female participants across all four proxemic zones on three different robot heights and two different methods of approach.

From Table 3.1 and Table 3.2 it is evident that the Pearson's *r* is close to 0 for all three different robot heights in both methods of approach across all four proxemic zones. Based on the Pearson's correlation test we conclude that the height of the robot nor the method of approach did not play a significant role across all four proxemics zones in case of both male and female participants.

3.2.2 Experiment Design

Based on the existing research in human proxemics and HRI as mentioned in 2, it is evident that both human and robot factors play a significant role in proxemic behavior. In this

	Public	**Social**	**Personal**	**Intimate**
R2H_NAO	-0.204	0.112	-0.026	-0.034
R2H_PR2	-0.067	0.040	-0.031	-0.094
R2H_PR2Tall	0.020	0.079	-0.004	-0.285
H2R_NAO	-0.102	0.091	0.220	0.019
H2R_PR2	-0.001	0.176	0.127	0.297
H2R_PR2Tall	0.041	0.218	0.067	0.104

Table 3.1: The table above represents the Pearson's r coefficient for male across all four proxemic zones and three different robot heights when a person approached the robot (H2R) and the robot approached the (R2H). In every case the r value is close to 0. Contradicting our hypothesis, no correlation was found between robot's height and preferred interaction distance.

	Public	**Social**	**Personal**	**Intimate**
R2H_NAO	0.083	0.156	0.104	0.154
R2H_PR2	0.055	0.197	0.095	0.243
R2H_PR2Tall	0.107	0.137	0.016	0.053
H2R_NAO	0.085	0.133	0.107	0.058
H2R_PR2	0.149	0.135	0.053	0.150
H2R_PR2Tall	0.192	0.142	0.079	-0.167

Table 3.2: The table above represents the Pearson's r coefficient for female across all four proxemic zones and three different robot heights when a person approached the robot (H2R) and the robot approached the (R2H). In every case the r value is close to 0. Contradicting our hypothesis, no correlation was found between method of approach and preferred interaction distance.

study, we present more specific research hypotheses and validate them through a controlled experiment, focusing mainly on the influence of robot's arm position and gaze behavior on personal spaces between people and robot. Analysis from our prior work [26] as mentioned in the above subsection 3.2.1 allowed a few modification for this study. First, we used only one method of approach i.e approaching the robot. Second, only one robot i.e PR2 robot was used to perform this study. This is because based on Table 3.1 and Table 3.2 we find that the method of approach and the height of the robot did not play a significant role in the physical distance between a robot and a person. Next, we limited the proxemic zones to only public, social, and personal zones. Upon further research we believe that intimate zone is mainly reserved for couples, pets, and children [20]. Following the above mentioned, we designed a within-participants 4x3 experiment with two factors: physical configuration of the robot and proxemic zones. The two different physical configurations for each factor include gaze and arm position. Proxemic zones had three levels: public, social, personal. With 30 participants, this results in 360 different data points gathered as data. This will investigate factors affecting the dimensions of personal space for each proxemic zone when a is interacting with a robot.

The independent variables include one for each robot's configuration that can be changed (gaze and arm pose). The dependent variable is the preferred interaction distance for a person. Different robot physical configurations include two different robot's arm position such as robot's arms tucked in and robot's arms extended and the two different gaze behavior involves robot directly looking at the participant and robot being distracted reading a newspaper.

3.2.3 Hardware Platforms

The PR2 [19] (Personal Robot 2) is a humanoid robot platform designed by Willow Garage for software developers and researchers. The robot is controlled using ROS and other open software modules. It is capable of navigating autonomously and manipulating a wide range of objects. The telescoping spine and an omnidirectional base allows for better mobility. Even though the spine of the PR2 robot can be adjusted, for this experiment the robot's height was set at 133cm.

3.2.4 Experiment Procedure

Conditions mentioned in 3.2.2 were tested in a laboratory setting as shown in Figure 3.6 and all participants approached the robot standing. The study was conducted inside a laboratory in the University of Nevada, Reno campus.

The participant was invited to enter the laboratory room along with the researcher only once he/she has agreed to take part in the study. The participants were asked to place any of their personal belongings in one corner of the room so they can freely perform the task 3.2.5. Next, a consent form was provided to the participant to fill out prior to the start of the experiment. Before performing any task, participants were asked to fill a pre-experiment questionnaire regarding their attitude towards situations and interactions with robots [29].

A demo of the task 3.2.5 was then shown prior to any task performed so that participants could get more familiar with the procedure. No training or practice was given to the participants since it may allow familiarity with a particular robot compared to the others. This in turn could skew resulting data. Participants were asked to stand at a marked position

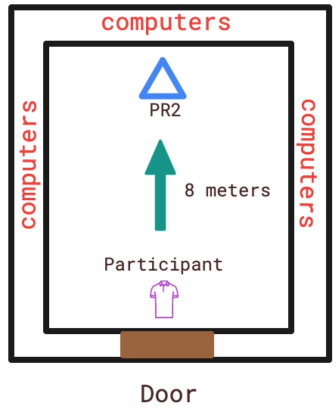

Figure 3.6: *Lab setup* - There is bank of computers around the edge of the room and the PR2 robot denoted by a blue triangle is placed at the end of the lab. The participant is positioned close to the lab entrance and a distance of 8 meters is maintained between the robot and the participant.

referred to as the starting point facing straight towards the robot. The distance between the robot and the starting point was set to $8m$. Next, the experimenter briefly explained about each of the three proxemic zones to the participants [12]. The participants were allowed to ask questions to clarify any details that they needed.

The robot's physical configuration was chosen at random. The participants were asked to perform a task, described in Section 3.2.5. Once the participant completed the task they were given an in-experiment questionnaire [3] asking their impression about the robot. A small 10-12 seconds break was given to the participants while the experimenters changed the physical configuration of the robot. Once the task was completed, the participants were provided with the post-experiment questionnaire, the same as the pre-experiment questionnaire in order to determine any significant changes regarding their attitude towards situations and interactions with robots [29]. In addition, the post questionnaire also included details involving demographic data. The entire process for each participant was complete in 12-15 minutes.

3.2.5 Experiment Conditions

The task required the participant to walk towards a stationary PR2 robot in four different physical configurations. The four physical configurations include robot's arms tucked in, robot's arms extended, robot making eye contact with the participant, and robot distracted reading newspaper.

The selection of robot's physical configuration and the proxemic zone that was being tested was chosen at random in order to avoid any display of pattern by the participant at the time of approaching the robot. The experimenter made sure that the participant understand the meaning and definition of each of the three proxemic zones. The participant then walked slowly from the starting point towards a robot and stopped when he/she felt that they reached the edge of the indicated proxemic zone as shown in Figure 3.8 when testing robot's arm position and Figure 3.7 when gaze factor was being tested. After stopping, the researcher recorded the position of both the participant and the robot. Next, the participant was asked to move back to the starting point. The researcher then let the participant know the next proxemic zone being tested. The previous steps were repeated for the remaining proxemic zones. Once all three proxemic zones were tested, the participants were asked to repeat the entire procedure for the remaining configurations.

Figure 3.7: PR2 robot demonstrating two different arm positions. **left:** PR2 robot's arms extended when participant approaches the robot; **right:** PR2 robot's arms tucked in at the time when participant approaches the robot.

Figure 3.8: PR2 robot displaying two different gaze behaviors. **left:** PR2 robot making eye contact with the approaching participant; **right:** PR2 robot distracted reading newspaper when participant approaches the robot.

3.2.6 Experiment Hypotheses

Based on our review, we constructed the following hypotheses at the time when a person approaches the robot for interaction:

- **H1**: The personal space will be larger when the robot's arms are extended compared to when the robot's arms are tucked.
- **H2**: The personal space will be larger when the robot is distracted compared to when the robot gazing at the person.

3.2.7 Participant Recruitment

We recruited a total number of 30 college students for our study (15 female and 15 male) from the University of Nevada, Reno. None of the participants chosen took part in our prior experiment nor had they any prior interaction with a robot. Recruitment occurred through word of mouth.

This chapter explained in detail on study design, hardware platforms, experiment procedure, experiment conditions, hypothesis, and participant recruitment for both Study 1 and Study 2. In addition, Pearson's correlation test was used to find out if any correlation between the robot's height and preferred interaction distance as well as well as method of approach and preferred interaction distance exists. The following Chapter 4 includes detailed analysis on all collected data in order to evaluate our proposed hypothesis mentioned in Section 3.1.5 and Section 3.2.6.

Chapter 4

Result

This chapter is divided as Study 1 and Study 2. An initial experiment referred as *Study 1* is the study that was conducted to investigate if factors such as participants' gender, robot's height, and method of approach have any effect on human personal space. A follow up study referred as *Study 2* investigated the effect of factors such as robot's arm position and robot's gaze behavior on proxemic behavior. We analyzed all collected data to evaluate how well it proved the hypotheses enumerated in Section 3.1.5 and Section 3.2.6. We ran an ANOVA analysis on the sole dependant variable collected across all levels of this experiment: Measured Proxemic Zone Size.

4.1 Study 1: Factors influencing human proxemic behavior

4.1.1 Hypothesis 1

H1 asserted that the size of each proxemic zone will differ based on the situation whether a human is approaching a robot or when a robot is approaching a human. The chart visible in Figure 4.1 shows that there is a subtle difference in the recorded values of measured

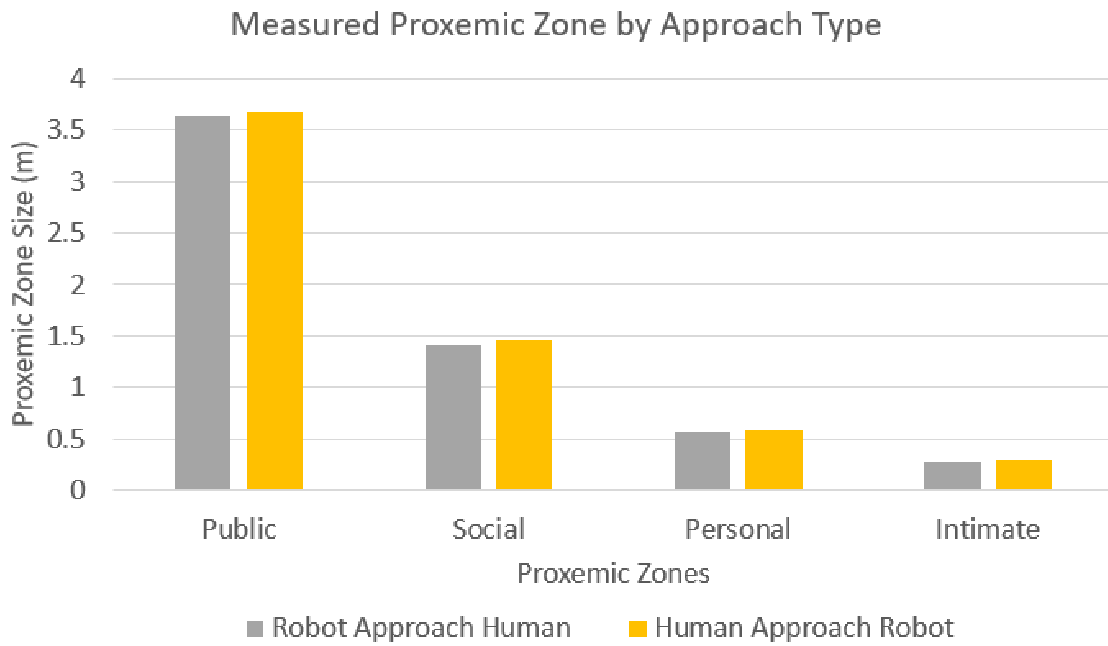

Figure 4.1: Averages of absolute distances of measured proxemic zones organized by approach type. Supporting **H1**, proxemic zones were smaller, in general, when robots approached humans compared to humans approaching robots. Upon further analysis we found no statistically significance ($F_{1,38} = 9.437$, $p < .01$) in proxemic size when averaged across all robots and both genders.

proxemic distance when averaged across all robots and both genders.

The difference in these measurements appear minimal (.032 meters for the public zone, 0.034 for the social zone, .004 meters for the personal zone and 0.017 meters for the intimate zone). Using an ANOVA ($F_{1,38} = 9.437$, $p < .01$), we found a significant difference in how close respondents judge a proxemic zone when approaching a robot compared to being approached by robot; respondents consistently stopped the robots closer upon approach to themselves compared with their approach to the robot. Analysis of interaction effects with approach type showed no statistically significant interactions between the method of approach with gender, robot height and the chosen interaction zone.

If we take the measured proxemic zone to be an indicator of social comfort and appropriate use of social space, these data indicate that participants were more comfortable being approached by a robot compared to approaching a robot. It is important to know that the operator's reaction time could have been involved in the subtle difference obtained between the approach types. No other independent variables played a significant role when the approach type was varied. This supports our conclusions about the effect of approach type on measured proxemic distance. However, the effect size is very minimal.

4.1.2 Hypothesis 2

For **H2** we predicted that the size of each proxemic zone will be smaller for men compared to women. Figure 4.2 shows the differences in measured proxemic zone as divided by respondent gender averaged across all robot heights and approach types. When juxtaposed against Figure 4.1, it appears that gender plays a significant role on the measured proxemic zone with male participants consistently allowing robots closer to them regardless of the approach method. Accordingly, this strongly supports our hypothesis that the proxemic zone will be smaller for males compared to females.

Numerically, this measured difference is higher in the social and personal proxemic zones, with relative differences of 31% and 19% respectively. It was lower for the public and intimate zones at 10.8% and 10.4% respectively. These measured values based only on the factor of gender were found to be statistically significant ($F_{1,38} = 9.201$, $p < .01$).

When looking at the independent variable of gender alone it can be hard to deduce exactly what might cause this large discrepancy without devolving into speculation. However, when we look at the interaction effect between gender and the robot height ($F_{2,76} = 4.039$, $p < .05$) this may give us some better clues as to what causes this gender based discrepancy in measured distance. In Table 4.1 we can see that gender-based differences between measured distance widen with the PR2 Tall when compared the PR2 and the NAO.

This intuitive examination is supported with an post-hoc analysis of the collected data averaged across approach type and proxemic zone. Of the 15 unique combinations analyzed by the post-hoc test the most meaningful, statistically significant, interaction was between gender and the PR2 Tall robot. Direct comparisons between genders and robot height with the NAO and PR2 were not statistically significant. When we compare this against the average heights of men and women surveyed we find an interesting relationship.

The average height of men studied in this experiment was 179.07 centimeters and the average height of women studied was 157.60 centimeters. Men averaged 15cm taller than the PR2 Tall robot, whereas women were 7cm shorter than the PR2 Tall robot, on average. As height is a cue for dominance, the difference in relative heights might explain the gender effects that were observed in this study. It should be noted that there are possibly other factors which influence this difference as there was a consistent difference across robots, however a more focused study may be needed to make more concrete conclusions.

4.1.3 Hypothesis 3

For **H3**, we predicted that the size of each measured proxemic zone would be directly proportional to the height of the robot. As can be seen in Figure 4.3, which shows an average of measured proxemic zones divided by each particular robot, we can see that this hypothesis holds true. Regardless of gender, or interaction method, individuals studied in this experiment gave the NAO a smaller distance for the public, social, personal, and intimate zones when compared with the PR2 and PR2 Tall. This distance difference held between the PR2 and PR2 Tall as well with the PR2 Tall being given a wider berth across all social zones.

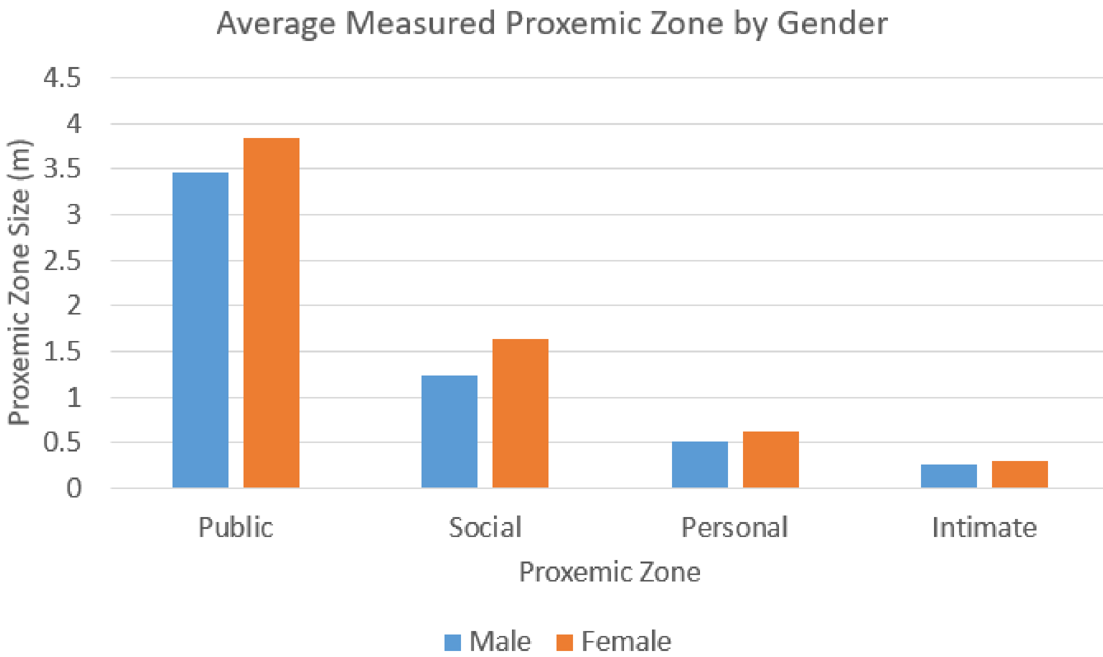

Figure 4.2: Averages of absolute distances of measured proxemic zones organized by gender. Proxemic zones are noticeably and consistently smaller for men compared to women across all proxemic zones. Further analysis of variable interactions with the type of robot shows statistically significance ($F_{1,38}$ = 9.201, $p < .01$) that these differences are more pronounced as the height of interacted robots increases, supporting **H2**

This effect of the robot height on measured proxemic zone was found to be statistically significant via an ANOVA analysis ($F_{2,76}$ = 188.019, $p < .001$). In addition to the aforementioned interaction effect between robot and gender there was also a statistically significant interaction effect between robot and a particular zone of interaction. This interaction effect indicates that the measured proxemic distance scales with both the robot being interacted with in addition to the proxemic zone we are evaluating. This effect can be seen very clearly by the proportionate downscaling of measured distances across zones and robots in Figure 4.3.

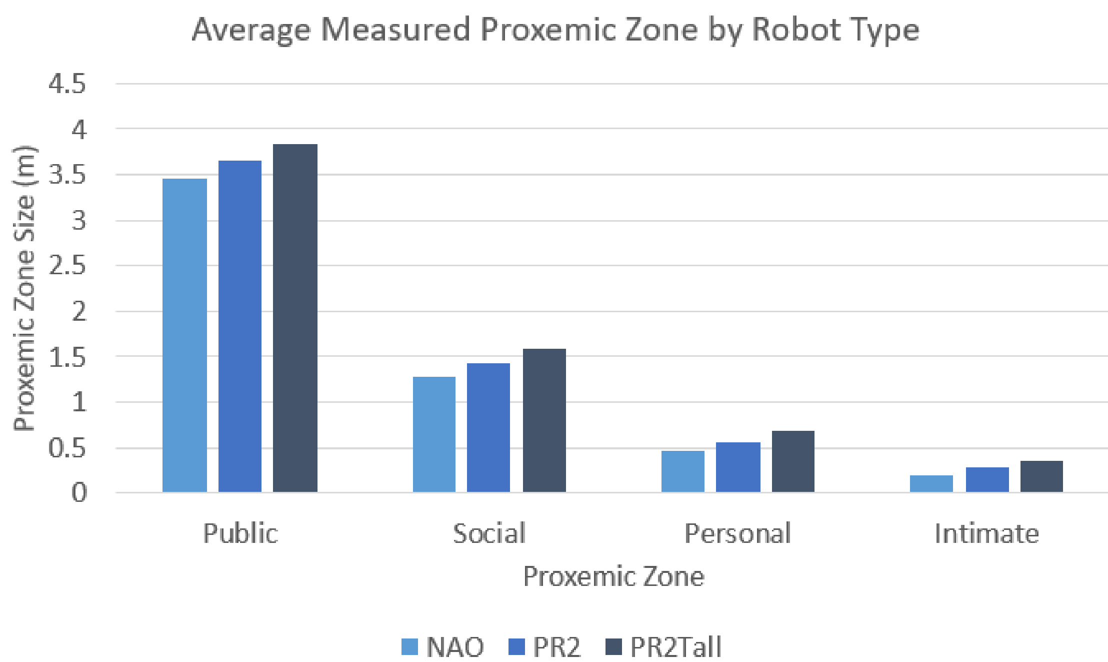

Figure 4.3: Averages of all measured proxemic zones organized by robot type. Supporting **H3**, a direct correlation between the height of a given robot and the measured proxemic zone shows statistically significance ($F_{2,76}$ = 188.019, p < .001) across all zones in this graph.

4.1.4 Additional Results

As was detailed in Section 3 users were given pre- and post-test surveys to see if this experiment made any measurable differences on their attitudes and perceptions toward robots. We asked seven Likert-scale questions, ranged 1-5 with 1 being strongly disagree and 5 being strongly agree, about the participants' feelings towards robots, such as: participants safety, nervousness, uneasiness, distrust, and robot's decision making skills when interacting with robots. A paired t-test was used to evaluate if the user study can change a participant's opinion about robots. The results obtained through the test showed no statistical significance ($t = 0.399$, $p > 0.5$) which shows that the robot experience did not have any short-term effect on the participants' opinion about robots.

Robot Approach Human											
NAO				PR2				PR2 Tall			
Public	Social	Personal	Intimate	Public	Social	Personal	Intimate	Public	Social	Personal	Intimate
3.262	1.1	0.43	0.18	3.47	1.22	0.52	0.26	3.62	1.32	0.60	0.33
3.60	1.43	0.51	0.21	3.82	1.601	0.60	0.29	4.045	1.826	0.742	0.36

Human Approach Robot											
NAO				PR2				PR2 Tall			
Public	Social	Personal	Intimate	Public	Social	Personal	Intimate	Public	Social	Personal	Intimate
3.34	1.14	0.41	0.19	3.49	1.27	0.52	0.29	3.62	1.38	0.63	0.35
3.63	1.45	0.52	0.22	3.87	1.64	0.61	0.30	4.07	1.82	0.75	0.38

Table 4.1: A table showing averages of all measured proxemic zones organized by approach type, robot type and social zone. The top row in both tables is measurements averaged across all 20 male respondents and the bottom row is measurements averaged across all female participants. All measurements are in meters.

4.2 Study 2: Robot's gaze and arm position's influence on human proxemic behavior

4.2.1 Hypothesis 1

For **H1** we predicted that the personal space will be larger when the robot's arm extended compared to when the robot's arms are tucked in. Supporting our statement, Figure 4.4 shows the differences in measured proxemic zone averaged across the two different arm positions of the robot. The average physical distance between the person and the PR2 robot when the robot's arms were tucked in was 3.50 meters in public zone, 1.39 meters in social zone, and 0.52 meters in personal zones. When the robot's arms were extended the average was found to be 3.56 meters, 1.55 meters, and 0.61 meters for public, social, and personal zones as shown in Table 4.2.

This effect of the robot's arm position on measured proxemic zones was found to be statistically significant via an ANOVA analysis ($F_{1,38} = 6.621$, $p < .02$). This further supports our hypothesis showing that people prefer a larger physical space when the robot's

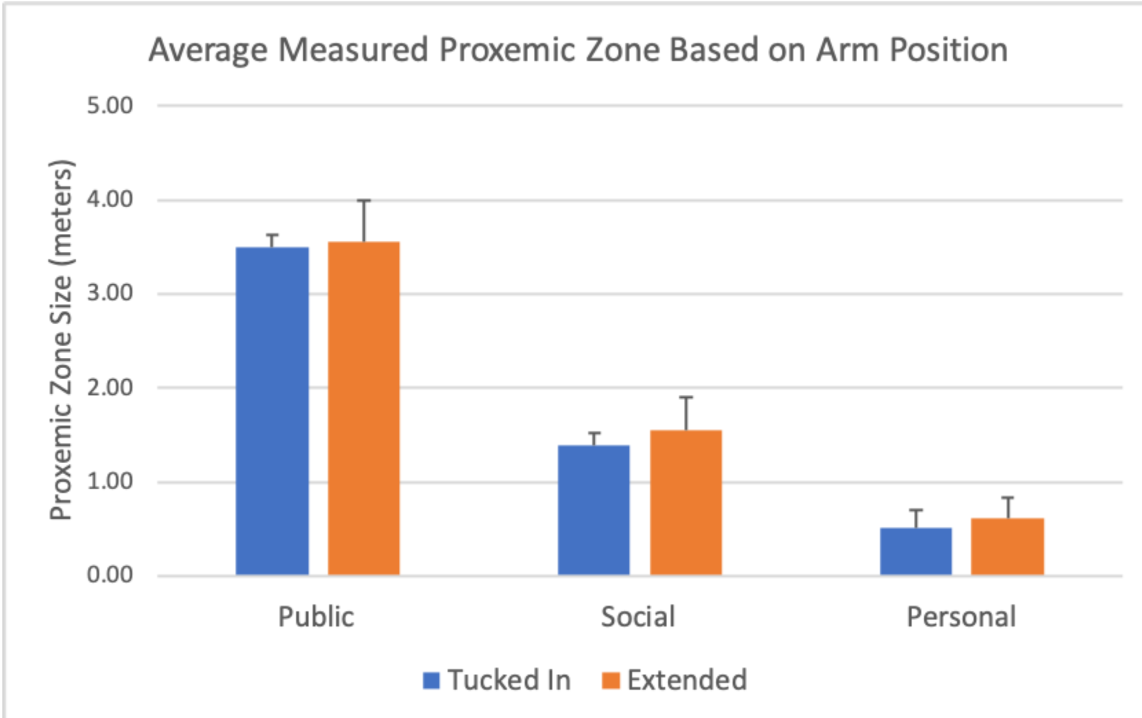

Figure 4.4: Averages of absolute distances of measured proxemic zones organized based on arm position. Proxemic zones are noticeably and consistently smaller when robot's arms are tucked in across all proxemic zones. Further analysis shows statistically significance ($F_{1,38}$ = 6.621, p $<$ .02) that these differences are more pronounced supporting **H1**

arms are extended compared to when the robot's arms are tucked In.

4.2.2 Hypothesis 2

H2 asserted that the personal space will be larger when the robot is distracted compared to the robot making eye contact when a person is approaching the robot. The chart visible in Figure 4.5 shows that there is a subtle difference in the recorded values when averaged across each measured proxemic distance based on robot's gaze.

The difference in these measurements appear minimal as shown in Table 4.2 ($.01$ meters for the public zone, 0.04 for the social zone, and $.1$ meters for the personal zone). Using an ANOVA ($F_{1,38}$ = 6.400, p $<$ .01) we found a significant difference in how close respondents

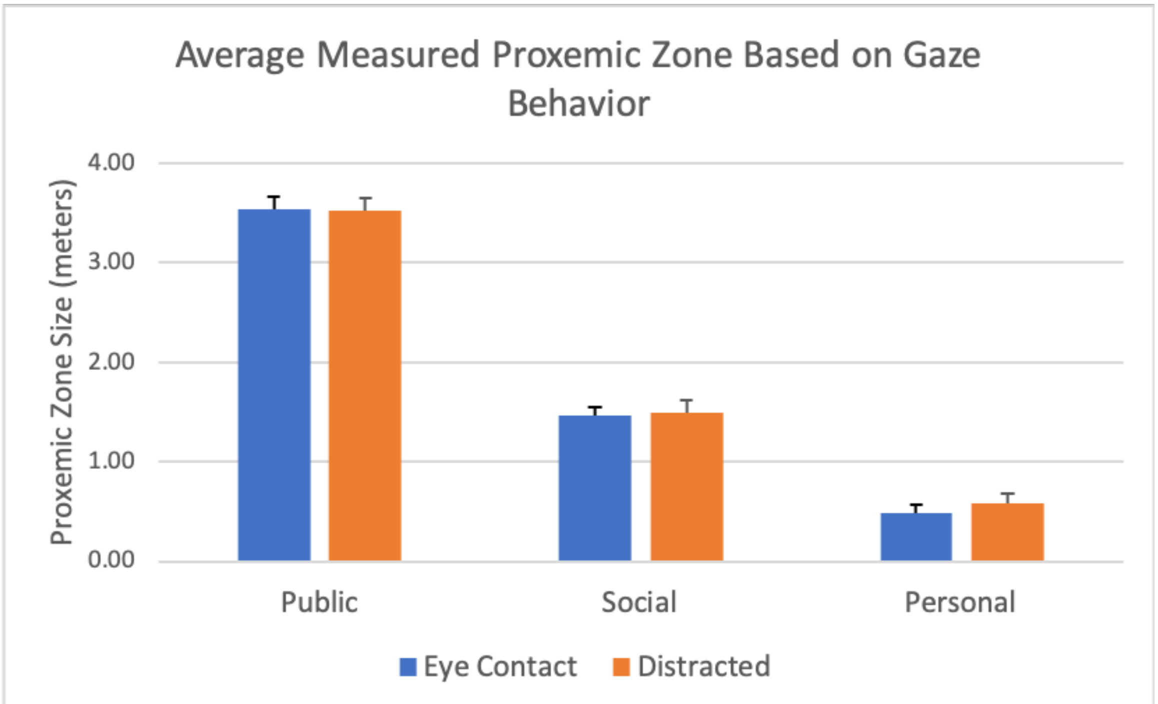

Figure 4.5: Averages of absolute distances of measured proxemic zones organized based on robot's gaze. Supporting **H2**, proxemic zones were smaller, in general, when robot was making eye contact with the human. Upon further analysis we found statistically significance ($F_{1,38} = 6.400$, $p < .01$) when averaged across all measured proxemic zones.

judge a proxemic zone when the robot's was making eye contact compared to the robot was distracted reading a newspaper when the participant approached the PR2 robot. This supports our initial hypothesis that people prefer a larger personal space when the robot is distracted compared to when the robot was directly looking at the person approaching the robot. It is important to know that the operator's reaction time could have been been involved in the subtle difference obtained between the approach types.

4.2.3 Additional Results

To evaluate if this experiment made any measurable differences on participants attitudes and perceptions toward robots, participants were given a survey before beginning the experiment and again once after completing the task as was detailed in Section 3. There

	Public	**Social**	**Personal**
Eye Contact	3.53	1.46	0.49
Distracted	3.52	1.50	0.59
Arm Tucked In	3.50	1.39	0.52
Arm Extended	3.56	1.55	0.61

Table 4.2: The table denotes values (in meters) of preferred interaction distance with the robot in two different robot's physical configuration (gaze and arm position) across three proxemic zones.

were a total of seven Likert-scale questions regarding the participants' feelings towards robots, such as: participants safety, nervousness, uneasiness, distrust, and robot's decision making skills when interacting with robots. The options ranged 1-5 with 1 being strongly disagree and 5 being strongly agree. A paired t-test showed a small statistical significance ($t = 0.7135$, $p < 0.5$) that was used to evaluate if the user study can change a participant's opinion about robots. Based on observation and the results obtained through the test one can say that the participants' experience with the robot did have some short-term effect on the participants' opinion about robots.

Chapter 5

Discussion

The aim of our initial work was to examine the factors that influence human preferred interaction distance in canonical proxemic zones for two movement types. Factors included the participant's gender, robot's height, and method of approach. The results indicated that all three of these factors did have a measurable impact on the proxemic zone across all 40 participants.

In a follow up study we investigate how interaction distance between a human and a robot changes with the change in the robot's physical configuration such as arm (extended versus tucked in) and gaze (robot making eye contact with the participant versus robot distracted such as reading a newspaper). In addition, we further analyse the results obtained from our prior work to investigate if the robot's height and method of approach played a significant role in influencing the size of the human's personal space in each proxemic zone.

By using an systematic method of hypothesis testing with the aid of ANOVA analyses on our collected data, we determined that all of our hypotheses held true for both experiments. The method of approach *did* impact the size of our measured proxemic zone. The gender of study participants *did* have an impact on proxemic zone size and, more specifically it was smaller for men compared to women. The size of each proxemic zone *was* directly proportionate to the height of the robot being approached by or approaching the participant. Across all zones it held true that the PR2 Tall provoked a larger zone compared to the PR2 and the NAO. Also, people *did* require a larger physical distance when the robot's arms were extended as supposed to when the robot's arms were tucked in. Finally, participants' maintained a larger distance when the robot was distracted compared to when the robot was gazing at a person when he/she approached the robot.

A Pearson's correlation test concluded no correlation between the robot's height and preferred interaction distance as well as well as method of approach and preferred interaction distance. Finally, based on the survey results one can say that the participant's experience with the robot did have a small effect in their opinion regarding the robot.

From these results we can make a few conclusions about nonverbal communication between humans and robots. First, a smaller robot will likely be favorable for social interactions over a tall one. A similarity between a human-robot interaction and a human-human interaction based on height can be seen through the results obtained in this experiment and a study conducted by Buunk *et al.* helps shows that height has influence on behavioural outcomes [28]. Next, women and men seem to perceive robots and interact with them differently, possibly a height effect. Finally, humans seem slightly more comfortable with robots approaching them compared to when they approach robots themselves based on our observation. People feel more safe and comfortable when the robot's arms are tucked in and also when the robot is directly gazing at the person during interaction compared to when the robot's arms are extended and when the robot is distracted. This could mean that humans are generally comfortable with robots as active social participants, entering into social spaces like humans.

Future work will examine similar factors in public places in order to obtain real world data. We would also include additional factors, such as angle of approach, handedness, etc. Additionally we would add open ended questions for participants to provide feedback on our user study.

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