Bachelor Project

Czech
Technical
University
in Prague

F3

Faculty of Electrical Engineering
Department of Cybernetics

# Personal Spatial Zones in Human-Robot Interaction Scenarios

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**Field of study: Cybernetics and Robotics**
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# BACHELOR‘S THESIS ASSIGNMENT

## I. Personal and study details

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Study program: **Cybernetics and Robotics**

## II. Bachelor’s thesis details

Bachelor’s thesis title in English:

**Personal Spatial Zones in Human-Robot Interaction Scenarios**

Bachelor’s thesis title in Czech:

**Osobní prostorové zóny v interakci člověka s robotem**

Guidelines:

1. Implementation of interaction behaviors consisting of torso, arm, and head movements of the Nao and Pepper robots (e.g., look at human, defensive / startle reaction).
2. Perception of the human partner - used as behavioral triggers - will involve:
a) detection and localization of human face and distance measurement from robot camera or RGB-D sensor (Intel Realsense) mounted on the robot or externally
b) use of data from tactile sensors
3. Study on proxemics. In human-robot interaction experiments, participants will be asked to approach the robot. Upon entering its personal or intimate zone, the robot will respond to signal that (e.g.. gazing, leaning back). Through questionnaires, we will study how people interpreted the robot behavior and also the effect of robot size on the extent of robot personal spatial zones people expect.
4. Study on touch/startle. In these experiments, participants will be asked to touch the robot. The robot will respond to demonstrate its surprise. How participants rate these responses will be assessed through questionnaires and interviews.
5. If time permits, based on the results obtained in 3. and 4., robot behaviors will be redesigned.

Bibliography / sources:

[1] E. T. Hall, R. L. Birdwhistell, B. Bock, P. Bohannan, A. R. Diebold Jr, M. Durbin, M. S. Edmonson, J. Fischer, D. Hymes, S. T. Kimball, et al., “Proxemics [and comments and replies],” Current Anthropology, vol. 9, no. 2/3, pp. 83–108, 1968.
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## III. Assignment receipt

The student acknowledges that the bachelor's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor's thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt

Student's signature

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# Declaration

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university theses.

Prohlašuji, že jsem předloženou práci vypracoval samostatně a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

V Praze, 5. ledna 2021

# Abstract

Social robots are intelligent agents developed to interact with people in a socially acceptable way. The human-robot interaction field is becoming increasingly important, for the robots are expected to create a positive impression and communicate adequately even under challenging circumstances. Nonverbal cues, such as movements, gestures, and body posture, are part of a research field called proxemics and constitute a key component of human-robot communication. In this work, we study two aspects in particular: interpersonal distances and responses to touch. Experiments with two humanoid robots of different sizes, Nao and Pepper, were conducted in two scenarios. Around 100 participants took part and filled personality questionnaires (TIPI) and rated the robot behavior using the Godspeed questionnaire. In the first scenario, participants played a simple game with the robot, while the robot responded to an intrusion of its personal spatial zones (personal and intimate) by gazing and leaning back. We studied the appropriateness of the robot behaviors and whether the participants expect these zones to scale with robot size. On average, participants stopped 76 cm away from the Nao and 74 cm from the Pepper, which is within the personal zone for humans and suggests that the robot size is not taken into account. The lean-back behavior was often correctly recognized as signaling the intrusion of the robot's intimate zone. In the second scenario, participants were asked to approach a robot that was looking away and touch the robot's hand. The robot displayed a startle reaction, and the particular form of this reaction was assessed. We introduced lean-back behavior into the field and found possible paths in the matter of unexpected touch that can be explored further.

**Keywords:** Personal spatial zones, Humanoid robots, proxemics, Interpersonal distances, Physical touch

**Supervisor:** Mgr. Matěj Hoffmann, Ph.D.

# Abstrakt

Sociální roboti jsou inteligentní agenti vyvinutí pro interakci s lidmi sociálně přijatelným způsobem. Odvětví interakce člověk-robot se stává stále důležitějším, protože se od robotů očekává, že budou zanechávat pozitivní dojem a budou adekvátně komunikovat i za náročných okolností. Neverbální podněty, jako jsou pohyby, gesta a držení těla, jsou součástí oboru zvaného proxemika a představují klíčovou součást komunikace člověka s robotem. V této práci studujeme zejména dva aspekty: mezilidské vzdálenosti a reakce na dotyk. Experimenty s humanoidními roboty různých velikostí, Nao a Pepper, byly provedeny ve dvou scénářích. Měli jsme přibližně 100 účastníků, kteří vyplnili osobnostní dotazníky (TIPI) a ohodnotili chování robota pomocí dotazníku Godspeed. V prvním scénáři účastníci hráli s robotem jednoduchou hru, zatímco robot reagoval na narušení svých osobních prostorových zón (osobní a intimní) - pohledem a záklonem. Zkoumali jsme vhodnost chování robotů a to, zda účastníci očekávají, že se tyto zóny budou měnit s velikostí robota. V průměru se účastníci zastavili 76 cm od Nao a 74 cm od Peppera, což je v osobní zóně pro lidi a naznačuje to, že na velikosti robota nezáleží. Záklon byl často správně interpretován jako signalizace narušení intimní zóny robota. Ve druhém scénáři byli účastníci požádáni, aby se přiblížili k robotovi, který se díval jinam, a dotkli se jeho ruky. Robot zareagoval záklonem s pohybem rukou. Účastníci následně posoudili konkrétní formu této reakce. Do odvětví interakce člověka s robotem jsme přispěli novou reakcí záklonem a našli jsme prostor pro rozvoj výzkumu reakcí na neočekávaný dotyk u robotů.

**Klíčová slova:** Peripersonální prostor, Humanoidní roboti, Proxemika, Mezilidské vzdálenosti, Fyzický dotyk

**Překlad názvu:** Osobní prostorové zóny v interakci člověka s robotem

# Contents

# Chapter 1

# Introduction

## 1.1 Motivation

Over the last decade, we have witnessed a significant leap in robotic technology. Using robots in such crucial spheres as medicine, agriculture, manufacturing industry, defense, and service creates a reasonably compelling argument for the conduction of high-quality, in-depth research in the field. This thesis focuses on social robots – intelligent agents developed to interact in a socially acceptable way. This kind of robot might be of practical value in retirement homes for the aged and facilities for disabled people as caregivers or support staff. Right now, social robots are recruited into advertising campaigns to enhance customer experience, as well as being presented at exhibitions and similar events for reasons of science, technology, engineering, and mathematics popularization.

This human-robot interaction study has been motivated by the prospects of using social robots in everyday situations. These prospects require that we significantly improve the efficiency and quality with which robots interact with human partners. It appears to be an insurmountable obstacle without incorporation into robotics knowledge from other fields like humanities and neurosciences. Robots of the future should have no difficulties expressing nor recognizing their interactional partners' emotions, have natural movements and reactions.

We now know that humans are susceptible to the intrusion into their different Personal Spatial Zones (PSZs). This work is driven by the desire to understand if people expect a robot to have its own PSZs. And if the robot does, what would they depend upon? In case its personal zones are invaded, what reactions would people expect the robot to display? This question is especially relevant in light of a recent publication [GMCM19] dealing with robot safety constraints for navigation through the cluttered environment.

## 1.2 Objectives

Our research seeks:

- to understand whether the size of the robot affects the extent of PSZs people expect the robot to have
- to determine how people interpret the robot behavior in case they enter its personal/intimate zone
- to find out how people evaluate different robot startle reactions to an unexpected touch

# Chapter 2

# Related work

The implementation relied on works from Human-Robot Interaction (HRI) field, which emerged and depends on collaboration between various fields, such as anthropology, psychology, robotics, and computer science [BBE+20]. The chapter will mainly focus on two aspects of the project: Proxemics in HRI and Human-Robot Touch Interaction.

## 2.1 Proxemics in HRI

For assessment of human interaction, Hall [HBB+68] proposed a five-distance classification that depends on culture, relationship, activity, and emotions present in a given situation. For Northern Europeans, those distances are shown in Table 2.1.

| PSZ | Range | Situation |
|---|---|---|
| Close Intimate | 0 to 0.15m | Lover or close friend touching |
| Intimate Zone | 0.15m to 0.45m | Lover or close friend only |
| Personal Zone | 0.45m to 1.2m | Conversation between friends |
| Social Zone | 1.2m to 3.6m | Conversation between non-friends |
| Public Zone | 3.6m + | Public speech |

**Table 2.1:** Human Personal Spatial Zones (PSZ) for northern Europeans according to Lambert [Lam04].

Marshal Durbin [HBB+68] highlighted the clarity of the proposed model. However, as Baldassare [BF75] pointed out, there are contradictions in some of Hall's statements that require further cross-cultural and sub-cultural studies.

Hall's model is assumed to be a plausible approximation for the latter Proxemics scenario 4.4.3, where the robot reacts to a human approaching the robot in a designed situation. The model is commonly used across HRI, as in [HEGT06, OSZ+16, WDTB+09, MM16]. Experiments such as [TCJvdP11, SSMI18] used two-dimensional Gaussian function from [ALSN09] for higher accuracy. Studies related to proxemics are abridged in Table 2.2, containing an overview of the experimental setups, distance models, and the resulting distances.

| Author | Robot | Robot appearance | Robot size [cm] | Robot pose | Human pose | Scenario | Approach HR/RH | Robot on a platform? | Robot on wheels? | Distance model | Distance average [cm] | Delay in interaction [ms] | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Huttenrauch [HEGT06] | PeopleBot | short mechanic | 112 | Standing | Standing | Follow/Show/Validate | HR, RH | No | Yes | Hall | - (personal zone) | operator | No detailed measures, data from 1 Hz video and ultrasound sensor. |
| Walters [WDTB+09] | PeopleBot | short mechanic | 120 | Standing | Standing | Human approaching until comfortable | HR | No | Yes | Hall | 45 | 150 - 300 | Fuzzy logic distance calculation with great variance (mechanoid, HR, giving object, preferred short from RH approach). |
| Walters [WDTB+09] | PeopleBot | short humanoid | 120 | Standing | Standing | Human approaching until comfortable | HR | No | Yes | Hall | 51 | 150 - 300 | Fuzzy logic distance calculation with great variance (humanoid, HR, giving object, preferred short from RH approach). |
| Walters [WDTB+09] | PeopleBot | tall mechanic | 140 | Standing | Standing | Human approaching until comfortable | HR | No | Yes | Hall | 42 | 150 - 300 | Fuzzy logic distance calculation with great variance (mechanoid, HR, giving object, preferred tall from RH approach). |
| Walters [WDTB+09] | PeopleBot | tall humanoid | 140 | Standing | Standing | Human approaching until comfortable | HR | No | Yes | Hall | 48 | 150 - 300 | Fuzzy logic distance calculation with great variance (humanoid, HR, giving object, prefered tall from RH approach). |
| Siegel [Sie09] | MDS | short humanoid | 121 | Standing | Standing | Handshake/Speaking | HR | No | Yes | - | - | operator | Participants were shown to stand at 76 cm or 152 cm. Females sightly prefered closer distance, for males it had negative effect. |
| Mumm [MM11] | Wakamaru | short humanoid | 91 | Standing | Standing | Male reads text on robot's back while mutual gaze | HR | No | Yes | - | 100 | - | Distance estimated from pixels with ±5 cm |
| Mumm [MM11] | Wakamaru | short humanoid | 91 | Standing | Standing | Male reads text on robot's back while averted gaze | HR | No | Yes | - | 118 | - | Distance estimated from pixels with ±5 cm |
| Mumm [MM11] | Wakamaru | short humanoid | 91 | Standing | Standing | Male reads text on robot's back while mutual gaze | HR | No | Yes | - | 102 | - | Distance estimated from pixels with ±5 cm |
| Mumm [MM11] | Wakamaru | short humanoid | 91 | Standing | Standing | Male reads text on robot's back while averted gaze | HR | No | Yes | - | 108 | - | Distance estimated from pixels with ±5 cm |
| Obaid [OSZ+16] | Nao | short humanoid | 50 | Standing | Standing | Human approaching until comfortable | HR | No | No | Hall, Agryle | 50 | operator (1 sec) | Delay due to lag. |
| Obaid [OSZ+16] | Nao | short humanoid | 42 | Standing | Standing | Robot approaching until comfortable | RH | No | No | Hall, Agryle | 42 | operator (1 sec) | Delay due to lag. Distance estimated from graph. |
| Obaid [OSZ+16] | Nao | short humanoid | 35 | Sitting | Standing | Human approaching until comfortable | HR | No | No | Hall, Agryle | 35 | operator (1 sec) | Delay due to lag. |
| Obaid [OSZ+16] | Nao | short humanoid | 52 | Standing | Sitting | Robot approaching until comfortable | RH | No | No | Hall, Agryle | 52 | operator (1 sec) | Delay due to lag. Distance estimated from graph. |
| Mead [MM16] | - | human | - | Standing | Standing | Comfortable speaking distance | HH | No | No | Hall | 144 | - | Constant with literature in HH scenario. |
| Mead [MM16] | PR2 | tall mechanic | 164 | Standing | Standing | Comfortable speaking distance | HR, RH | No | Yes | Hall | 94 | - | Used controller to position itself. Distance difference might be due to robot's long reach (92 cm). |
| Chen [CFD18] | Baxter | tall mechanic | 178/191 | Standing | Standing | Human in most comfortable position for drilling and cutting. | HR | Yes | No | - | - | - | Optimizes for peripersonal space (PPS). Further distance is not always better. |
| Samarakoon [BSC+18] | MIRob | short mechanic | 110 | Standing | Standing/Sitting/ Walking/Laying | Distance for given action. | HH, HR | No | Yes | - | - | - | Compares HH with HR. Does not look for comfort. |

**Table 2.2:** Proxemics summary

Huttenrauch [HEGT06] also used Hall's model in 2006. The experiment seemed to lack measurement precision due to the technology available at that time. The same year, Lee [LJKK06] found out that those participants who reported to experience loneliness felt higher social presence of the robot.

In 2009, Walters [WDTB+09] proposed a fuzzy logic model based on Hall's model. This model considers dimensions of the interaction such as the approach style (robot-human or human-robot), robot appearance, etc. The same year, Siegel [Sie09] found a prevalence of gender stereotypes when they changed the robot's voice. Two years later, Mumm [MM11] found out that pet owners distance themselves significantly further than non-pet owners, while men also maintained a greater distance than women. Obaid [OSZ+16] observed that the robot's posture made a difference in the distance regardless of the robot's size, see Table 2.2.

All of those works show that many individual factors combine to influence the final distance.

### 2.1.1 Peripersonal space (PPS)

In the case of animals, Hediger [Hed55] reported that they are protecting their PPS according to fight-flight zones, suggesting dependency on dimensions of the animal. Later Hunley [HL18] showed that body size affects those defensive behaviors. Holthaus [HW12] found indications that people expect the robot to also react in its PPS, which leads to the question of what the dependency on body size is.

### 2.1.2 Robot's gaze

In 2001, Bailenson [BBB02] ran an experiment in a virtual environment reporting that mutual gaze brings intimacy, attentiveness, competency, and a feeling of power. Women tend to tolerate gazing from a virtual agent more than men. Mumm [MM11] came to the same conclusion in 2011 with a robot. Takayama [TP09] conducted an experiment in 2009, where she found out that personal experience with pets decreases PPS around the robot, and the same goes for the personality trait of agreeableness. Neuroticism increased the PPS around the robot. In 2013, Sciutti [SBN+13] was able to measure motor resonance, that is the ability to connect and share emotions and intentions, even during an interaction with a robot. She determined this by measuring the anticipatory gaze shifts to the goal during action observation. This may be compatible with observations from Renner [RPW14], who had shown that gaze improves interaction in general and provides information to predict gestures. In 2015, Lehmann [LspSD15] discovered the positive effect of robot's head-gaze increasing the Likeability attribute of a robot. Additionally, the participants perceived that robot to be more intelligent compared to a non-moving robot. The next year, Lehmann [LRPM16] focused on blinking and found out that it makes a robot seem more intelligent as well. During a conversation, the average blinking rate was 23.3 blinks per minute. The robot had single (85 %) and double blinks (15 %).

To sum up, many experiments had shown that gaze for men leads to a greater distance than for women [BBB02, TP09, MM11]. Admoni [AS17] wrote in his review that gaze is used to regulate intimacy, convey emotional state, manage turn-talking, predict intentions. He also stated that more gaze induces better memory retention and faster task accomplishment. Shiomi [SSI20] proposed the importance of gaze height for relations, e.g., a nurse standing above a patient, an adult talking to a child.

### 2.1.3 Robot's lean-back

Lean-back seems to be quite a novel reaction for robots, as there are few studies present on the topic. Lambert [Lam08] notes that the lean-back is a sign of losing interest. However, it appears that in the scenario considered in the publication, one of the people involved has always been in a sitting position. Takayama [TP09] reported that when two people stand too close, they will share less mutual gaze and lean away from each other. The lean-back might be perceived as negative if it appears too clumsy due to uncanny valley effects as in Figure 2.1.

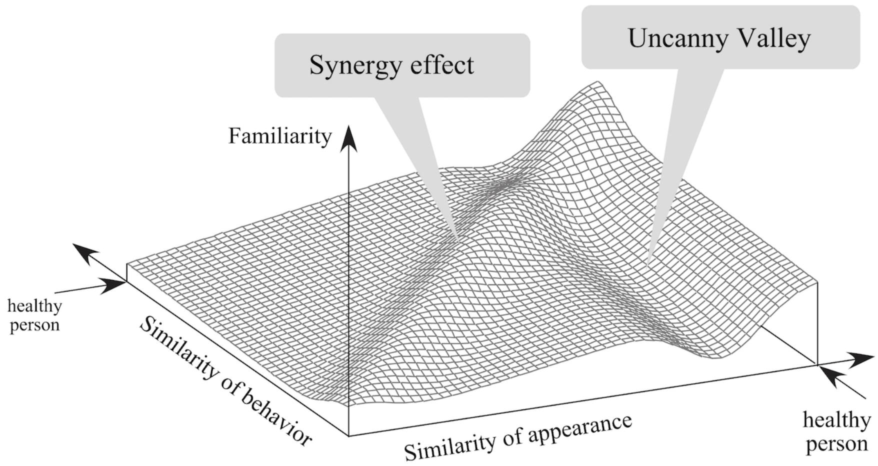



**Figure 2.1:** Uncanny valley from Ishiguro [Ish07]

## 2.2 Human-Robot Touch Interaction

Heslin [HNN83] in 1983 studied pleasantness and intrusiveness of touch between sexes in relation to a stranger, a friend, and a close friend in the United States and found out the stroke to be the least invasive. The pleasantness greatly depends on the relationship; see Figure 2.2.

In 1984, Crusco [CW84] reported midas touch effect, where a customer in a restaurant was briefly touched by the waitress as they were returning change. Regardless of whether they noticed or not, the gratuity was larger with

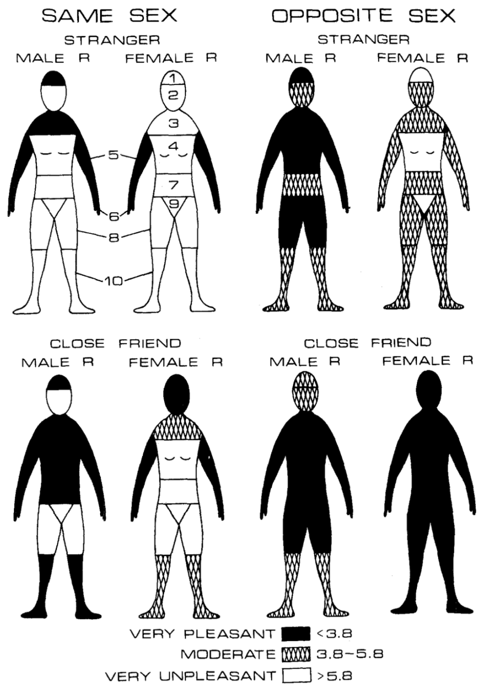



**Figure 2.2:** Rated pleasantness of touch (the darker, the more pleasant the touch is ) [HNN83]

those touched. Lee [LJKK06] found that people open up more when touched. However, it is essential to note the cultural differences. Lambert [Lam08] gives an example of a European businessman in an Arab country being surprised when a friendly Arab businessman chooses to take his hand as they walk down a road. In 2010, Gallace [GS10] noted the importance of touch, its health benefits, such as lowering blood pressure and creating bonds between people in general. The same year, unexpected touch with robots was suggested for future work in a review from Argall [AB10].

Touching robots seem more proactive and look less machine-like, as stated by Cramer [CKA+09]. Francois [FDP09] experimented with a cascaded information bottleneck method, making children with autism more engaged and having richer tactile interactions.

In 2018, Arnold [AS18] confirmed enhanced appraisal of the robot when the robot touches a person. Shiomi [SSMI18] found minimal pre-touch reaction, reaction right before the robot was about to be touched by the participant, to be around 20 cm. In 2019, Garcia [GMCM19] experimented with a Pepper robot in a crowded environment, classified types of contact, and made a compliance reaction for the robot. Smyk [SWM18] measured brain activity and found a difference in interaction with a human in contrast to the interaction with a robot. The data imply that robotic interactional partners appeared more predictable to the participants. That might suggest robots should act in predictable ways, which agrees with the idea from Bartneck [BBE+20] of a robot immediately responding to touch or sound being perceived as more anthropomorphic. Furthermore, Zheng [ZSMI20] was able to change the emotional impression of the robot by varying length, type, and location of a touch.

# Chapter 3

# Robot platforms

The experiment required at least two robots of similar design but having a significant height difference. The design had a significant effect on the size of PSZs in Walters [WDTB$^{+}$09], but the height did not. However, the height difference was 20 cm with the bigger-to-smaller robot ratio being only 140 cm : 120 cm ≈ 1.2.

For our experiments, Nao and Pepper robots were chosen. Their height difference is 61 cm and bigger-to-smaller robot ratio is 120 cm : 59 cm ≈ 2.0. They have certain design aspects in common as they are both developed by SoftBank Robotics (formerly Aldebaran Robotics). These robots fitted our criteria.

## 3.1 Nao

The robot was publicly introduced for Robot Soccer World Cup (RoboCup) in 2008. It is typically used for educational purposes and research, as in our case. In works from Alenljung [AAL$^{+}$18], they found that Nao's size and its hard surface might have a negative effect when the robot is touched. Nevertheless, they reported the robot being viewed as interesting and fun. Those qualities were amplified during the participant's first encounter with a robot.

### 3.1.1 Hardware

We used Nao version Evolution V5 alias H25 V50, which has 25 degrees of freedom and various sensors such as cameras, microphones, sonars, and bumpers. However, none of the sensors were used during the experiment. For touch, the robot is equipped with unique artificial skin (Figure 3.1a), making the robot 1.6 cm taller (59 cm), than without it (57.4 cm). The skin is a capacitive tactile system commonly used on the iCub robot [MMC$^{+}$13] and custom-designed for the Nao robot. This type of skin did not have many heat problems, as found by Stiehl [SB] in 2005. Furthermore, we did not have any skin resolution problems due to our experiment's setup, as it was not important for touch detection. However, it might be handy for future analysis of the touch to have better resolution, as suggested by Silvera-Tawil [STRV15].

The robot and the artificial skin were both accessed as a standalone device connected via Ethernet, which was necessary due to latency (more on that in Discussion, Section 9.1.1). The RGB-D camera is used for vision. More details can be found further in Section 4.1.1.

**(a)** Nao with artificial skin

**(b)** Nao with uncovered artificial skin

**Figure 3.1:** Nao robot

### 3.1.2 Software

Nao comes with its own NAOqi API version 2.1.4, allowing full control of the robot. It is accessible through Python 2.7 or C++. The newer version NAOqi API 2.4.3 has a function providing asynchronous calls to the robot; however, standard functions are not compatible with our Nao version. Including both versions in Python in specific order allowed us to use the asynchronous calls even with the older version of NAOqi. Since vision and touch are standalone devices, only the robot joint movement is controlled. Those movements were created in Choregraphe 2.1.4, as in Figure 3.2 and then exported into Python code. The skin communicates over Yet Another Robot Platform (YARP), which is also accessible from Python.

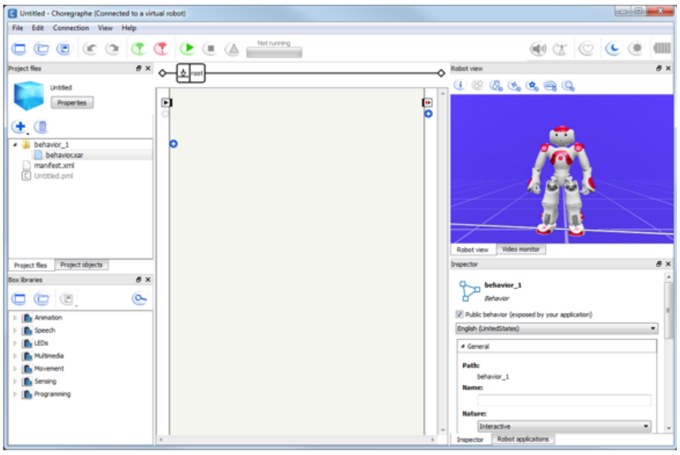


**Figure 3.2:** Choregraphe 2.1.4 from Aldebaran website [ALD20a]

## 3.2 Pepper

SoftBank Robotics presents Pepper as the world first social humanoid robot being able to recognize faces and basic human emotions, engage with people through conversation and having a touch screen. It is available for businesses and schools. [Sof20] One specimen serves as a receptionist at Václav Havel Airport in Prague [Vá20].

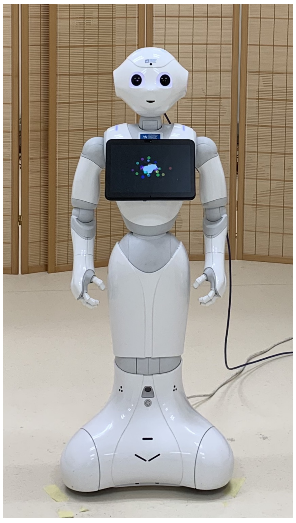


**Figure 3.3:** Pepper robot

### 3.2.1 Hardware

Pepper also comes with a variety of sensors. It has touch sensors on its arms used instead of the skin as on Nao. With its 120 cm height, it is 61 cm taller than Nao. In our case, the robot is also connected via Ethernet to avoid lag. More in Section 9.1.1.

For more details on vision, please refer to Section 4.1.1.

### 3.2.2 Software

Pepper also comes with NAOqi API with Python wrapper, but a newer version 2.4.3, that already contains asynchronous calls. For movement animation, it has Choregraphe 2.4.3, which is similar to Nao's version.

# Chapter 4

# Experimental setup and Scenarios

This chapter describes the hardware used during the experiment, recruitment of participants, room setup, calibration of the robot before the experiment, followed by Proxemics and Startle scenarios. Those two scenarios were designed and executed together as one experiment. Their results were evaluated separately.

## 4.1 Additional hardware

The robots described in the previous Section 3 required a camera and a computer with a GPU as a processing unit for vision. The experiment itself included a shape matching game, instruction text for the robot's chest, and the Nao robot's platform.

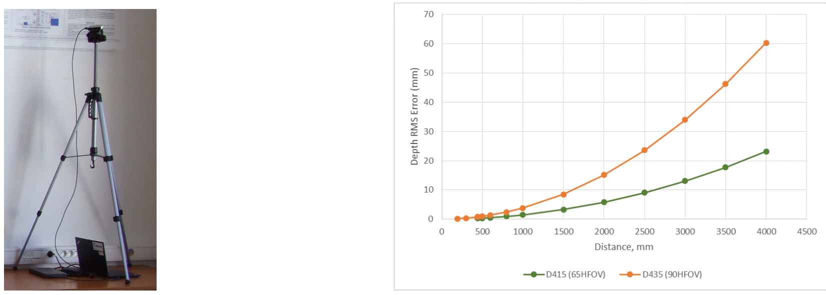
### 4.1.1 Camera

To get the correct 3D positions of participants w.r.t. the robot, we used an external RGB-D camera because the robot ultrasound sensors are not suitable. We used Intel® RealSense™ D435 (Figure 4.1a), which was already available to us with its sufficient resolution and accuracy of the depth measurements. The distance measurement quality was crucial to carry out the experiments correctly and varied with distance (Figure 4.1b). The camera should not move during the whole experiment to ensure consistency of the data; thus, it was placed on a tripod. Both the robot and the participant had to be within the field of view. Later on, this affected the room setup in Section 4.2.1.

The camera was connected via USB 3.1, and its data were processed in Python script as a 3D point cloud (Figure 4.2a), which is a combination of a BGR (swapped order from the usual RGB to Blue-Green-Red) image and a depth image (Figure 4.2b). More information about the implementation is in Section 5.

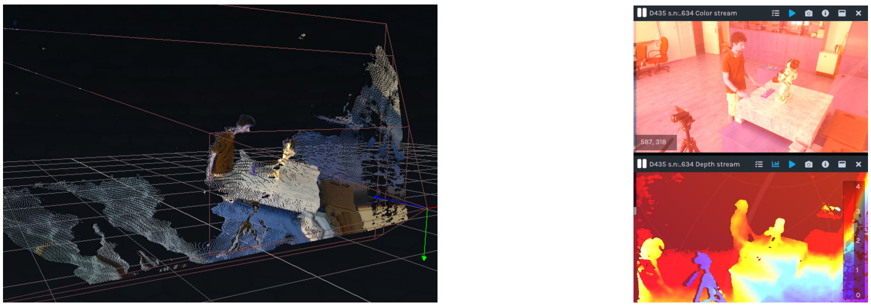
### 4.1.2 Camera-to-Robot calibration

A transformation from the camera frame to the robot's frame was needed to measure the distance between the robot and the participant.




**(a)** **(b)**

**Figure 4.1:** RGB-D Intel® RealSense™ D435 camera on a stand (a) and its theoretical depth RMS limits in relation to distance (orange) from [And20] (b)



**(a)** **(b)**

**Figure 4.2:** Point cloud in BGR (a) and BGR (top) and depth (bottom) images from RGB-D Intel® RealSense™ D435 (b)

To find it, we used ArUco Marker (Figure 4.3b) on the robot's hand (Figure 4.3a). The robot moved its hand to ideally linearly independent positions. We got linearly independent positions from the camera frame and robot's frame using forward kinematics, allowing us to find the transformation between those two.

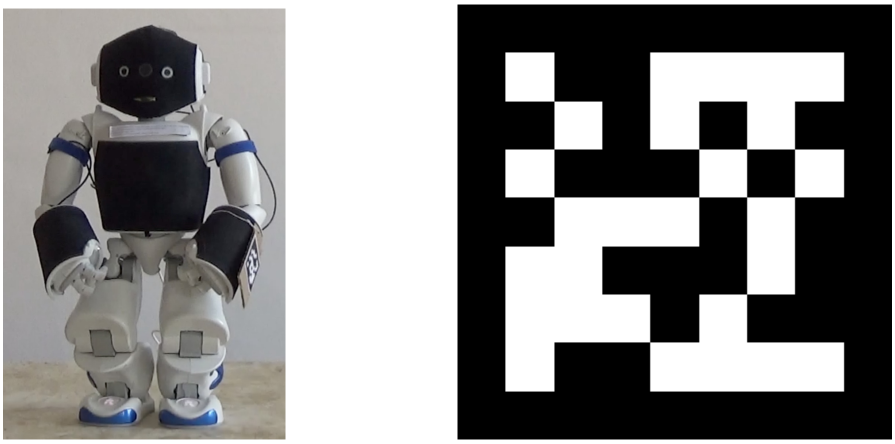
For implementation please refer to Section 5.2.3.

### 4.1.3 Notebook and External GPU

We used a Lenovo X280 notebook that comes with Intel UHD 620 GPU. Its graphics card does not support Cuda, and pose estimation using OpenPose was too slow - around one frame per second. The minimal required speed suggested by Hagen Lehmann was at least 10 frames per second. Adding around three times faster [Use20] external GPU, Lenovo Thunderbolt 3 Graphics Dock, to the setup allowed us to use Cuda and CuDNN, as it came with GTX 1050 (Mobile) graphics card, and got us to around 15 frames per second.

### 4.1.4 Shape matching game

It is a part of a staged interaction game with the instructions placed on the robot's chest to keep the participant's attention. The task was to pick and



**(a)** **(b)**

**Figure 4.3:** Nao robot during calibration with ArUco Marker on its hand (a) and ArUco Marker 7x7, ID: 2 from [Ole20] (b)

match a block of given color or shape. During the experiments, we did not check for the correctness of the task.

### 4.1.5 Instructions on the chest

We had three different instructions for each proxemics scenario (Section 4.4.3). For the Nao robot, we used instruction text on its torso pinned via hook-and-loop tape, whereas for Pepper, we used its touch screen to show the instructions (Figure 4.5). We found that the font size was crucial during the first experiment and may have affected the first proxemics experiment with the Nao robot. Thus the instructions for the following experiments were bigger; more about this in the discussion (Section 9.1.2).

### 4.1.6 Nao's platform

During the first proxemics experiment, we used a platform under the Nao robot (59 cm) to match the participant height (±20 cm). The platform itself was 20 cm, and then we adjusted it with 0.75 cm high blocks. The table was 75 cm high.

## 4.2 Experimental setup

### 4.2.1 Room setup

The experiment was executed three times in three different rooms. We had a few pilots preceding each experiment. The first (NAO-1, Figure 4.6a) and third (NAO-2, Figure 4.6c) experiments took place at Charles square in the Czech Technical University with the Nao robot. The second experiment

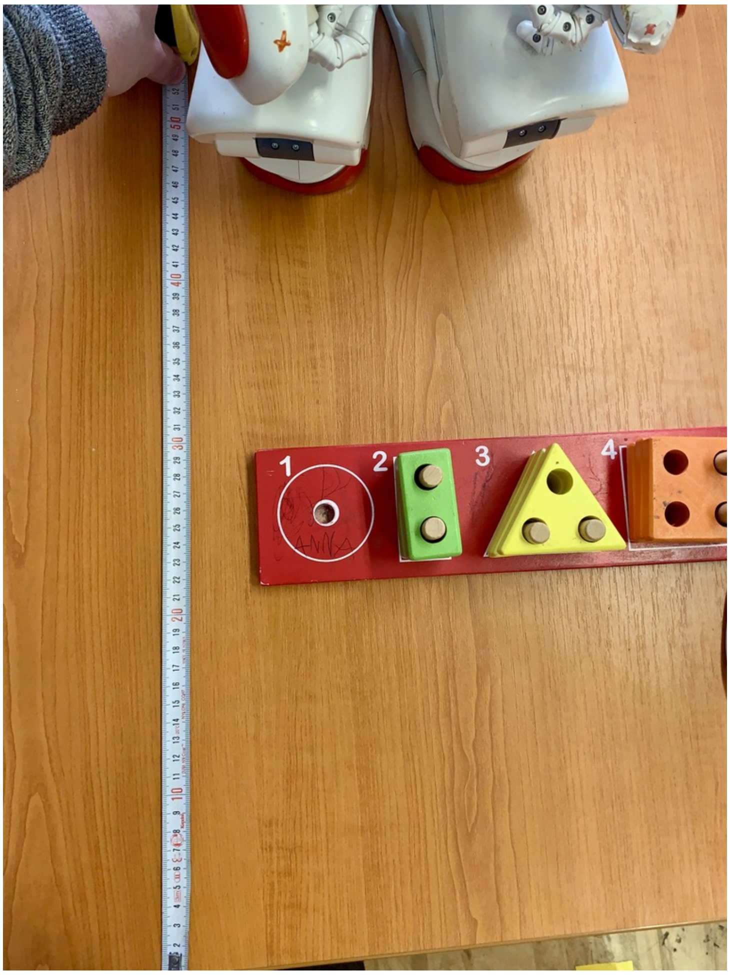


**Figure 4.4:** Nao standing 45 cm away from the edge of the table and the shape matching game at 21—29 cm

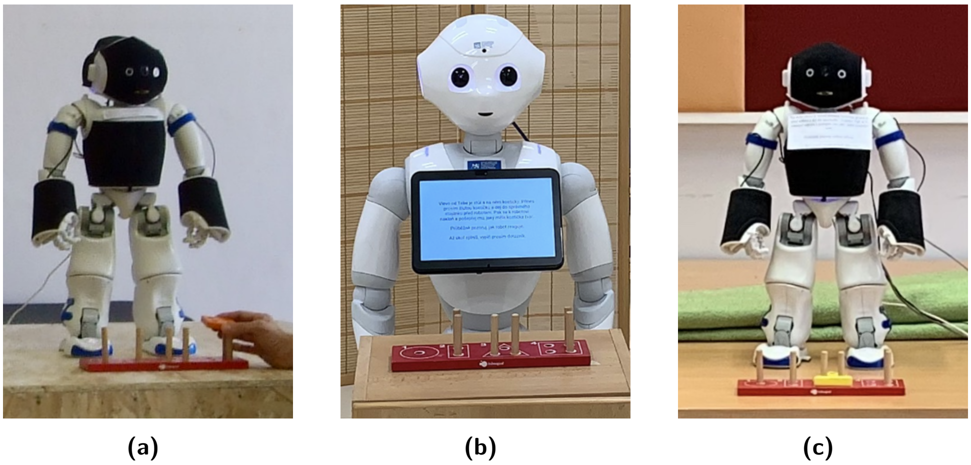


**Figure 4.5:** Nao robot with instructions during NAO-1 (a), NAO-2 (c) experiments, and Pepper with instructions (b)

was in Dejvice (Pepper, Figure 4.6b) in the Czech institute of informatics, robotics, and cybernetics (CIIRC) with the Pepper robot.

(a) (b) (c)

**Figure 4.6:** Room setups for the first (NAO-1) (a), the second (Pepper) (b) and the third (NAO-2) (c) experiment.

All of the experimental layouts were designed similarly. The conditions were kept roughly the same throughout the day. The second room 4.6b at CIIRC was perfect for this as it did not have any windows.

The positioning of the robots required that they have at least 3.6 m in front of them to simulate the human public zone proposed by Lambert [Lam04]. During the interaction with Nao (Section 3.1), it stood roughly 45 cm away from the edge of the desk. For the Pepper robot, it was similar; however, the robot stood behind a table of that length.

As for the robot vision, the RGB-D camera was used to see both the participant and the robot's hand. The hand of the robot was essential for the Calibration (Section 5.2.3). The camera stood behind the robot on the right side from the participant's point of view.

The table for the shapes from the shape matching game was on the left side of the room, outside the personal zone.

We had a startle scenario, where we simulated a situation with an unexpected touch. The robot was looking elsewhere, and the participant startled the robot. At Charles square, we used a window as a target for the robot to look at. At CIIRC, a picture was used. We removed the table from the Pepper robot during this scenario.

### 4.2.2 Recruitment

Participants were recruited from Facebook local area groups, experimenters' social circles such as family, friends, neighbors from Strahov dormitory, classmates, and people from social networking applications.

In total, we had 94 participants with the pilots excluded (47 female, 47 male; mean age 29.9, ranging from 18 to 68; mean experience with robots 2.1 from 1 to 5). Eight out of ninety-four attended two setups and one of them took part in all three experiments.

This method of recruitment might have affected the average participant's education level. An estimate would be that most of the participants have at least a high school or college degree. However, we did not ask this in the questionnaires.

## 4.3 Questionnaires

Before each experiment, the participants filled in a consent form and the Ten Item Personality Inventory (hereafter TIPI) [GRSJ03]. Prof. Marek Franěk kindly provided the Czech version of the TIPI questionnaire used in [ŠFZ15]. The questionnaire can be found in Appendix B. After each proxemics condition, the participants filled in an abbreviated version of the Godspeed questionnaire [BKCZ09] with the Anthropomorphism, Animacy, and Likeability subscales, which were translated into Czech by Matej Hoffmann. They can be found in Appendix A. The internal consistency of the individual subscales of the Godspeed questionnaire and their separate usability has been shown in various previous studies (e.g., [LspSD15]). The proxemics scenario ended with a final summarizing questionnaire.

For the startle scenario, we made a custom questionnaire, where the participant picked the most appropriate / fitting reaction with the photos of the different startle reactions included.

After the interaction, we had an interview where we spoke about the scenarios and how the participant perceived them. Due to technical difficulties, only some of the interviews were recorded, and those were used for further analysis.

## 4.4 Executing the scenarios

We had three experiments in which we ran the scenarios - summarized in the Table 4.1.

| Robot | Experiment setup | Participants | Familiarization phase | Proxemics scenario | Startle scenario |
|---|---|---|---|---|---|
| Nao (Section 3.1) | NAO-1 (Fig. 4.6a) | 40 | No | Yes | No |
| Pepper (Section 3.2) | Pepper (Fig. 4.6b) | 28 | Yes | Yes | Yes |
| Nao (Section 3.1) | NAO-2 (Fig. 4.6c) | 26 | Yes | Yes | Yes |

**Table 4.1:** Executed experiments and their scenarios

### 4.4.1 Calibration

Before running the experiment, we had to calibrate the position of the robot and find the transformation from the camera frame to the robot frame as described in Section 4.1.2.

Whenever the robot's position was off during the scenarios, we would rerun the calibration.

### 4.4.2 Familiarization phase

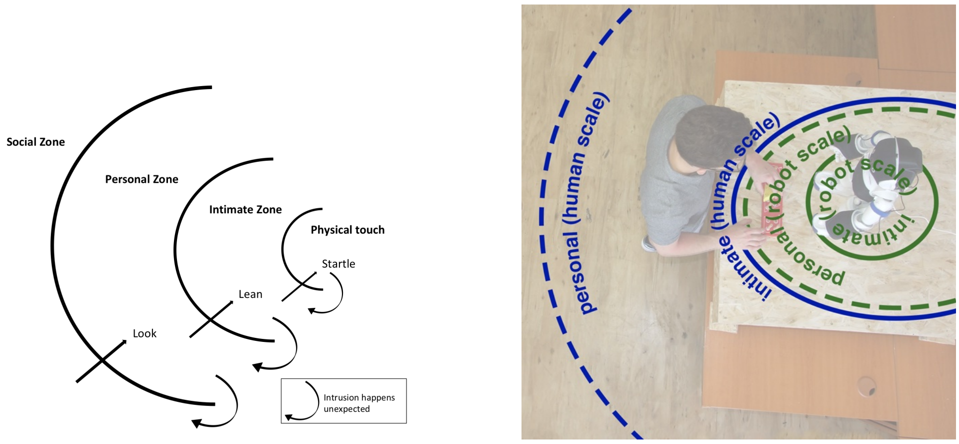
The participants were instructed to stand in front of the robot for about 40 s, while the robot performed its movements in random order. This was to negate the novelty effect as in [OSZ$^+$16].

We did not have this phase during the first NAO-1 experiment. It was added from the second experiment and on.

### 4.4.3 Proxemics scenarios

The participants were instructed to approach the robot, read the instructions (Section 4.5) and fill in a questionnaire about the interaction as explained in Section 4.3.

It consisted of three conditions permuted over the experiment. The first was the Control condition. During this condition, the robot behaved randomly – was looking at random coordinates and leaning back. In other conditions, the robot reacted to PSZs intrusion by gazing and leaning back as in Figure 4.7a. There was no startle reaction during the proxemics scenarios as it was a part of the startle scenarios.




(a) (b)

**Figure 4.7:** Triggered reactions depending on the zone (a) and human and scaled Nao robot zones comparison (b)

The second was the Robot condition when the robot reacted to an approaching human at robot scaled zones. The third was the Human condition, where the robot reacted at non-scaled down zones. Those distances are summarized in Table 4.2.

| Experiment | Robot | Condition | Gaze distance | Lean-back distance | Differential lean-back distance |
|---|---|---|---|---|---|
| **NAO-1** | Nao | Robot<br>Human | 0.42 m<br>1.2 m | 0.16 m<br>0.45 m | - |
| **Pepper** | Pepper | Robot<br>Human | 0.81 m<br>1.2 m | - | 0.3 m—0.1 m<br>0.45 m—0.1 m |
| **NAO-2** | Nao | Robot<br>Human | 0.42 m<br>1.2 m | - | 0.16 m—0.1 m<br>0.45 m—0.1 m |

**Table 4.2:** Triggering distances for different conditions and robots. Control condition is omitted as it is random.

Further information about the gazing 5.2.6 and differential lean-back 5.2.7 behavior are in the Implementation Section 5.2.

### 4.4.4 Startle scenarios

The participants were instructed to touch the robot's right hand. In this staged scenario, the robot is looking elsewhere and does not know about the participant.

The participant then goes towards the robot and touches its right hand. The robot is startled by an unexpected touch and starts gazing at the person.

The scenario was repeated for four (six during the pilot study) different startle reactions. After this, the participants filled in a questionnaire on which reaction was the most fitting / reasonable and why.

Those four startle reactions differed in the robot's hand positioning and timing. More about this in the Implementation Section 5.1.2.

# Chapter 5

# Implementation

The development followed user-centered design principles [BBE+20]. The chapter begins with an overview of the necessary methods for the scenarios. Those are followed by implementation, describing the changes which were made based on the feedback provided by the participants during the pilot study and throughout the experiments. We will talk about the feedback in more detail later in Chapter 7.

## 5.1 Decomposition of the scenarios

### 5.1.1 Robot's perception

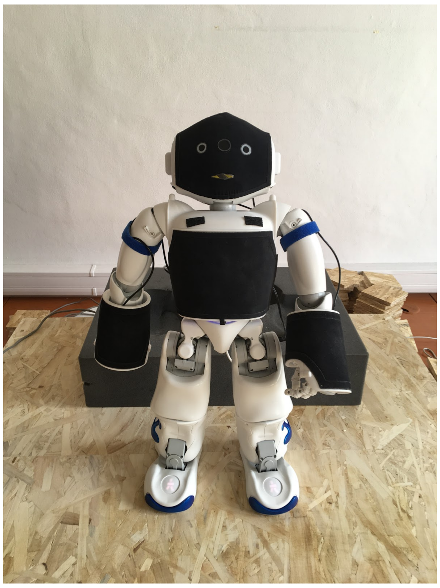
The RGB-D camera is used for vision. The robot cameras were considered but not used due to their limited resolution and small field of view on the Nao robot.

The robot determines the distance between it and the participant by first detecting the body using OpenPose library [CHS+18] from an RGB image. After that, the output is connected with the depth data and filtered using median 3D filtering as in [NBP+18, NHR+18].

For the startle scenario, touch detection is necessary. It is unique to each robot. Nao has artificial skin for detecting touch. Pepper uses touch sensors on its hands.

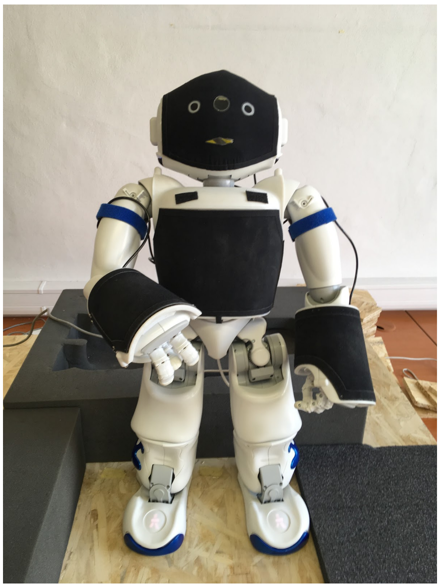
### 5.1.2 Robot's reactions

Those reactions are lean-back and startle. They have been modeled in Choregraphe. Robot's reactions are designed to imitate the same movements as if a human was reacting. The startling behavior had four final versions - they came from watching YouTube videos of people touching and scaring strangers (e.g., `https://youtu.be/BTl5HC9VfAE` (Touching Hands On Escalator Prank | Guy vs Girl Edition), `https://youtu.be/oKGerjB-d1w` (Human Chair Scare Prank (original))) and from trying it on the experimenters.

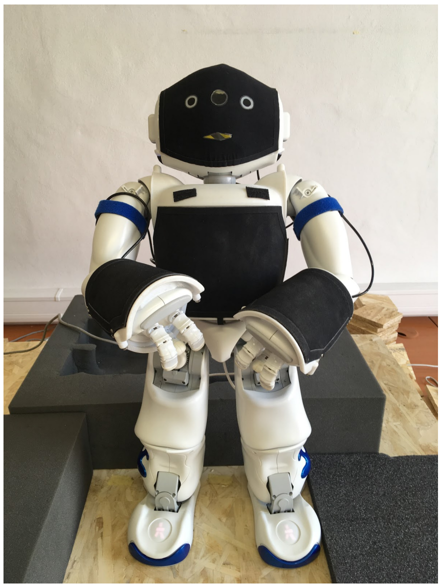


**(a)** Touched hand back, left unchanged.

**(b)** Touched hand back, left front.



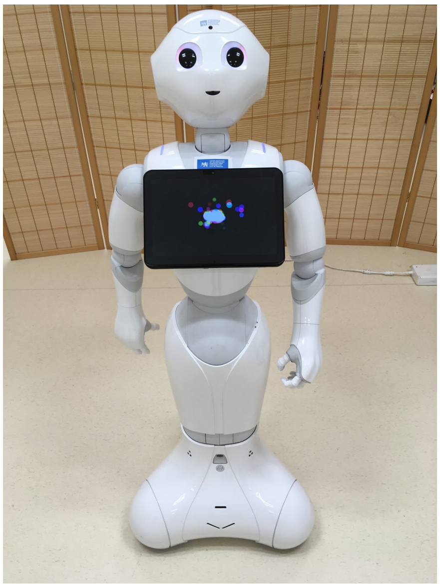
**(c)** Touched hand front, left unchanged.



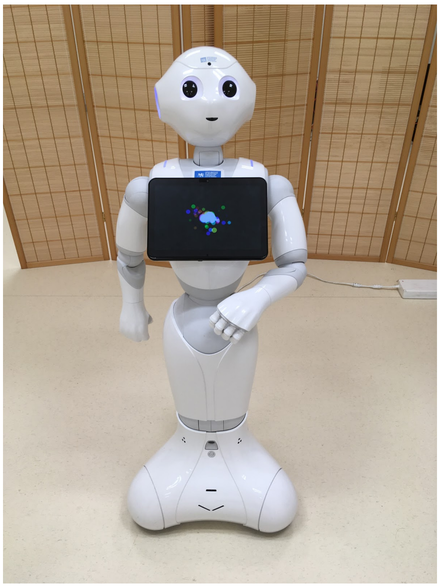
**(d)** Touched hand front, left front.

**Figure 5.1:** Nao startle behavior

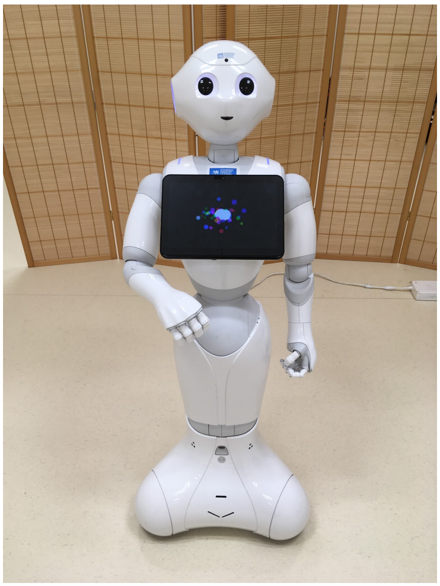
Choregraphe exports the movements as joint positions with a timestamp for the Python code. This is also used in differential lean-back by creating a transition between two different movements so that both use the same joints and timing.



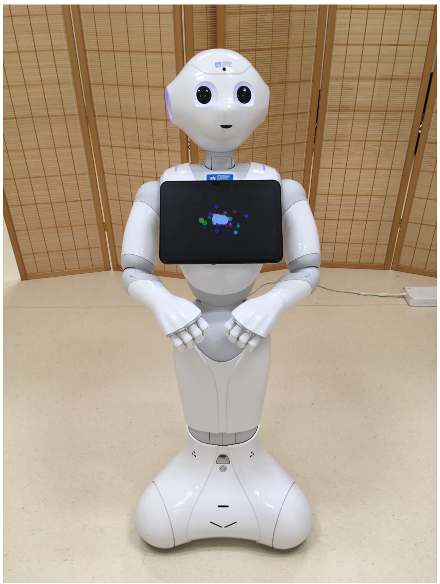
**(a)** Touched hand back, left unchanged.



**(b)** Touched hand back, left front.



**(c)** Touched hand front, left unchanged.



**(d)** Touched hand front, left front.

**Figure 5.2:** Pepper startle behavior

## 5.2 Code implementation

### 5.2.1 Software architecture

The software used during the experiments is available at [Roj20]. The experiments from the Section 4.6 were executed in the following order:

1. NAO-1
2. Pepper
3. NAO-2.

The architecture itself stayed the same for all the experiments and is best described by Figure 5.3.

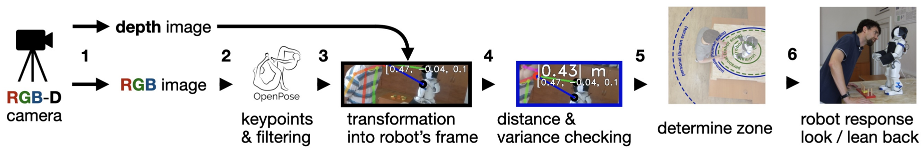



**Figure 5.3:** Participants interacting with the robot are recorded using an external RGB-D camera (1). The RGB image is fed to OpenPose [CHS+18], which estimates human keypoints in the image, applying confidence thresholds (2). The image is then fused with the depth information to acquire 3D coordinates of the human keypoints, which are transformed into the robot frame of reference (3). The distances are checked for consistency (4) and used to determine the personal spatial zone in which the participant is located (5). Appropriate robot behaviors are triggered (6). From [LRH20]

### 5.2.2 Touch detection

Touch is detected differently for each robot. For Pepper, we used the robot's touch sensor. The sensor outputs true or false, depending on whether somebody touches its hand or not.

With the Nao robot, it is more complicated, as we used additional artificial skin (Section 3.1). The detection is done by a module running in a separate thread and checking the hand signal sensor outputs for the threshold value. When the touch is detected, the robot is triggered to react.

### 5.2.3 Calibration

Finding a transformation matrix from the camera frame to the robot frame $\mathbf{T}_C^R = \mathbf{R_C}$ is necessary to measure the distance between the robot and the participant. That is possible by getting two sets of 3D points and finding the transformation between them [AHB87].

One set contains the hand position from the robot's perspective $\mathbf{H_R} = \mathbf{T}_R^H$. The other set contains a position from the camera $\mathbf{H_C} = \mathbf{T}_C^H$, where the position is represented as the center of the ArUco Marker (Section 4.1.2) on the robot hand.

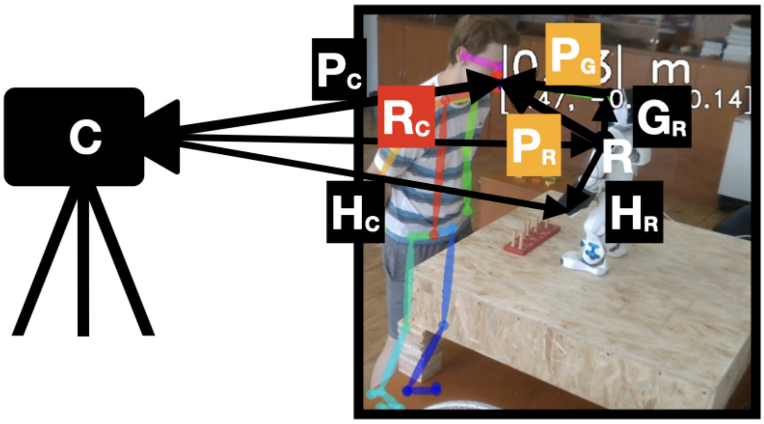



**Figure 5.4:** **C**amera and **R**obot are reference frames. **H**and, **P**articipant, **G**aze are positions in a subscript given reference frame. Red represents unknown transformation, orange is dependent on red and black are known transformations.

With enough samples, we can get the $\mathbf{R}_C = \mathbf{T}_C^R$, because $\mathbf{T}_C^H = (\mathbf{T}_R^C)^{-1}\mathbf{T}_R^H$ and from this, the transformation is estimated. The Python implementation of the optimization comes from [Ho].

### 5.2.4 Filtering the keypoints

Acquisition of the keypoints from the RGB image is made by OpenPose [CHS+18]. We did not use all the keypoints. For gaze, we used all head keypoints. For distance measurement, we used all head keypoints as well as the neck and the hip keypoint (Figure 5.5).

In Figure 5.3, step 3 involves checking for consistency of the depth pixels. The camera works roughly by emitting a matrix of infrared dots, then waits for them to be reflected back. After that, the camera measures the time it takes the dots to be reflected and calculates the distances. However, it means that the accuracy depends on the reflective surface and density of the dots emitted. In case a person stands sideways, the measurement can theoretically fail. The beam can overshoot

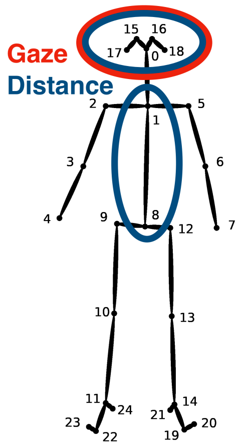



**Figure 5.5:** Allowed keypoints for gaze and distance measurement. Skeleton obtained from [CHS+18].

the nose. Subsequently, the distance between the wall and the camera is measured instead. This is filtered by checking the average depth over the area around the keypoint (Figure 5.6a).


**(a)** Taking average depth for every keypoint over the area.

**(b)** Average Z-depth from all keypoints is substracted from a keypoint Z.

**Figure 5.6:** Filtering of each keypoint

The area dimensions on the Figure 5.6a are $11 \times 11$ and $15 \times 15$ in the first and second implementation respectively.

The mean of those averages is used to estimate the Z-depth body coordinate and it is subtracted in Figure 5.6b. The filtered values are then corrected by taking into account the camera intrinsics, which were omitted for better speed. After this, they are transformed into the robot's point of view, so the distance between the robot and the participant can be measured.

### 5.2.5 Distance and variance filtering

The resulting distances are also filtered in order to avoid oscillation when determining the zone.

It helps to have a sliding window over the last three distance measurements. If the variance between them is large (i.e., a person can not move faster than $2\,\mathrm{m\,s^{-1}}$), the frame is skipped.

The last part—determining the zone—is straightforward and is done by checking the distance threshold. This triggers respective actions such as gazing and lean-back.

### 5.2.6 Gazing

To make the robot gaze at the person, it is necessary to calculate the head yaw and head pitch angles (Figure 5.7) using trigonometry. First, we transform the person's coordinates into the robot's head frame, and then we calculate the corresponding angles.

The robot looks at the person, but it can not be done instantly, as that would not be natural. Thus the speed of the gaze is determined by the function

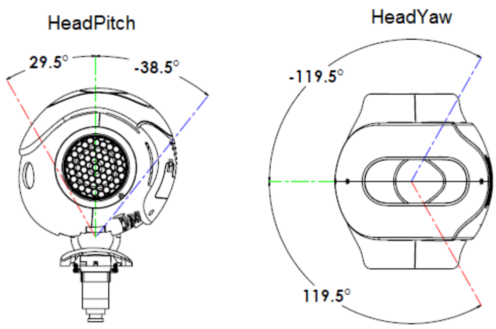



**Figure 5.7:** HeadPitch and HeadYaw joints on Nao. From [ALD20b]

$f(x) = max(0.01, min(0.15, x * 0.4))$ (Figure 5.8), where $x$ is distance (in meters) between the previous gaze position and the new one. When the distance is small, the head does not move.

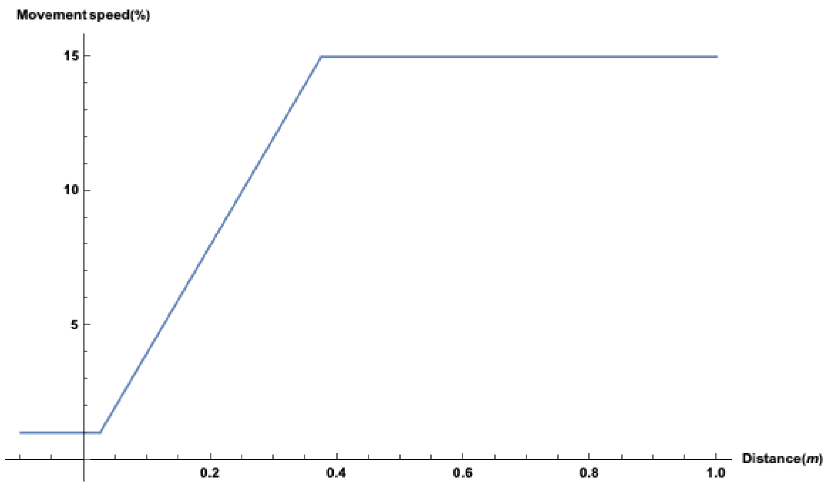



**Figure 5.8:** Movement speed of the head joints for different distances.

### 5.2.7 Movements

As explained in Section 5.1.2, the movements are modeled in Choregraphe and then exported into Python code and run with one line of code. This works for the lean-back and startle reactions. The differential lean-back is not the same as it requires interpolation between the movements.

#### Differential lean-back

Interpolation between standing position and leaning position allows the robot to do actions like "Do 30% of the standing position and 70% of the lean-back position". The distance where the robot started to lean-back was in between the distance of the intimate zone and 10 cm from the robot's head. The ratio between the movements is expressed by the following formula:

$$f(d,t) = min(max(\frac{d-0.1}{t-0.1}, 0), 1),$$

where $d$ is the participant distance and $t$ is the intimate zone distance for the current zone setup. For example, we are running the robot condition with Nao, then $t = 0.16\,\text{m}$ and $f_t(d) = min(max(\frac{d-0.1}{0.6}, 0), 1)$. Those distance ranges are in Table 4.2 in Section 4.4.3.

## 5.3 First implementation

The first implementation comes from the first room setup (Section 4.4). The experiment had only the proxemics scenario; thus, there is no code for the startle scenario nor touch detection. Furthermore, it does not have differential lean-back.

For the setup, we had a platform (Section 4.1.6) under the robot to match the participant height.

## 5.4 Second implementation

This implementation comes from the second and the third experiments (Section 4.4). There were a few changes since the first experiment:

- Removed platform, because we can not have Pepper on a platform.
- Bigger instruction text font-size – too small font-size made participants come close enough to read – interfered with the distance from the robot they would naturally take.
- Added familiarization phase.
- Added startle scenario.
- Added differential lean-back because the "on/off" implementation was perceived as disturbing and unfriendly.
- Modular code (Pepper only, later extended for Nao, but not used).

# Chapter 6

# Methods for processing of experimental data

The data collected from the experiments required filtering and processing before evaluation due to noise and anomalies (e.g., the participant did not follow the instructions). Analysis of these methods is the intention of this chapter.

## 6.1 Distance measurement

In 1995, Remland [RJB95] used a sampling method to measure distances between people as the distance between heads and torsos. For proxemics, the useful distance is where a person feels most comfortable. The determination of this distance can be divided into two problems with separate solutions. First, measuring the distance from each frame; next, assigning a single distance to each condition (control, robot and human — Section 4.4.3).

### 6.1.1 Distance assigned during the condition

During every experimental condition in the proxemics experiments, the distance of participants from the robot must be determined continuously online, so that appropriate behaviors (gaze, lean-back) can be triggered.

In the first version (Section 5.3), the distance comes from the 3D coordinates of the participant neck keypoint transformed into the robot's head position when the robot is standing. That is less precise than in the following version (Section 5.4), where the distance calculation includes the robot's head position even when the robot is not standing but leaning back instead. Similar keypoints to ours were used by Samarakoon [BSC+18].

### 6.1.2 Distance assigned to each condition

The distances from the previous section were processed further. Minimum distance is often used in the literature [BBB02, MM11]. However, in our scenario, participants were explicitly asked to approach the robot and whisper to it (Section 4.5), making the minimum distance inapplicable. Instead, we measured “natural” distance, which is the distance where the participant stopped in order to read the instructions.

We attempted to determine those “natural” distances automatically by measuring the median distance from each condition. However, the experiment usually started with somebody explaining the instructions to the participant. That had to be filtered out. Moreover, the time spent near the desk with the cubes from the shape matching game (Section 4.1.3) is not essential, and that also had to be filtered out. The final measuring script had some anomalies even after the filtering. Thus the final distances were visually estimated from the outputted videos with overlaying measurements, and the automatically measured distances were used just as references. Visual estimation of “natural” distances is much simpler for a human.

# Chapter 7

# Experiments and results

Three experiments named NAO-1, Pepper, and NAO-2 were executed in consecutive order. Results from NAO-1 are used in First proxemics study (Section 7.1). Results from Pepper and NAO-2 experiments are used in Second proxemics study (Section 7.2) and Startle study (Section 7.3).

## 7.1 First proxemics study

This experiment has its setup and results already published in [LRH20]. Therefore, the results are mostly cited from there. The data for First proxemics study are from the NAO-1 experiment only.

### 7.1.1 NAO-1 experiment

The room setup for this experiment is described in Section 4.2.1. During this setup, the first implementation detailed in Section 5.3 was used.

#### Pilots before the experiment

We had three pilots during this experiment. The reported problems were that the robot oscillated back and forth when it leaned back. We fixed this by not updating the robot's head coordinates when the robot leans back.

More problems occurred during the Control condition, where the robot did not have enough time to lean back. We fixed this by changing frequency of the movements. The lean-back was updated to happen once every $(20 \pm 1)$ s from previous $(38 \pm 1)$ s. The pause before returning from the lean-back position to the standing position was changed from $(5 \pm 1)$ s during the pilot study to $(6 \pm 1)$ s. The robot shifted its gaze at random. Previously, it looked at a new random spot every 5 s; this was changed to $(6 \pm 1)$ s.

The last problem was with the shape matching game. The game was too easy, always having the same instructions. Thus we had to vary the instructions on the robot's chest throughout the different conditions.

## Results

As people approached the robot, we measured the distances by the method described in Section 6.1.2. A histogram from the NAO-1 experiment (Figure 7.1) shows no significant difference between the varied conditions [LRH20]. The conditions were Control, Robot, and Human as previously described in Section 4.4.3.

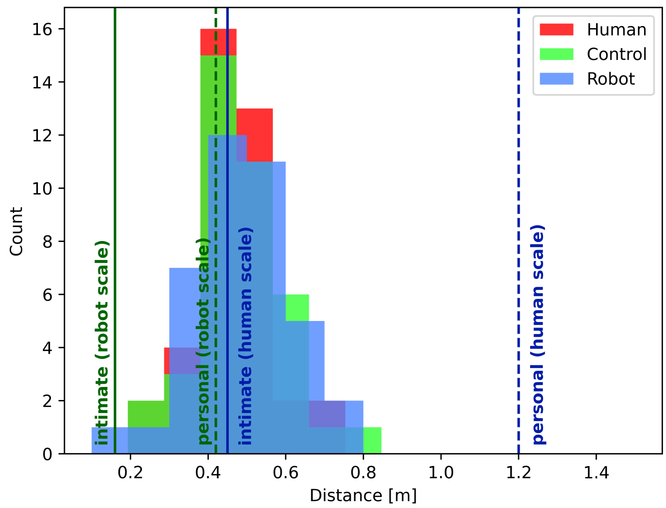



**Figure 7.1:** Histogram of the natural distances from the NAO-1 experiment.

On average, the participants stayed (47.7 ± 11.3) cm away from the robot [LRH20]. There was a small drop from the first condition to the last (average 49.3 cm over 47.3 cm to 46.6 cm), which may be due to familiarization with the robot [LRH20].

Results from the Godspeed questionnaire are in Figure 7.2. There was a positive correlation between the average (over all conditions) anthropomorphism score and the distance ($r(38) = .5504$, $p = 0.0002$), and a positive correlation between the average (over all conditions) animacy score and the distance ($r(38) = .4337$, $p = .005$) [LRH20].

To further explore the structure of the collected data, we examined the correlations between the different measured variables. We calculated Pearson Correlation Coefficients to investigate potential correlations between our participants' TIPI scores and the average distance they kept from the robot. We found a positive correlation between the agreeableness score and the distance ($r(38) = .348$, $p = .028$), and a weak positive correlation between the conscientiousness score and the distance ($r(38) = .327$, $p = .04$).

We further tested for correlations between the experience with robots score and the Godspeed questionnaire results and the participants' age and the Godspeed questionnaire results. For the experience with robots score, we found a negative correlation with the Likeability subscale ($r(38) = -.322$, $p = .044$).

| Condition | Variable | Mean (SD) | Median |
|---|---|---|---|
| Control | Anthropomorphism | 2.93 (0.75) | 3 |
| Robot Scale | Anthropomorphism | 3.02 (1.03) | 3.2 |
| Human Scale | Anthropomorphism | 2.9 (0.91) | 2.9 |
| **Condition** | **Variable** | **Mean (SD)** | **Median** |
| Control | Animacy | 3.14 (0.91) | 3.3 |
| Robot Scale | Animacy | 2.96 (0.59) | 3 |
| Human Scale | Animacy | 3.25 (0.81) | 3.3 |
| **Condition** | **Variable** | **Mean (SD)** | **Median** |
| Control | Likeability | 3.57 (0.99) | 3.5 |
| Robot Scale | Likeability | 3.59 (0.95) | 3.7 |
| Human Scale | Likeability | 3.47 (0.94) | 3.4 |

**Figure 7.2:** Descriptive statistics for Anthropomorphism, Animacy and Likeability. [LRH20]

For age, we found a positive correlation with the Likeability subscale (r(38) = .369, p = .019).

We also had a custom-made questionnaire. All 40 participants except one noticed some difference between the conditions. The participants rated the situation in which gaze and lean-back were the most fitting (Figure 7.1).

| Condition | Gaze behavior | Leaning behavior |
|---|---|---|
| Control | 10 | 8 |
| Robot Scale | 13 | 15 |
| Human Scale | 17 | 17 |

**Table 7.1:** Participant ratings of in which situation gaze behavior or leaning behavior was most appropriate.

Next, we were interested in how the participants interpreted the lean-back. We used an open question and then categorized the responses (Figure 7.2).

| Interpretation | Count |
|---|---|
| The robot reacted to the intrusion of its personal space. | 13 |
| The robot was shocked. | 7 |
| The robot was afraid. | 5 |
| The robot was astonished. | 1 |
| The robot was displeased. | 1 |
| The robot acknowledged my presence. | 1 |
| I don't know. | 3 |
| Other – indistinct. | 9 |

**Table 7.2:** Participant interpretation of the leaning back behavior of the robot.

In the last part of the questionnaire, we allowed participants to post miscellaneous comments. We analyzed those responses in combination with the responses from the structured interview after the experiment. The main qualitative findings pertain to the leaning back behavior, which was perceived as unfriendly or detached. This had in part to do with a contradiction in the scenario, which was reported explicitly by some participants. As part of the interaction, they were asked to lean towards the robot and whisper to it, but the robot on this occasion would lean back. Additionally, some participants reported that the lean-back was too fast and scared them the first time it was triggered. Some participants also reported that they perceived the gazing behavior (Human or Robot condition) as being "stared at" due to the robot's lack of facial expressions.

### Future experiments

As the abrupt on/off lean-back implementation was problematic, we planned differential lean-back in future experiments. One of the possible reasons why there was no significant difference in the distances between the conditions was that the instructions text font size on the robot's chest was too small. For future experiments, we also added a Familiarization phase (Section 4.4.2) preceding the first condition to circumvent a participant tendency to stay away farthest on the first condition. Those were the major changes. All changes are listed in Section 5.4.

## 7.2 Second proxemics study

This study reflects the feedback from the previous study. We ran experiments with Pepper and Nao.

### 7.2.1 Pepper experiment

The Pepper experiment was conducted in a room at CIIRC with the Pepper robot. The setup is detailed in Section 4.2.1.

#### Pilots before Pepper experiment

We had four pilots during this study. Reported problems were the lean-back timing, where we changed the frequency from 20 s to 15 s. Next, we had a problem with the robot's gaze as it was switching between face keypoints and waist keypoints. This was fixed by having a 1.5 s moving window delay.

People also reported a contradiction within the scenario, that the participant is asked to lean towards the robot and whisper to it. The robot then reacts by leaning back when the human tries to whisper to it, which is a contradiction. However, we could not change that as it would require us to remake the whole scenario.

#### Results

During this experiment, we realized we could record distances from Familiarization phase. We recorded only 10 participants whose distances are plotted in Figure 7.3. The average distance was $(99 \pm 29)$ cm, but there is not enough data to make any conclusions.

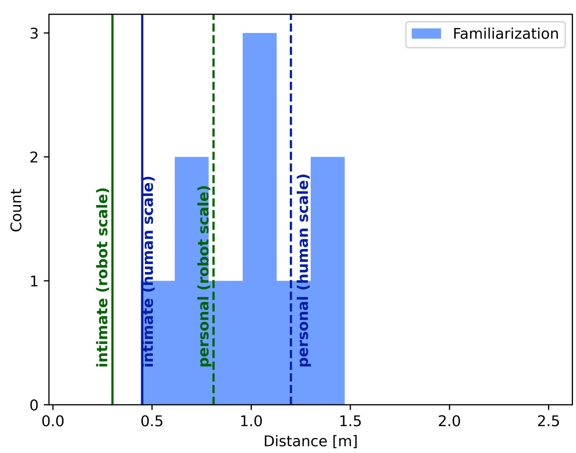



**Figure 7.3:** Histogram of the distances from the Familiarization phase from the Pepper experiment.

We measured the distances by the method described in Section 6.1.2, and there is a visible trend in the Figure 7.4.

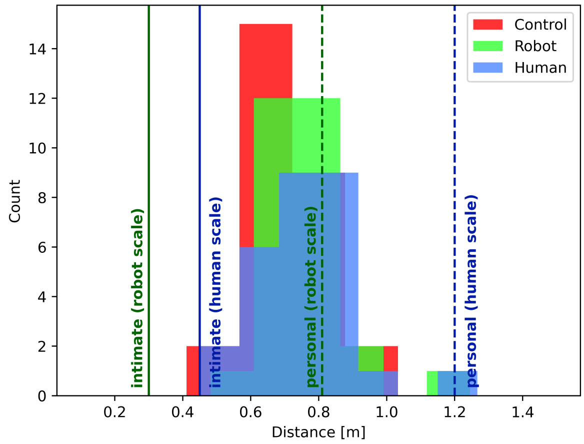



**Figure 7.4:** Histogram of the natural distances from the Pepper experiment.

The average natural distance across all conditions was $(74 \pm 13)$ cm. For Control, Robot and Human conditions the natural distances were $(72 \pm 12)$ cm, $(75 \pm 13)$ cm and $(76 \pm 13)$ cm respectively.

We checked the Godspeed questionnaire and found no significant difference across the conditions (Figure 7.3).

| Godspeed Pepper | C | R | H | Total |
|---|---|---|---|---|
| Anthropomorphism | The F-ratio value is 2.90262. The p-value is .06289. The result is not significant at p < .05. | | | |
| Mean | 2,86 | 3,1 | 3,28 | 3,08 |
| Std.Dev. | 0,7431 | 0,9421 | 0,8164 | 0,8463 |
| Animacy | The F-ratio value is 1.84219. The p-value is .167622. The result is not significant at p < .05. | | | |
| Mean | 3,1557 | 3,279 | 3,4777 | 3,304 |
| Std.Dev. | 0,6325 | 0,768 | 0,7571 | 0,726 |
| Likeability | The F-ratio value is 1.68919. The p-value is .193627. The result is not significant at p < .05. | | | |
| Mean | 3,54 | 3,82 | 3,8667 | 3,742 |
| Std.Dev. | 0,9294 | 0,9238 | 0,8006 | 0,8885 |

**Table 7.3:** Results from the Godspeed questionnaire.

In the custom-made questionnaire, we asked participants to interpret the lean-back behavior in an open question. We then categorized the answers into a Table 7.4. During the Control and Human conditions 16 % (4 people) commented on the robot keeping its distance/protecting its personal space.

| Lean-back meaning | C | R | H | Responses |
|---|---|---|---|---|
| keeping distance | 16.00% | 4.00% | 16.00% | 9 |
| shock | 8.00% | 8.00% | 4.00% | 5 |
| surprised | 4.00% | 8.00% | 4.00% | 3 |
| curious | 0.00% | 0.00% | 8.00% | 2 |
| distrust | 0.00% | 4.00% | 4.00% | 2 |
| gazing | 0.00% | 4.00% | 0.00% | 1 |
| odd | 0.00% | 0.00% | 4.00% | 1 |
| respect | 0.00% | 4.00% | 0.00% | 1 |
| tallness | 0.00% | 0.00% | 4.00% | 1 |
| SUM | 28.00% | 32.00% | 44.00% | 25 |

**Table 7.4:** Participants interpretation of the Pepper's lean-back behavior.

As part of the questionnaire, the participants voted for the most natural/appropriate behavior separately for gazing and lean-back. Those answers are shown in Table 7.5. We can see 10 people (19.23 %) liked the gazing behavior most often during the Robot condition. The lean-back was rated best during the Human condition by 11 people (21.15 %).

| Most fitting | C | R | H | Total |
|---|---|---|---|---|
| Gazing | 15.38% | 19.23% | 15.38% | 26 |
| Lean-back | 13.46% | 15.38% | 21.15% | 26 |
| SUM | 28.85% | 34.62% | 36.54% | 52 |

**Table 7.5:** Most fitting gazing and lean-back behavior chosen by the participants for Pepper.

We also checked what the spotted differences in reactions across the conditions were. As this was an open question, we categorized those responses 7.6.

| Differences in reactions | Total |
|---|---|
| intensity | 10 |
| movement | 8 |
| interactivity | 7 |
| awareness | 3 |
| personality | 1 |
| SUM | 29 |

**Table 7.6:** Differences spotted in Pepper's reactions across the conditions.

Furthermore, it was interesting to find out why people chose the conditions. The answers are categorized in Table 7.7. And the other way round, why the participant did not like the other conditions – categorized in Table 7.8.

| Why voted for condition | Total |
|---|---|
| natural | 5 |
| pleasant | 2 |
| attentive | 2 |
| SUM | 9 |

**Table 7.7:** Reasons why people chose a condition as the most fitting for gaze or lean-back.

| Why did not like the other conditions | Total |
|---|---|
| mechanical | 3 |
| no eye contact | 2 |
| frightened | 1 |
| delay | 1 |
| SUM | 7 |

**Table 7.8:** Reasons why people did not chose other conditions as the most fitting for gaze or lean-back.

### 7.2.2 NAO-2 experiment

The NAO-2 experiment was conducted in the second room at Charles square with the Nao robot. The setup is detailed in Section 4.2.1. We did not need pilots during this experiment as the setup was already refined from the previous NAO-1 experiment; thus, this section is omitted.

#### Results

We recorded distances from the Familiarization phase and made a histogram of those distances (Figure 7.5). During this phase, the average distance was $(1.16 \pm 0.43)$ m for all 26 participants.

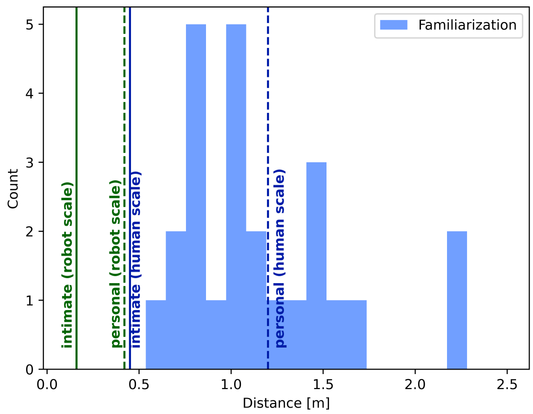



**Figure 7.5:** Histogram of the distances from the Familiarization phase from the NAO-2 experiment.

We measured the distances by the method described in Section 6.1.2 and made a histogram (Figure 7.6).

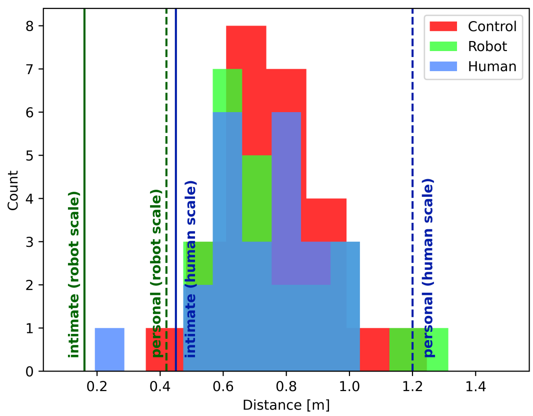



**Figure 7.6:** Histogram of the natural distances from the NAO-2 experiment.

The average natural distance for Control, Robot and Human conditions were $(75 \pm 18)$ cm, $(78 \pm 25)$ cm and $(77 \pm 23)$ cm respectively. Throughout the conditions, the average distance was $(77 \pm 22)$ cm.

In the custom-made questionnaire, we asked the participants to interpret the lean-back behavior in an open question. We then categorized the answers into a Table 7.9. We can see that lean-back during the Human condition was perceived as the robot being aware by 14.29 % (4 people). During the Robot condition, lean-back behavior was rated as the robot being surprised. During the Control condition 14.29 % people commented on it as keeping its distance/protecting its personal space.

| Lean-back meaning | C | R | H | Total |
|---|---|---|---|---|
| awareness | 7.14% | 7.14% | 14.29% | 8 |
| surprise | 10.71% | 17.86% | 3.57% | 8 |
| keeping distance | 14.29% | 3.57% | 7.14% | 7 |
| shock | 0.00% | 3.57% | 3.57% | 2 |
| tallness | 0.00% | 3.57% | 0.00% | 1 |
| respect | 0.00% | 3.57% | 0.00% | 1 |
| agreement | 0.00% | 3.57% | 0.00% | 1 |
| SUM | 32.14% | 42.86% | 28.57% | 28 |

**Table 7.9:** Participants interpretation of the Nao's lean-back behavior.

We checked the Godspeed questionnaire and found a significant difference across the conditions (Table 7.10), the robot scored the highest for Anthropomorphism, Animacy and Likeability during the Human condition.

| Godspeed NAO-2 | C | R | H | Total |
|---|---|---|---|---|
| Anthropomorphism | (The F-ratio value is 11.10101. The p-value is .000109. The result is significant at p < .05.) | | | |
| Mean | 2,688 | 2,744 | 3,416 | 2,949 |
| Std.Dev. | 0,676 | 0,8216 | 0,5857 | 0,7677 |
| Animacy | (The F-ratio value is 19.89749. The p-value is < .00001. The result is significant at p < .05.) | | | |
| Mean | 2,8396 | 2,58 | 3,6268 | 3,015 |
| Std.Dev. | 0,7634 | 0,6801 | 0,5492 | 0,7985 |
| Likeability | (The F-ratio value is 9.5483. The p-value is .000323. The result is significant at p < .05.) | | | |
| Mean | 3,336 | 3,536 | 4,04 | 3,637 |
| Std.Dev. | 0,9069 | 0,7868 | 0,688 | 0,8426 |

**Table 7.10:** Results from the Godspeed questionnaire.

The participants also voted for the most natural/appropriate behavior separately for gazing and lean-back. Those answers are shown in Table 7.11. We can observe that people liked gazing behavior the most during the Human condition. The lean-back was most appropriate during the Robot condition.

We checked what the spotted differences in reactions across the conditions were. As this was an open question, we categorized those responses in Table 7.12.

Furthermore, it was interesting to find out why people chose the conditions. The answers are categorized in Table 7.13. And vice versa, why the participant did not like the other conditions – categorized in Table 7.14.

| Most fitting | C | R | H | Total |
|---|---|---|---|---|
| Gazing | 12.96% | 12.96% | 24.07% | 27 |
| Lean-back | 16.67% | 20.37% | 12.96% | 27 |
| SUM | 29.63% | 33.33% | 37.04% | 54 |

**Table 7.11:** Most fitting gazing and lean-back behavior chosen by the participants for Nao.

| Differences in reactions | Total |
|---|---|
| intensity | 10 |
| movement | 8 |
| interactivity | 7 |
| awareness | 3 |
| personality | 1 |
| SUM | 29 |

**Table 7.12:** Differences spotted in reactions across the conditions with Nao.

| Why voted for condition | Total |
|---|---|
| natural | 5 |
| pleasant | 2 |
| attentive | 2 |
| SUM | 9 |

**Table 7.13:** Reasons why people chose a condition as the most fitting for gaze or lean-back.

| Why did not like the other conditions | Total |
|---|---|
| mechanical | 3 |
| no eye contact | 2 |
| frightened | 1 |
| delay | 1 |
| SUM | 7 |

**Table 7.14:** Reasons why people did not choose other conditions as the most fitting for gaze or lean-back.

### 7.2.3 Results from both Pepper and NAO-2 experiments

We evaluated the feedback on gazing and lean-back from both experiments. The results are presented in Table 7.15. We can see that overall there is a trend in preference towards the Human condition. With the NAO-2 natural distances being for Control, Robot and Human conditions $(75 \pm 18)$ cm, $(78 \pm 25)$ cm and $(77 \pm 23)$ cm respectively; and $(77 \pm 22)$ cm throughout the conditions. For Pepper, the average natural distance across all conditions was $(74 \pm 13)$ cm; for Control, Robot, and Human conditions, they were $(72 \pm 12)$ cm, $(75 \pm 13)$ cm and $(76 \pm 13)$ cm respectively. We can see that our first hypothesis about whether the perceived PSZs scale down with the size of the robot can be rejected.

| Nao and Pepper with both gaze and lean-back | C | R | H | Total |
|---|---|---|---|---|
| Nao | 16 | 18 | 20 | **54** |
| Pepper | 15 | 18 | 19 | **52** |
| **SUM** | 31 | 36 | 39 | **106** |
| **Percantages** | 29.25% | 33.96% | 36.79% | **100.00%** |

**Table 7.15:** Most appropriate reaction for both gaze and lean-back combined during NAO-2 and Pepper experiments.

During the NAO-2 experiment, the conditions significantly affected the Godspeed subscales – Anthropomorphism, Animacy, and Likeability. It was not the case for the Pepper experiment. We also ran correlations against the TIPI questionnaire, gender, age, height, experience with the robot, and there was nothing significant found.

# 7.3 Startle study

## 7.3.1 Pepper experiment

The Pepper experiment was conducted in the second room at CIIRC with the Pepper robot. The setup is detailed in Section 4.2.1.

### Pilots

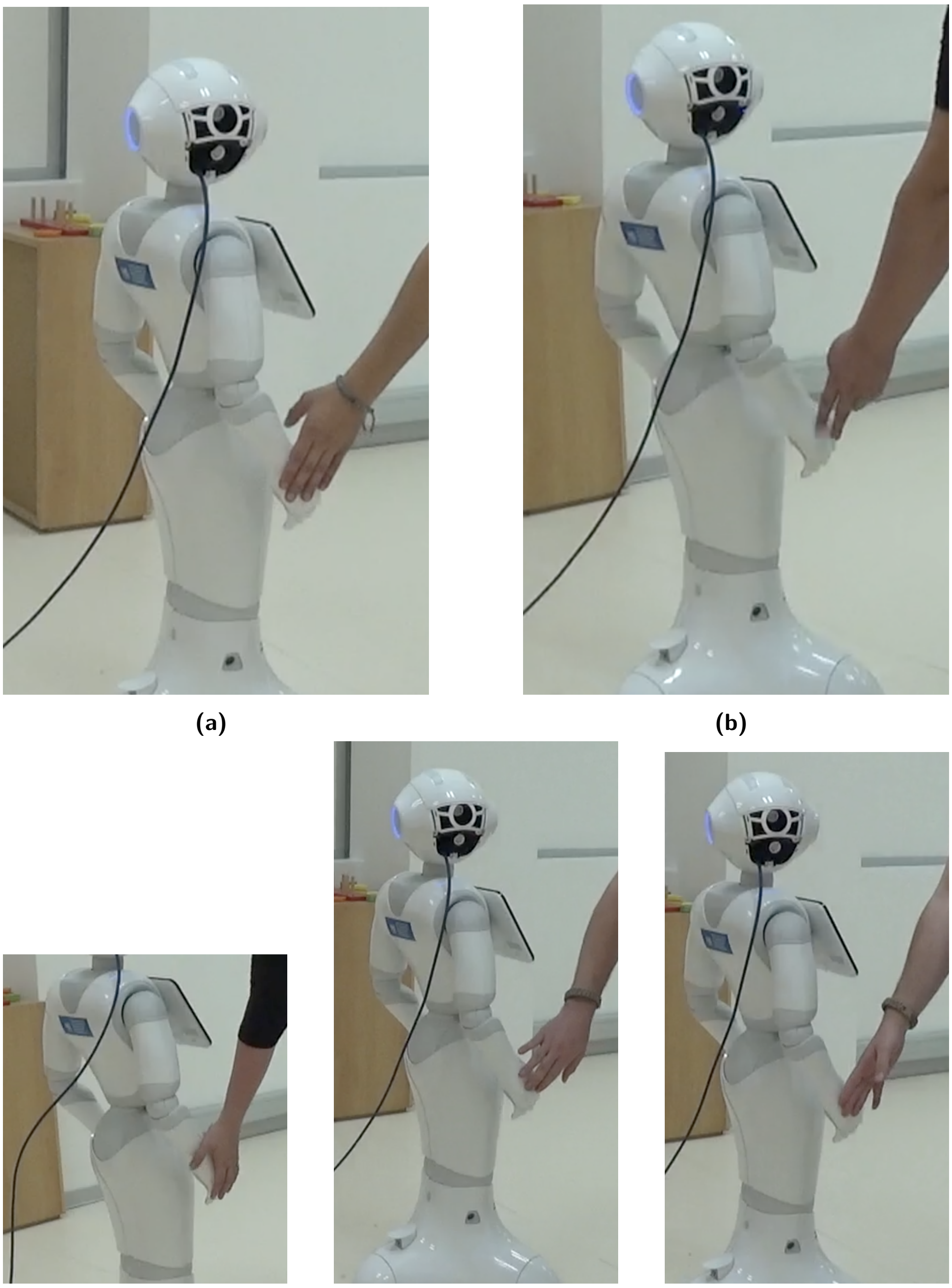
We had three pilots, mostly due to misleading instructions. We previously asked the participant to “surprise him” (the robot), but we changed it to “get his attention”. Moreover, the participants had to be instructed from which side they should touch the robot’s hand.

### Results

We analyzed different touch styles from the videos. We divided them into categories, on Figure 7.7. Frequency of those touch styles are in Table 7.16. Some participants touched the robot in more ways, and they were also added to the sum.

| Touch style | Total |
|---|---|
| palm pat | 15 |
| finger pat | 13 |
| wrist handshake | 7 |
| right hand | 3 |
| back of the hand pat | 2 |
| SUM | 40 |

**Table 7.16:** Participants touch styles when touching Pepper.



(a) (b)

(c) (d) (e)

**Figure 7.7:** Touch styles: palm pat (a), finger pat (b), wrist handshake (c), right hand (d), back of the hand pat (e)

Further, we evaluated the questionnaires to determine why the participants decided on a reaction to be the most fitting/appropriate. This is shown in Figure 7.17. From the data, it seems that the most natural and appropriate reaction is reaction A. Photos of the robot reactions are available in Section 5.1.2. For better readability meanings of the A-D reactions:

- A (touched hand back, left unchanged)
- B (touched hand back, left front)
- C (touched hand front, left unchanged)
- D (touched hand front, left front).

| Why voted for one reaction | A | B | C | D | Total |
|---|---|---|---|---|---|
| natural | 23.08% | 11.54% | 7.69% | 11.54% | 14 |
| appropriate | 11.54% | 7.69% | 0.00% | 7.69% | 7 |
| curious | 0.00% | 3.85% | 0.00% | 3.85% | 2 |
| restrained | 0.00% | 0.00% | 7.69% | 0.00% | 2 |
| pleasant lean-back | 0.00% | 3.85% | 0.00% | 0.00% | 1 |
| SUM | 34.62% | 26.92% | 15.38% | 23.08% | 26 |

**Table 7.17:** Why the participant chose the reaction as the most fitting/appropriate.

We asked why they did not vote for the other reactions, and the answers are in Figure 7.18. All reactions except the selected one got a negative rating. This is more of an overview result and must be interpreted carefully as it implies bilateral implication of the negative rating.

| Why did not like the other reactions | A | B | C | D | Total |
|---|---|---|---|---|---|
| mechanical | 8.33% | 6.25% | 6.25% | 10.42% | 5 |
| aggressive | 2.08% | 8.33% | 6.25% | 8.33% | 4 |
| unfriendly | 4.17% | 4.17% | 6.25% | 4.17% | 3 |
| frightened | 0.00% | 4.17% | 4.17% | 4.17% | 2 |
| delay in reaction | 2.08% | 2.08% | 2.08% | 0.00% | 1 |
| pleasant | 0.00% | 2.08% | 2.08% | 2.08% | 1 |
| SUM | 16.67% | 27.08% | 27.08% | 29.17% | 16 |

**Table 7.18:** Why the participant did not vote for the other reactions.

We allowed the participants to leave a note (Table 7.19). From those notes, two people reported the lean-back as being natural. One person liked the robot blinking. We had one comment about the robot looking offended.

| Notes | Total |
|---|---|
| natural lean-back | 2 |
| liked blinking | 1 |
| robot looked offended | 1 |
| SUM | 4 |

**Table 7.19:** Notes from the startle experiment with Pepper.

### 7.3.2 NAO-2 experiment

The NAO-2 experiment was conducted in the second room at Charles square with the Nao robot. The setup is detailed in Section 4.2.1.

#### Pilots

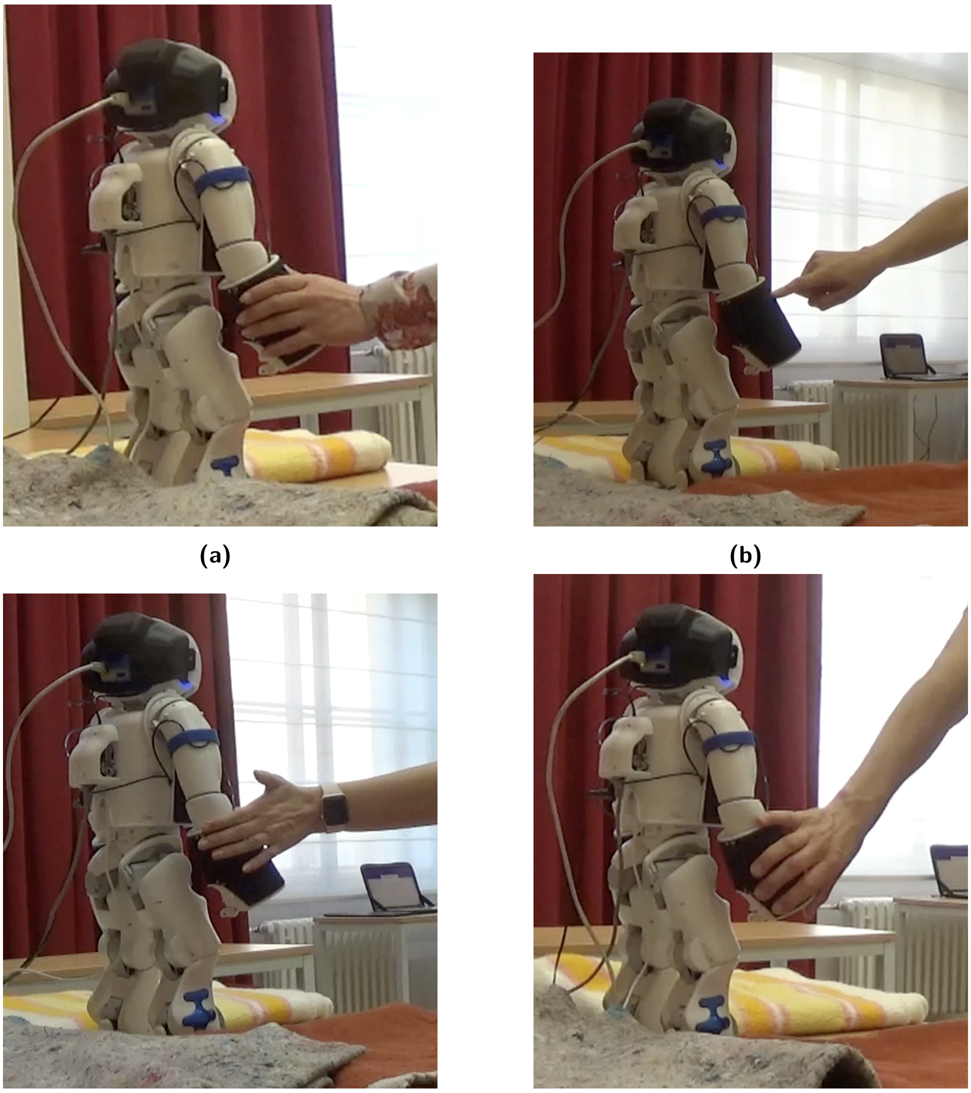
We had four pilots. At first, we had six different startle behaviors, but two of them were omitted. The first reaction had the robot raise both its hands up to the height of its shoulders. It was called a boxing position, rated as too aggressive and exaggerated during the pilot study. The second omitted reaction had the same problem, but only the touched hand was moving up.

#### Results

We analyzed different touch styles from the videos. We divided them into categories, on Figure 7.8. Frequency of those touch styles are in Table 7.20. Some participants touched the robot in more ways, and they were also added to the sum.

| Touch style | Total |
|---|---|
| handshake touch | 8 |
| finger touch | 4 |
| palm touch | 2 |
| right hand | 1 |
| SUM | 15 |

**Table 7.20:** Participants touch styles when touching Nao.



(a) (b) (c) (d)

**Figure 7.8:** Touch styles: handshake touch (a), finger touch (b), palm touch (c), right hand (d)

Further, we evaluated the questionnaires to find out why the participants decided on the reaction to be the most fitting/appropriate. This is shown in Figure 7.21. From the data, it seems that the most natural and appropriate reaction is reaction B. Furthermore, only reactions A and B were rated as logical by four people. Photos of the robot reactions are available in Section 5.1.2.

| Why voted for one reaction | A | B | C | D | Total |
|---|---|---|---|---|---|
| natural | 12.00% | 24.00% | 20.00% | 8.00% | 16 |
| logical | 8.00% | 8.00% | 0.00% | 0.00% | 4 |
| curious | 4.00% | 0.00% | 4.00% | 0.00% | 2 |
| pleasant | 0.00% | 4.00% | 0.00% | 4.00% | 2 |
| least scary | 0.00% | 0.00% | 0.00% | 4.00% | 1 |
| SUM | 24.00% | 36.00% | 24.00% | 16.00% | 25 |

**Table 7.21:** Why the participant chose the reaction as the most fitting/appropriate.

We asked why they did not vote for the other reactions, and the answers are in Figure 7.22. All reactions except the selected one received a negative rating. This is more of an overview result and must be interpreted carefully as it implies bilateral implication of the negative rating. Reaction A was indirectly rated as the most fearful.

| Why did not like the other reactions | A | B | C | D | Total |
|---|---|---|---|---|---|
| fearful | 10.42% | 6.25% | 6.25% | 8.33% | 5 |
| odd | 6.25% | 6.25% | 8.33% | 4.17% | 4 |
| aggressive | 4.17% | 4.17% | 6.25% | 4.17% | 3 |
| mechanical | 4.17% | 4.17% | 4.17% | 6.25% | 3 |
| aggravating | 2.08% | 0.00% | 2.08% | 2.08% | 1 |
| SUM | 27.08% | 20.83% | 27.08% | 25.00% | 16 |

**Table 7.22:** Why the participant did not vote for the other reactions.

We allowed the participants to leave a note (Table 7.23). Three people commented on the robot's skin sensitivity as being not sensitive enough. We also had a comment about the movement, that during a reaction, the head and hand movement is out of sync. This corresponds with the label odd in the previous section. More in Table 7.23.

| Notes | Total |
|---|---|
| robot had to be touched too hard (not sensitive enough) | 3 |
| liked body movement | 1 |
| liked gaze | 1 |
| missing face expression | 1 |
| natural lean back | 1 |
| out of sync head and hand movement | 1 |
| SUM | 7 |

**Table 7.23:** Notes from the startle experiment with Nao.

### 7.3.3 Results from both Pepper and NAO-2 experiments

Since we modeled the reactions in the same way, we could compare those results in Table 7.24. The most appropriate reactions are A and B. In both of them, the touched hand was pulled back. For better readability meanings of the A-D reactions once again:

- A (touched hand back, left unchanged)
- B (touched hand back, left front)
- C (touched hand front, left unchanged)
- D (touched hand front, left front).

| Best reaction | Nao | Pepper | Total |
|---|---|---|---|
| A | 6 | 11 | **17** |
| B | 10 | 6 | **16** |
| C | 6 | 5 | **11** |
| D | 4 | 6 | **10** |
| **SUM** | 26 | 28 | **54** |

**Table 7.24:** Most fitting startling reaction from Pepper and NAO-2 experiments.

We asked the participants whether they perceived the movement as natural and whether they noticed the robot leaning back. The answers to those questions are in Table 7.25 and Table 7.26 respectively. From those data, it seems that the Nao robot behaved less naturally than Pepper. Additionally, the participants did not notice Nao's lean-back as often as the Pepper robot's lean-back.

| Natural behavior | Nao | Pepper | Total |
|---|---|---|---|
| Yes | 18 | 26 | **44** |
| No | 8 | 2 | **10** |
| **SUM** | **26** | **28** | **54** |

**Table 7.25:** Was the robot's movement natural during the startle study?

| Noticed lean-back | Nao | Pepper | Total |
|---|---|---|---|
| Yes | 21 | 26 | **47** |
| No | 5 | 2 | **7** |
| **SUM** | 26 | 28 | **54** |

**Table 7.26:** Did you notice the robot leaning back during the startle study?

# Chapter 8
# Conclusion

## 8.1 Accomplishments

We had three experimental setups for two different robots – Nao and Pepper. Those setups include programming the robot's behavior, measuring the distances in real-time using an RGB-D camera, finding the transformation matrix from the camera to the robot, finding the keypoints of the participants, logging the data for further investigation. This study had around 100 participants. The results from the First proxemics study have already been published [LRH20].

## 8.2 Checking with objectives

### 8.2.1 Does the size of the robot affect the extent of PSZs?

We wanted to understand whether the robot's size affects the extent of personal spacial zones (PSZs) people expect the robot to have using distance measurement.

From the results of the Second proxemics study (Section 7.2.3), both the distance measurements and the questionnaires suggest that we can reject this hypothesis even though Nao was approximately half as tall as Pepper, the distance people stayed away from the robot was similar. However, in our scenarios, the Nao robot was elevated on a table, and we did not have a control condition with a robot standing on the ground.

### 8.2.2 How do people interpret the robot behavior in case they enter its personal/intimate zone?

During the First proxemics study (Section 7.1), people found the lean-back to be unnatural and did not like it. We then updated the leaning back behavior from being a discrete response to a continuous one. The behavior was, most of the time, interpreted as the robot keeping distance. From Section 7.2.3, the leaning back behavior was interpreted as keeping distance during the Pepper experiment. However, during the NAO-2 experiment, it was interpreted as the robot being aware by 8 participants, surprised by 8 participants, and as keeping distance by 7 participants. The condition affected the interpretation during this experiment. This might suggest that the interpretation depends on more factors and would require further research.

Nao's gazing behavior was perceived as the most appropriate during the human condition. Pepper's gaze was rated as the most appropriate during the robot condition. It might be important to note that the difference between the robot and human conditions is not as significant for Pepper as for the Nao robot.

### 8.2.3 How do people evaluate different robot startle reactions to an unexpected touch?

From the Startle study (Section 7.3), we found that the most natural reaction to unexpected touch always involved the touched hand moving back. During the Pepper experiment, the reaction where the robot did not move the other hand, was rated as more natural. However, during the NAO-2 experiment, people preferred the other hand to go to the front. This may have to do with the robot size: for the Pepper robot, which is bigger, moving one arm toward the participant may have been perceived as threatening. However, this would also require further research.

# Chapter 9

# Discussion

## 9.1 Limitations

### 9.1.1 Latency

Controlling the robot required an external computer (Section 4.1.3). Even though WiFi is available for both robots, Ethernet connection had to be used during all experiments due to latency. Whenever latency peaked over 100 ms, the robot reaction started to look clumsy, which would have affected the experiment. First participants affected by this were labeled as pilots. For next participants, we switched to an Ethernet connection.

### 9.1.2 Instruction text

During the first experiment with Nao (Section 4.2.1), our results regarding the distance participants stayed away from the robot were confounded by the fact that the instructions participants had to read were written in very small letters. Their font size was only 12 px. For the next experiments with Nao, we increased the font size to 16 px, and on Pepper's chest, we used 34 px.

### 9.1.3 Distance assigned to each condition

We measured the distance at which the participant has begun to read the instructions on the robot's chest. Nevertheless, in many cases, the robot did not lean-back at this stage of the condition. The various triggering distances throughout the conditions were not applied at this stage yet.

We tried a different method to measure the distances. We truncated distances greater than 1.5 m and measured the average distance from every scenario from both NAO-2 (Figure 9.1) and Pepper (Figure 9.2) experiments.

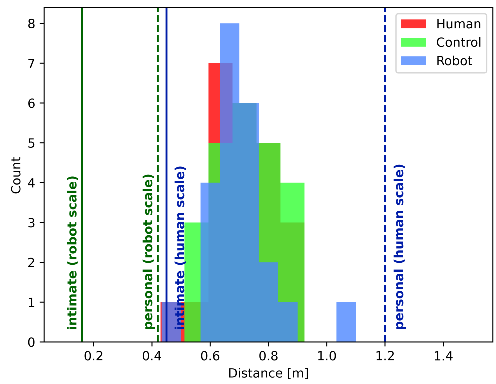



**Figure 9.1:** Histogram of the average distances truncated at 1.5 m from the NAO-2 experiment.

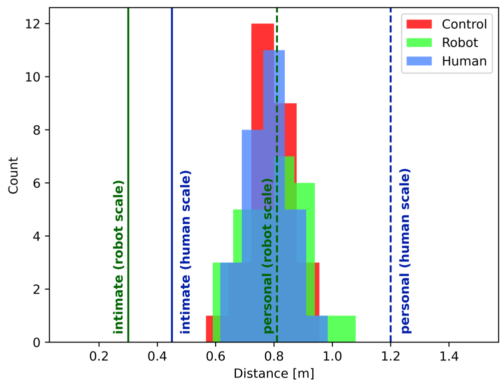



**Figure 9.2:** Histogram of the average distances truncated at 1.5 m from the Pepper experiment.

The distances during the NAO-2 experiment for the different conditions – Control, Robot and Human were $(0.72 \pm 0.09)$ m, $(0.70 \pm 0.12)$ m and $(0.71 \pm 0.10)$ m respectively. The total average was $(0.71 \pm 0.10)$ m. For the Pepper experiment they were for the different conditions – Control, Robot and Human $(0.78 \pm 0.08)$ m, $(0.80 \pm 0.10)$ m and $(0.79 \pm 0.08)$ m respectively. The total average was $(0.79 \pm 0.09)$ m. We run correlations against the TIPI questionnaire, gender, age, height, experience with the robot, but nothing significant was found.

This might be investigated more in the future.

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# Appendix A
## Godspeed questionnaire

Anthropomorphism, Animacy, and Likeability subscales. Czech translation by Matej Hoffmann.

# O robotovi

Vyplňte, prosím, své identifikační číslo (ID). Poté ohodnoťte, jak na Vás robot působil.

*Required

1. ID *

2. Antropomorfismus (podobnost člověku) *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| napodobenina, "fake" | ◯ | ◯ | ◯ | ◯ | ◯ | přirozený |

3. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| strojový | ◯ | ◯ | ◯ | ◯ | ◯ | lidský |

4. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| nevědomý | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | vědomý |

5. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| umělý | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | jako živý |

6. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| pohybuje se strnule | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | pohybuje se plynule, elegantně |

7. Životnost *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| mrtvý | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | živý |

8. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| statický | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | temperamentní |

9. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| mechanický | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | organický / přírodní |

10. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| umělý | ◯ | ◯ | ◯ | ◯ | ◯ | jako živý |

11. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| nečinný | ◯ | ◯ | ◯ | ◯ | ◯ | interaktivní |

12. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| apatický | ◯ | ◯ | ◯ | ◯ | ◯ | vnímavý |

13. Byl robot sympatický? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Nebyl mi sympatický. | ◯ | ◯ | ◯ | ◯ | ◯ | Byl mi sympatický. |

14. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| nepřátelský | ◯ | ◯ | ◯ | ◯ | ◯ | přátelský |

15. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| nevlídný | ◯ | ◯ | ◯ | ◯ | ◯ | hodný |

16. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| nepříjemný | | | | | | příjemný |

17. *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| strašný | | | | | | milý |

# Appendix B

## TIPI questionnaire

Prof. Marek Franěk kindly provided the Czech version on the TIPI questionnaire used in D. Šefara, M. Franěk, and V. Zubr, “Socio-psychological factors that influence car preference in undergraduate students: the case of the Czech Republic,” Technological and Economic Development of Economy, vol. 21, no. 4, pp. 643–659, 2015.

# Základní informace

*Required

1. ID *

2. věk *

3. pohlaví *

   *Mark only one oval.*

   - muž
   - žena
   - jiné

4. výška (cm) *

5. obeznámenost / zkušenost s roboty *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| neobeznámený | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | velmi obeznámený |

### Jaký je typ mé osobnosti

Použijte, prosím, jedno z následujících čísel 1-7, abyste vyjádřili, jak dalece souhlasíte či nesouhlasíte s následujícími tvrzeními. Považuji se za člověka, který je / jsem:

6. extravertní, rád(a) se pro věci nadchnu *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | rozhodně souhlasím |

7. kritický(á), snadno se rozčílím *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | rozhodně souhlasím |

8. spolehlivý(á), cílevědomý(á) *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | rozhodně souhlasím |

9. úzkostlivý(a), snadno se rozruším *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | rozhodně souhlasím |

10. otevřený(a) k novým zkušenostem *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | rozhodně souhlasím |

11. uzavřený (á), tichý(á) *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | rozhodně souhlasím |

12. chápavý(á), vřelý(á) *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | rozhodně souhlasím |

13. nesystematický(á), nedbalý(á) *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | | | | | | | | rozhodně souhlasím |

14. klidný(á), citově vyrovnaný(á) *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | | | | | | | | rozhodně souhlasím |

15. tradičně zaměřený(á), nevymýšlím nové věci *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| rozhodně nesouhlasím | | | | | | | | rozhodně souhlasím |