Bodily Manipulation of the Expressed Dominance on a Humanoid Robot

by

Kangqi Li

to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on Monday September 18, 2017 at 13:00 PM.

Student number:	4518942	
Project duration:	November 1, 2016 – September 18, 2017	
Thesis committee:	Dr. J. Broekens,	TU Delft, supervisor
	Dr. M. Neerincx,	TU Delft
	Dr. H. Hung,	TU Delft

An electronic version of this thesis is available at http://repository.tudelft.nl/.

TU Delft

Contents

1

Abstract

The subject of this thesis is to find a way to manipulate the bodily dominance expressions of robotic behaviors. The expression of emotion is an important part of the development of Socially Interactive Robots. Previously, studies about the robotic emotions usually focus on single behaviors. Because the generation and testing of new behaviors are time consuming, this kind of emotional manipulation procedure requires a lot of work when applied in practical use. The innovation of this thesis is to explore a solution that can modify the dominance level of a wide range of robotic behaviors without the re-creation of new behaviors. The results of this work can be used for the design of the robotic movements and the development of robotic applications.

2

Introduction

2.1. Research Background

2.1.1. Socially Interactive Robots

With the appearance of artificial intelligence technology, robots are likely to have more social roles in our daily life. The need of functionalities about the interaction between a robot and its environment gradually caught researcher's attention [41]. People are exploring the possibility of robotic applications that can be used in various social contexts [4, 10, 20, 26, 34, 35]. Therefore, one of the goals in current robotics research is to attach social abilities to robots which can communicate with different people without any specific training, including elderly people and children. This gradually arouses people's attention towards various studies of human-robot interaction (HRI) [17]. HRI addresses how humans interact with robots, and how best to design and implement robot systems which are capable of accomplishing interactive tasks in human social scenarios[18]. In this paper, we use "socially interactive robots (SIR)" to indicate robots with social abilities and are able to participate in human-robot interactions.

One of the important social characteristics of socially interactive robots is the ability to express emotions [41]. This need brings new challenges to HRI study because the emotional expression is not a robot-centered function but a complicated problem that involves the psychological research about how the human think about the robot.

2.1.2. Nonverbal Behaviors

Similar to human communication, the interaction between human and humanoid robots consists of both verbal and nonverbal behaviors. Nonverbal behaviors refer to the use of many wordless and visual cues, such as body language, facial expressions, distance, physical environments, eye contacts, clothing, and gestures [1]. Moreover, besides the convey of information, the nonverbal behaviors are proved as a significant way to convey feelings and attitudes[1, 29].

It is imperative for socially interactive robots to have a correct system to convey the correct emotions through nonverbal behaviors. However, the development and manipulation of nonverbal behaviors is a complex problem which is largely affected by the mechanism of the robots in use. For example, Pepper (2.1(a)) is available to convey emotions through bodily expressions and clothing with only its upper body; Asimo (2.1(b)) is capable to deliver through its entire body but is unavailable to use facial expressions due to the lack of facial features; Sota (2.1(c)) cannot represent hand gestures because it doesn't have fingers; Interactive Cat (2.1(d)) is designed to show various facial expressions but it is not capable to perform any bodily expressions; Kobian (2.1(e)) can execute various nonverbal behaviors both facially and bodily since it supports the movement of facial components, limbs, fingers and clothing customization.

Therefore, it is hard to build a standard nonverbal behavior system that is suitable for all socially interactive robots. Researchers and developers should design the nonverbal behaviors based on the physical characteristic of different robots. However, it is still possible to explore the features for each type of nonverbal behaviors. For example, studies can be conducted to derive the similarities of bodily expressions on all the robot which supports limb movements, or gesture designs for all the robots with fingers. These results can provide ideas about how to design robots and robotic applications. In this thesis, we investigate the manipulation of bodily expressions.

(a) Pepper (b) Asimo (c) Sota (d) Interactive Cat (e) Kobian

Figure 2.1: Different designs of socially interactive robots.

2.1.3. Parameterized Behavior Modulation

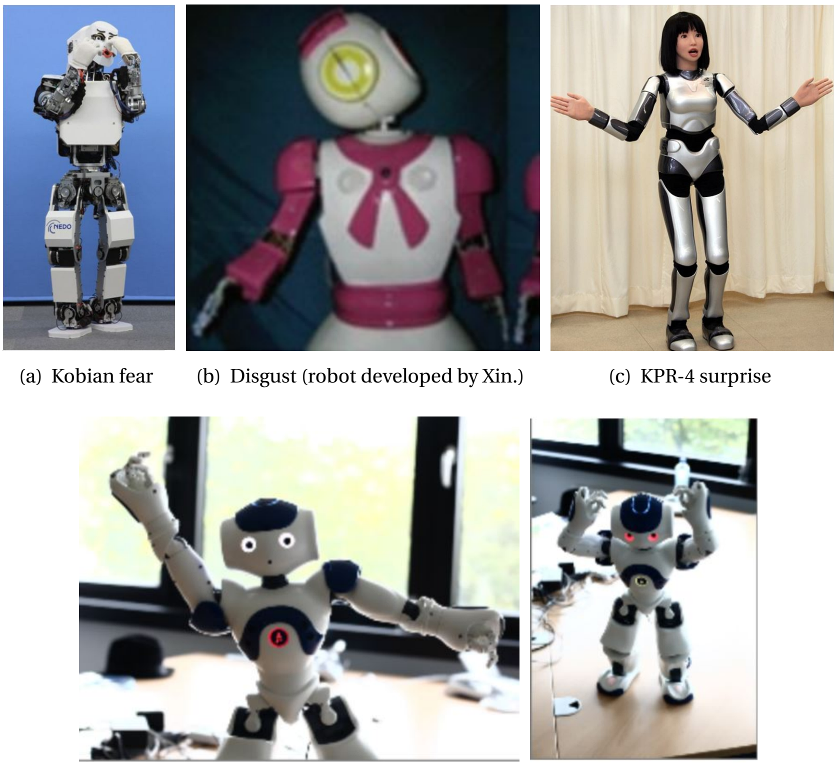
Previously, the studies about the nonverbal expressions of emotions of socially interactive robots are based on various approaches. One of the major procedures is to make the robot mimic human behaviors [2, 8, 15, 23, 24, 27, 46, 47, 49]. Some studies exhibited the potential of using behavior parameters to control behavior expressivity. Zecca et al. first created multiple facial behaviors and tested them through perception experiment, then implemented 7 emotional facial expressions on Kobian robot based on the experimental results [49]. Haring et al. investigated 4 emotions (anger, fear, joy, sadness) and build 2 different bodily expressions on NAO robot for each emotion. And tested and compared the effects of these behaviors through experiment.[23]. Breazeal et al. created 9 facial expressions for 9 basic emotions. Then delivered a robotic facial expression system by modulating the parameters of the basic expressions [8]. Xin et al. generated 6 facial emotions with the same parameters they recognized from real-time human expressions to make the robot mimic real human behaviors [46]. Part of the generated emotional behaviors of these research are shown in 2.2.

Hence, parameterized behavior modulation is a commonly used procedure for the design and creation of nonverbal behaviors of robots. However, one similarity of all these works is that every behavior is created manually to express one specific emotion. Therefore, with this method, to establish a completed nonverbal expression system for socially interactive robots, various behaviors should be implemented independently to perform different emotions. Expressions for happiness, sadness, fear, anger and so on are all in need. And lots of experiments are required to evaluate the performance of these behaviors, which brings enormous tasks to researchers and developers. Furthermore, emotions are often intertwined with mood, temperament, personality, disposition, and motivation [39]. For example, one simple movement, waving hand, can be conducted gently to show friendless, and also can be conducted fast to express anger or excitement. Thus, it is difficult to let the robot act naturally in all possible circumstances by using a limited amount of behaviors for specific emotions.

Xu et al. presented another innovative procedure for parameterized behavior modulation [47]. In this work, bodily behaviors of the NAO robot are investigated. Unlike other studies who developed whole body expressions for specific emotions, Xu et al. focused on the parameters of the movement. For example, how the speed, the hand height and the hold time can affect the emotional expression of the hand waving movements. Once the relations between the parameters with the emotions are explored, it is possible to establish an efficient solution to manipulate the conveyed emotions through changing the related parameters. Compared to previous modulation of robotic emotions, this strategy does not require the manual creation of new behaviors. Given the information of an existing movement, different emotions can be conveyed through the manipulation of parameters. Based on this idea, the requirement of the analysis of emotional parameters arouses.

2.1.4. Interpersonal Circumplex

To simplify the procedure and reduce the workload of the development of robotic nonverbal behaviors, we focus on the study about the related bodily parameters of different emotions. Among all emotions, the dominance and the warmth are the most important one since they are thwo axes of the interpersonal circumplex model. The interpersonal circumplex – also known as the interpersonal circle – is a model for conceptualizing, organizing, and assessing interpersonal behavior, traits [44]. Fundamentally, the interpersonal circumplex is a two-dimensional representation of a given interpersonal space (of interpersonal needs, values,



(a) Kobian fear (b) Disgust (robot developed by Xin.) (c) KPR-4 surprise

(d) NAO joy (e) NAO angry

Figure 2.2: Nonverbal emotion expressions of different socially interactive robots.

problems, traits, etc.) in which the set of variables are organized theoretically as a circle. [43]. As shown in Figure 2.3, the two dimensions which define this emotional space are dominance and warmth. Dominance represent ideas of power, status, and control, whereas valence suggests love, affiliation, union, and friendliness. Circumplex models also assume that each interpersonal variable, usually represented as a type of emotion, can be regarded as a particular blend of dominance and valence, depending on that variable's location on the circle [21].

Interpersonal circumplex models are regarded as useful tools for identifying or differentiating personality disorders, since interpersonal dispositions are key features of most personality disorders [28]. Hence, we expect that it can also be used for the design of robotic nonverbal behaviors.

2.2. Research Questions

Instead of creating multiple behaviors to represent different emotions, we want to build a generic procedure that can be used to attach different emotions on every single nonverbal behavior. This parameterized behavior manipulation system aims to manipulate the position on the two dimensions in the interpersonal cirsumplex model by changing the expressed dominance and warmth. In this way, with the modulation of the interpersonal circumplex model, it is possible to reach any target position in the interpersonal space and make the robotic behavior express expected emotions. Compared to previous parameterized behavior models about robotic emotions, this solution is expected to be capable to adjust the dominance degrees of various implemented behaviors automatically without the creation of new behaviors.

In this work, we focus on the nonverbal expression of the horizontal dimension: the dominance. These following general research questions will be discussed:

- Which bodily features are regarded as the symbols of dominance in human communication? (Chapter 2)

- Do the dominant bodily features of human behaviors have a similar effect on robotic behaviors? (Chapter 3)

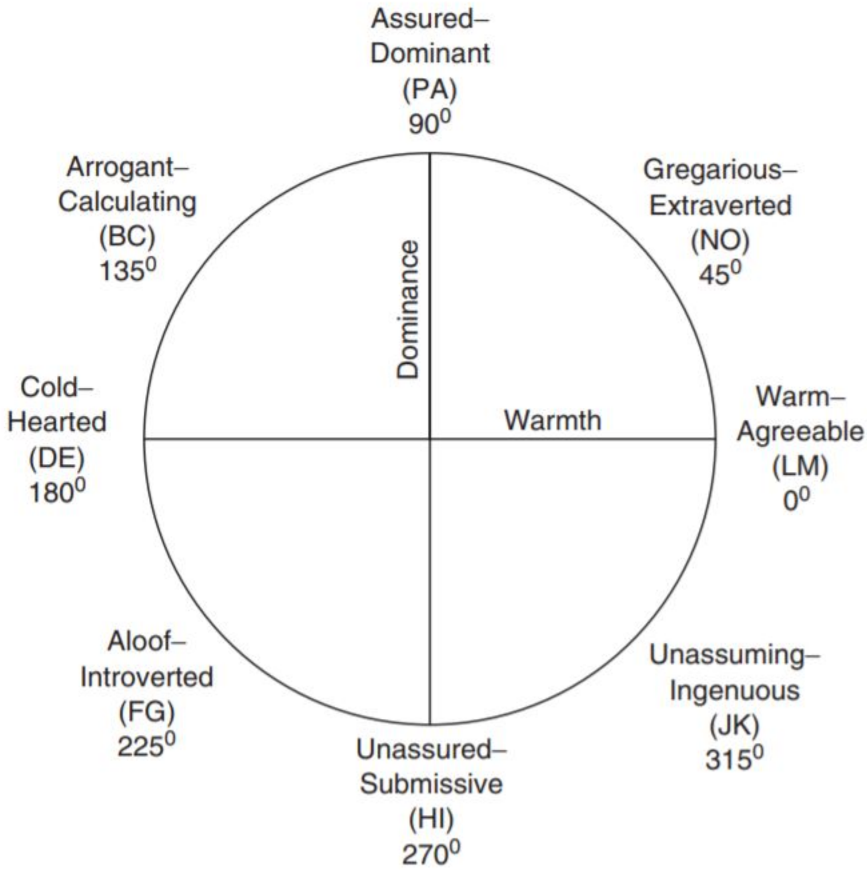


Figure 2.3: A generic interpersonal circumplex model [21].

- What are the related parameters of dominant bodily features and how to manipulate them on the NAO robot? (Chapter 3 and 4)
- What is the performance of the parameterized dominance manipulation of the robotic behaviors? (Chapter 5)

2.3. Thesis Overview

As explained in the previous sections, we want to build a generic method for the development of robotic nonverbal behaviors. Therefore, the modulation of the dominance and the valence is important to let the socially interactive robot express proper emotions as we expected.

Here we give a brief overview of the following chapters:

- Chapter 2: This chapter is the literature study of the previous researches of the nonverbal dominant expressions of human interactions. Factors that may affect the dominance expression of the human are summarized.
- Chapter 3: To verify whether the factors we got from Chapter 2 can also affect the human-robot interaction, we manipulate these factors on several bodily behaviors. Then an online experiment is developed to check the effect.
- Chapter 4: In this chapter, we implement the parameterized modulation in an application, personal assistant for a healthy lifestyle (PAL), which aims for the study of long-term child-robot interaction. The implementation achieves the manipulation of dominant factors upon dynamic behaviors.
- Chapter 5: To evaluate the performance of our implementation, we build a perception experiment with three behavior patterns. The result is analysed by ANOVA.
- Chapter 6: This chapter concludes the thesis and summarizes the findings. We discuss the results and limitations of our work, envision possibly interesting research directions, and propose potential applications.

3 Dominant Bodily Expressions of Human Interactions

In this chapter, we explore the features of dominant expressions in human interactions. The studies about nonverbal expressions of dominance can be driven by different purposes and methods. For example, some research focus on the experiments and analysis of the effects of specific human behaviours while others may try to conclude the different patterns of expressions in different contexts. The potential dominant factors which are possible to be used for the development of the dominance manipulation of the NAO robots are selected for following implementations.

3.1. Overview

There are only a few of works focuses on the exact parameterization of specific nonverbal expressions and the corresponding effects. For example, Mignault and Chaudhuri et al. conducts several experiments about the relation between the head tilt angles with the dominance perception [31]. Some studies do not have an exact research purpose about dominant expressions, but they also provide some related results indirectly. For example, Rule and Jr et al. investigate the performer's ability to recognize several dominance expressions under some physical and temporary constraints [38]. They created several postures for testing and assumed they can represent dominant, neutral, or submissive feelings. Therefore, besides their original research goal, they also proved the perceived dominance level of tested postures are in consist with their expectation. Therefore, the created postures can be used to derive the related dominant features.

In addition to the research with experimental evaluation and validation, there are also some works based on the meta-analysis of experimental results from previous studies. Hall and Coats et al. present a detailed review about the existing studies of dominance expressions. Nonverbal behaviors are categorized and compared in order to explore the cues related to dominance.

Since implementation of nonverbal behaviors is affected by the mechanism and functionality of the robot, and our implementation is based on NAO robots, there are several limits when selecting available dominant cues. For instance, facial expressions are not feasible for NAO. Hence, we only discuss feasible bodily behaviors in the following sections. The unfeasible dominant bodily features are shown in Appendix A for further studies. An overview of the general content and research purpose of the selected papers is given in Table 3.1. The discussion of these studies are summarized in the next section.

3.2. Dominant Cues of Human Communication

3.2.1. Head Pitch

Carney and Hall et al. (2005) [11] have investigated potential nonverbal expressions related to social power. A wide range of nonverbal behaviours (NVBs) are investigated under the same experimental procedure: displaying pictures of NVBs to observers and let them rate the dominance / submissiveness degree. In this work, various NVBs are considered by category. Within the head movement category, high power individuals were expected to engage in more upward tilting of the head, orienting head toward other, and shaking head when listening. However, orienting head toward other and shaking head when listening are complicated interactive

Table 3.1: Overview of studies about non-verbal dominant postures with experiments

Article and experiment	Posture type	Variable	Tested subjects	Cover story	Findings	Key features
Bialobrzeska, Parzuchowski (2016): Experiment 1	Standing	Body expansiveness	Two photos of real human	Communication skills	The expansive standing photo is considered as more dominant	Postures comparision
Carney, Cuddy (2010)	Standing, sitting	Body expansiveness	Videos of real human	Neuroendocrine levels changes	Powerful posing causes physiological, psychological, and behavioral changes	Posture configuration
Arnette, Pettijohn II (2012)	Sitting	Positiveness	Pictures of real human	Leadership	The positive sitting posture is considered to have higher leadership	Postures comparision
Reuderink (2006)	Head tilt	Head angle	Videos of virtual characters	Impressions of artificial agents	Larger head angle can result in less dominance when in combination with short, down direction gaze.	Combination of multiple factors
Rule, Jr (2012): Study 1&2	Head tilt, Standing	Angle, body expansiveness	Pictures of real human	Impoverished dominant stimuli	Dominance could be judged from posed faces and bodies with accuracy	Postures comparision
Mignault, Chaudhuri (2003)	Head tilt	Head angle	Images of rendered human faces	None	Perception of dominance as a function of head angle	Posture configuration
Bee, Pollock (2010)	Gaze	Gaze direction (head angle), linguistic content	Pictures of virtual characters	None	When cues to dominance are inconsistent, perception depends on the trait being conveyed;linguistic modality had a greater effect	Combination of multiple factors
Cuddy, Wilmuth (2015)	Standing	Body expansiveness	Real human performance	Job interview	Highpower posers appeared to achieve higher overall performance evaluations during a stressful job interview	Posture comparison

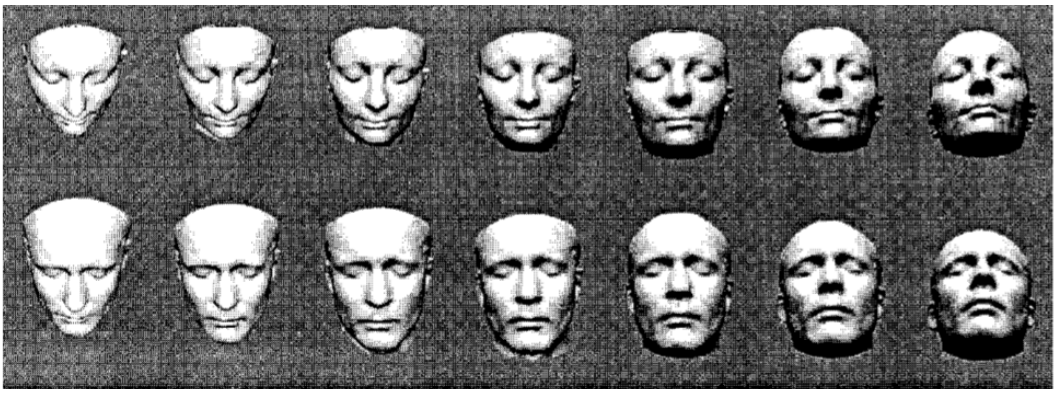


Figure 3.1: Mignault and Chaudhuri (2003): The tested sample of a female (top row) and male (bottom row) actor at different head angles [31].

behaviors during communication, which requires a real-time detection of the user's location and behavior, which is not available with the current PAL system. Since the development of these functions are beyond the scope of this thesis, the head tilt is the only suitable one in current condition.

Mignault and Chaudhuri (2003) [31] investigated the function of dominance perception and head angles. Additional factors that may affect people's perception, like hair and skin tone, are removed from the pictures of real human heads at different angles and they are displayed in a gray background. The result clearly shows that a bowed head connotes submission while a raised head connotes dominance (especially for women) under pure single stimuli. The experimental materials are shown in Figure 3.1.

Rule and Jr et al.(2012) [38] also proved the same conclusion. Moreover, instead of using pictures of human head directly, some image processing procedures are applied to extract the contour and the key features of these pictures. Therefore, it may also be possible for robots without facial expression to use the same tiled head expression to express dominance. 3.2.

On the other hand, Bee and Pollock et al. (2010) [3] and Reuderink (2006) [36] focus on the dominant effect when various factors are simulated together. Bee and Pollock et al. (2010) revealed an unexpected finding that when both verbal and nonverbal stimuli are applied together through the same virtual character and have inconsistent meaning, the perception of dominance will be different[3] . Reuderink (2006) analyzed the overall expression effect with tilted head in combination with gaze. The result shows that though up-tilted head usually represents dominance, it could also express submissiveness with an opposite eye gazing direction and short gazing time. Based on these concerns, we do not use verbal expression and eye gazing functions of NAO in the following implementation and experiments.

In conclusion, many works have proved that the angle of the head tilt could be configured to express various levels of dominance / submissiveness of human. And it is feasible for the NAO robot to mimic this behavior. So this factor is selected for the following implementation. To indicate the moving direction of the head more clearly, we use "head pitch" to represent this factor in subsequent chapters.

3.2.2. Body Expansiveness

Carney and Hall et al.(2005) [11] have proved the erect body and extended or stretched out legs are symbols of power while Hall and Coats (2005) [22] found openness is also related to dominance. Though these two research do not provide any clear picture or definition of the body features they tested in their experiment, some other studies are inspired by these findings and have recreated the probable standing postures which are available in their literature.

In the work of Carney and Cuddy (2010) [12], expansiveness is described as "taking up more space or less space" and openness is described as "keeping limbs open or closed". And a pair of standing postures are captured to represent dominance or submissiveness. The experiment of this work shows that the selected postures can successfully express expected emotions. The standing posture is shown in Figure 3.2.

After this work, various studies are conducted to analyze the social effect of body expansiveness. Many additional experiments have been published and proves that expansive posture will result in: an increased thought of confidence [9], an imagined role of dominance [14], marginally increased power feelings [16], an increased power feeling [19], pride feelings [40], the decreased threat and the increased mood [42], an increased cognitive accessibility of power-related words [25], a higher self-esteem and less fear [32]. Beyond

(a) Expansive standing (b) Constrictive standing

Figure 3.2: Carney and Cuddy (2010): Tested standing postures with different levels of expansiveness.

the dominance expression, there are also evidences showing that the expansive body has a positive impact on many other phenomenon, for example, cheating and traffic violations [48], recall of negative words [30], pain tolerance [6]. These results are all reviewed in Carney and Cuddy et al. (2015) [13].

However, among all these related works, a clear definition of body expansiveness is missing. There is no parameterized standard to distinguish which postures are expanssive and which are constrictive. Moreover, some studies do not provide the image or video stimuli they used in their experiments with only a vague description. Part of the available image stimuli or the example pictures are shown in Figure 3.3, from which we summarize that the expansive body usually has these traits:

- legs and arms are extend out of the body
- the angle between the arms and the trunk is large
- the distance between two feet is large
- the limbs stretch out
- the body is erect

In contrast, a constrictive posture usually has:

- legs and arms are crossed
- the angle between the arms and the trunk is small
- two feet are close to each other
- the limbs and the body are squeezed

Currently, there is no study presenting a parameterized result of the dominance perception and body shapes. But we can also use the postures displayed in these figures for a more concrete function describing the relation of perceived dominance with posture parameters. This will be discussed in the following chapters.

3.3. Conclusion

In conclusion, the head pitch and the body expansiveness are commonly believed as symbols of human dominance expressiveness. And they are also feasible to be manipulated on NAO robots. There are also many other NVBs related to dominance, however, they are constrained by the functionality of NAO and the PAL system. These results are listed in Appendix A which may be investigated in the future for other humanoid robots and applications.

(a) Expansive postures

(b) Constrictive postures

Figure 3.3: Image stimuli or examples of experiments about body expansiveness in related studies.

4

Validation of Factors

The bodily expressions of dominance / submissiveness are quite complicated for humans. Many features can affect observer's perception, such as the body expansiveness and the head pitch. As for humanoid robots, it is still unknown that these features also can play a role in human-robot interactions. In order to explore the bodily behavior and the method to manipulate dominant expressions of humanoid robots, we investigate the influences of the body expansiveness, the head pitch as the potential bodily symbols of dominance. The observation distance, the observation height are also studied to check whether the bodily manipulation can work in different observation conditions and can be applied on different types of postures. The conclusions can be used for further manipulation of the dominance / submissiveness.

4.1. Experiment Overview

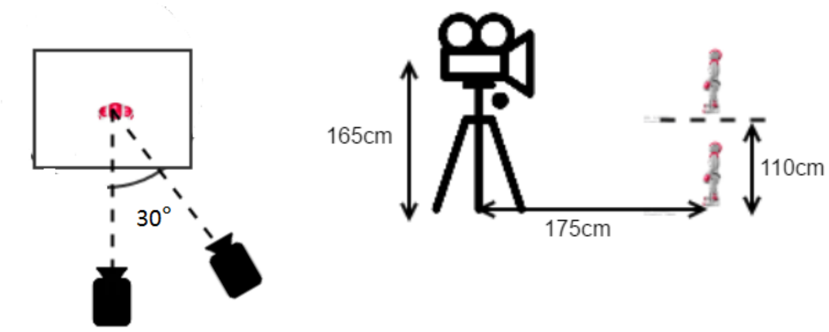
Our goal is to figure out whether the body expansiveness and the head pitch can significantly affect observer's perception of dominance from humanoid robots and then explore the possibility to control the dominant / submissive expression by manipulating the related parameters. To avoid the probable effect brought by the observation angle and height, the height of the robot position and the observation angle are also and evaluated to generate comprehensive conditions since they may affect the observer's recognition of our bodily manipulation. For this experiment, we capture multiple images of the NAO robot with different postures and observation conditions. Then, an online experiment is deployed on Amazon Mechanical Turk.

4.2. Image Stimuli

A programmable humanoid robot, NAO (Aldebaran Robotics, France), is used to perform bodily expressions. It is also used in the PAL system. As shown in Figure 6.1, the distance between the robot and the height of the camera are fixed. Photos of robots are captured by the camera from observation angles of 0° and 30°. A 110cm-tall table is used to adjust the height of the robot. The body expansiveness of the NAO robot is represented by the angle between the arm and the trunk, the angle between the leg and the trunk and the stretch of legs and hips. The head pitch is the angle between the head and the horizontal. For each posture, limbs of the NAO robot are configured in two sets of parameters as shown in Figure 4.2. In Chapter 2, most of the work about human behaviors focus on only one variable each time, the head pitch or the body expansiveness, and there is no existing study about the combined performance of the head pitch and the body expansiveness. It is unknown what the overall effect will be when the manipulation of the body expansiveness is contrary to the manipulation of the head pitch. Therefore, in this experiment, we set the manipulation of the body expansiveness in consistent with the manipulation of the head pitch. The expected dominant postures are all in an expansive body and an upward tilt head while the expected submissive postures all have a constrictive body with a downward tilt head.

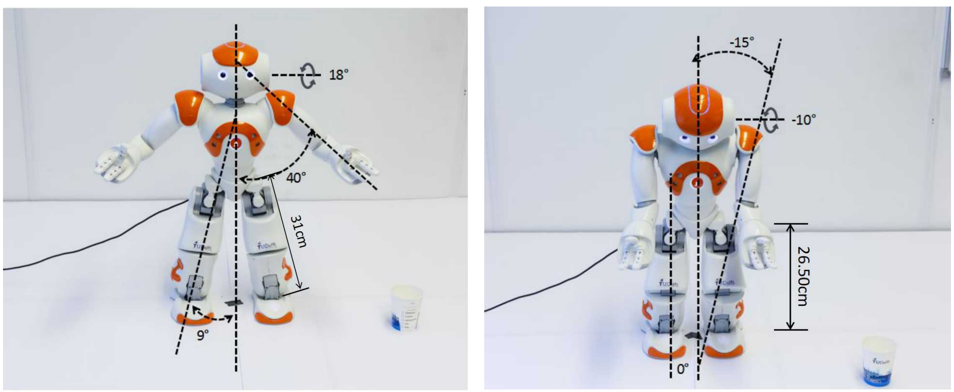
To give a comprehensive analysis of the effect of postures, we picked 11 typical postures with different features: sitting, standing, symmetric arms, asymmetric arms, symmetric legs, asymmetric legs, arms in front of the body, arms behind the body, stretched arms, bend arms, raised arms, lowered arms. We make all postures have the same bodily parameters as shown in Figure 4.2.

There are 2×2×2 conditions for each posture with different combinations of other three factors. There are 88 images collected for the following experiment in total.



(a) Top view (b) Side view

Figure 4.1: The image acquisition procedure.



(a) Dominant Manipulation (b) Submissive Manipulation

Figure 4.2: The example postures of different manipulation

Table 4.1: Group conditions of the web survey

Factors	1	2	3	4	5	6	7	8
Angle	0°	0°	30°	30°	0°	0°	30°	30°
Height	Ground	Table	Table	Ground	Ground	Table	Table	Ground
Expansiveness	High	High	High	High	Low	Low	Low	Low
Posture	1-11	1-11	1-11	1-11	1-11	1-11	1-11	1-11

Table 4.2: Results of Multivariate Tests

Source	Hypothesis df	Error df	F	P
Posture	144.661	10.000	773.000	<0.001
Posture * Height	7.053	10.000	773.000	<0.001
Posture * Angle	8.310	10.000	773.000	<0.001
Posture * Expansiveness	42.095	10.000	773.000	<0.001
Posture * Height * Angle	3.128	10.000	773.000	0.001
Posture * Height * Expansiveness	13.133	10.000	773.000	<0.001
Posture * Angle * Expansiveness	6.762	10.000	773.000	<0.001
Posture * Height * Angle * Expansiveness	1.048	10.000	773.000	0.401

4.3. Measurement

An online web survey is created to collect people's responses toward images of the NAO robot. Participants are required to rate their perception of how dominant / submissive they feel about the robot image. Images are displayed independently and in a random order. Every participant was required to rate all 11 images in one of eight image groups. The conditions of each group are listed in Table 4.1.

The experiment is deployed on Amazon Mechanical Turk (Amazon, U.S.) in order to gather responses from a wide range of gender and age distribution, cultural diversity, educational level[33].

4.4. Results and Analysis

835 participants joined our experiment through Amazon Mechanical Turk in total. Before the questions about our experiment, two questions with typical images of dominance and submissiveness are displayed as trails for us to filter the responses. 45 participants were rejected because they failed to meet our requirements for the trial questions. The trail questions with typical images of dominance and submissiveness were presented to test whether they understood the definition of dominance/submissiveness and experimental requirements. Therefore, 790 responses are selected and analyzed finally.

To figure out whether the observation angle, the height of robots, postures and the bodily manipulation will affect people's perception of dominance, the two-way ANOVA with repeated measures is applied for each factor. In our case, the within-subject variables are the tested 11 postures and the between-subject factors are the perception angle, the height and the body expansiveness. Statistical calculations were performed by using IBM SPSS Statistics for WINDOWS (IBM Corporation, Armonk, New York, U.S.).

By using Mauchly's test of sphericity, there is a significant deviation from the assumption of sphericity with $P < 0.001$. Therefore, as shown in Table 4.2 and Table 4.3, the multivariate tests and the ANOVA within-subject test after Greenhouse-Geisser correction are used to analyze the effect of postures. Both strategies show there is a significant effect of postures on the perception of dominance with $confidenceinterval =$ 95.0%, $P < 0.001$. Furthermore, there is also a significant interaction between postures with the bodily manipulation, the angle and the height as $P < 0.001$. In conclusion, the posture factor works for the expression of dominance.

Table 4.3 and Figure 4.3 give the same results about the effects of height, angle, bodily manipulation and their interactions. The significance values suggest that only the body expansiveness can significantly affect observer's perception of the dominant feeling. In Figure 4.3(a), the high body expansiveness will result in the perception of a more dominant feeling on overall with posture 1 as the only exception. Consistent with the results in Table 4.3, Figure 4.3(b) and Figure 4.3(c) depict that neither the perception angle nor the robot

Table 4.3: Repeated measures ANOVA

Source	SS	df	MS	F	P
Posture	1770.871	9.307	190.280	187.065	<0.001
Posture * Height	66.346	9.307	7.129	7.008	<0.001
Posture * Angle	69.727	9.307	7.492	7.366	<0.001
Posture * Manipulation	435.557	9.307	46.800	46.010	<0.001
Height	4.231	1	4.231	1.603	0.206
Angle	1.189	1	1.189	0.451	0.502
Manipulation	715.477	1	715.477	271.078	<0.001
Height * Angle	3.279	1	3.279	1.242	0.265
Height * Manipulation	25.369	1	25.369	9.612	0.002
Angle * Manipulation	0.104	1	0.104	0.040	0.842
Error	2063.993	782	2.639		

height can affect the perception of dominance. However, the robot height and the body expansiveness have the interaction effect. In Figure 4.3(d), although the marginal mean of high body expansiveness is always larger than that of low body expansiveness, the higher height seems can amplify the effect of the body expansiveness.

4.5. Discussion

As can be observed from Figure 4.3, different postures give different dominant feelings for observers. For example, Posture 6 is always less dominant than Posture 5 and Posture 7. And in most cases, for one specific posture, a high body expansiveness can result in a higher dominance perception. The reason for Posture 1 may be that is a sitting posture and it is hard to adjust the joint parameters for this posture, because the Nao robot has short limbs which cannot be compressed as real humans. This affects the perception of expansiveness.

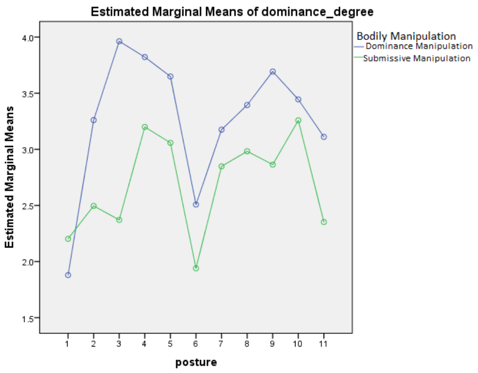
Therefore, in general, we succeed in proving the posture and our bodily manipulation are two factors that can affect NAO robot's expression of dominance. One potential strategy to control the dominance degree of humanoid robot through bodily expression could base on the posture selection and the bodily manipulation. For a specific socially interactive robot, based on the purpose of design, postures that have a significant dominant, or submissive, impression are selected for interactions. And for a specific posture, the parameters of the head pitch angle, angles between limbs and the trunk, the limbs stretch can be manipulated to control the expressive style of the humanoid robot. Moreover, a proper height of the position of the robot may help to amplify the effect of the manipulation of postures and expansiveness.

This strategy can be adopted by various humanoid robots which support the movement of the head and the limbs. However, we cannot conclude dominance cannot be affected by the observation angle because in this research, only 0° and 30 ° are taken into concern. Further studies are needed to extend the measured range of the angle variable. And though we tested postures with different traits, the parameters we used to control the expansiveness are always symmetric. No matter what posture is performed, the angles between arms/legs and the trunk are symmetric. How to measure the overall expansiveness is unknown if one side of the body is stretched and the other side is pulled back.

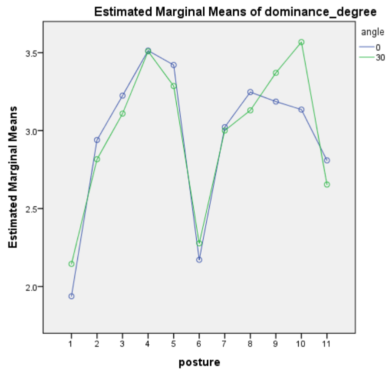
4.6. Conclusion

This study depicts that the bodily manipulation and the posture of the humanoid robot influence people's perception of dominance and submissiveness. Based on studies about human's expression of dominance, we figured out the proper parameters that can be controlled on humanoid robots and used to convey the dominant feelings. Then the experimental results indicates that our manipulation for postures and body expansiveness has a significant effect on the dominance perception. This manipulation of nonverbal behavior can be used to adjust the emotional expression of socially interactive robots for different purposes.

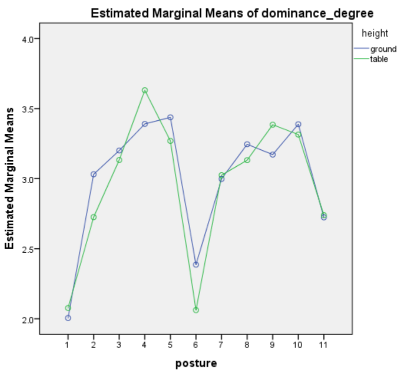
However, in this experiment, only static images are tested. But in a practical scenario for the use of socially interactive robots, dynamic motions are used in the human-robot interaction. Robots are expected to move while speaking and listening. Therefore, this experiment is a preliminary test to check whether there



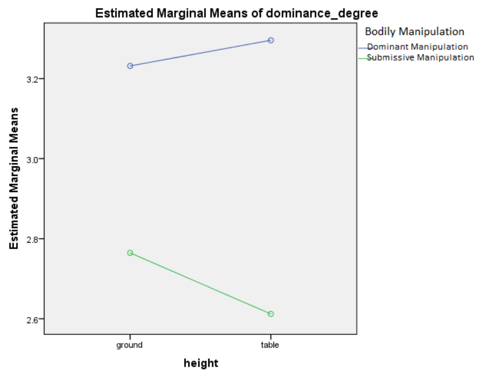
(a)



(b)



(c)



(d)

Figure 4.3: Profile plots of estimated marginal means.

is a potential that dominant bodily features of human also affect the expression of humanoid robots. In the following chapters, the implementation procedure about the real-time bodily manipulation of robotic movements is introduced. Further experiments are conducted to evaluate the bodily manipulation on dynamic movements.

5
Implementation

In preceding chapters, we find that the body expansiveness and the head pitch have a significant effect on the perception of dominance. In this chapter, we start from the introduction to the PAL system. The manipulation of the parameters related to the dominant factors is illustrated. This achieves the dominant manipulation on dynamic movements.

5.1. PAL Project

Our implementation is based on the PAL (Personal Assistant for healthy Lifestyle) project. PAL aims to improve child's diabetes regimen by assisting the child, the health professional and the parents. The PAL system is composed of a socially interactive robot (NAO), an (mobile) avatar, and an extendable set of (mobile) health applications (diabetes diary, educational quizzes, sorting games, etc.), which all connect to a common knowledge-base and reasoning mechanism.

The NAO robot is designed to support children with diabetes mellitus type 1 (T1DM) in self-management education. The control system and the applications of the robot are on a remote server. The behaviors that the robot needs to perform are generated by the remote system, which is a JAVA project consists of various modules. In this case, we focus on the Behavior Manager module which manipulates the behaviors.

5.2. Behavior Manager

The behavior manager is the module for the generation and manipulation of the application behaviors in the PAL system. During the execution of health applications, both verbal and nonverbal behaviors are required based on the current task. These behaviors are generated and managed by the behavior manager. The architecture of Behavior Manager is described in Figure 5.1. All the implemented behaviors are firstly designed in *Choreographe*, the software for the development of *Aldebaran Robotics*, and then imported to a `XML` file. Since this experiment does not involve the use of any health application, a GUI is used to change the dominant factor value and select the target behavior. Once a movement is requested by the application or the GUI, the robot will first perform the behavior then take a transition motion and stop at a fixed position. This makes all behaviors can start and end in the same position. There are also a TECS server and other application modules working behind for the management of task threading, the connection and communication with the robot.

In Figure 5.1, we focus on the part related to the dominance manipulation, which is circled by the red line.

5.3. Dominance Manipulation

Based on the definitions of the factors in Chapter 2 and the validation results in Chapter 3, the body components we want to manipulate on NAO include the head and the limbs. Due to the characters of the movements, we use different manipulation approaches for different body components.

Here we define a parameter f as the dominance degree which is positive correlated to the expression level of dominance. The range of f is $[-1.00, 1.00]$, where 0 is the neutral expression, -1 and 1 represent the most submissive and the most dominant condition respectively. The manipulation procedure is shown in Figure 5.2. The PAL system uses `ALMotionProxy::angleInterpolation()` function to control the motion of the robot, which is from the main software running on the robot and controlling it – `NAOqi` [37]. This is

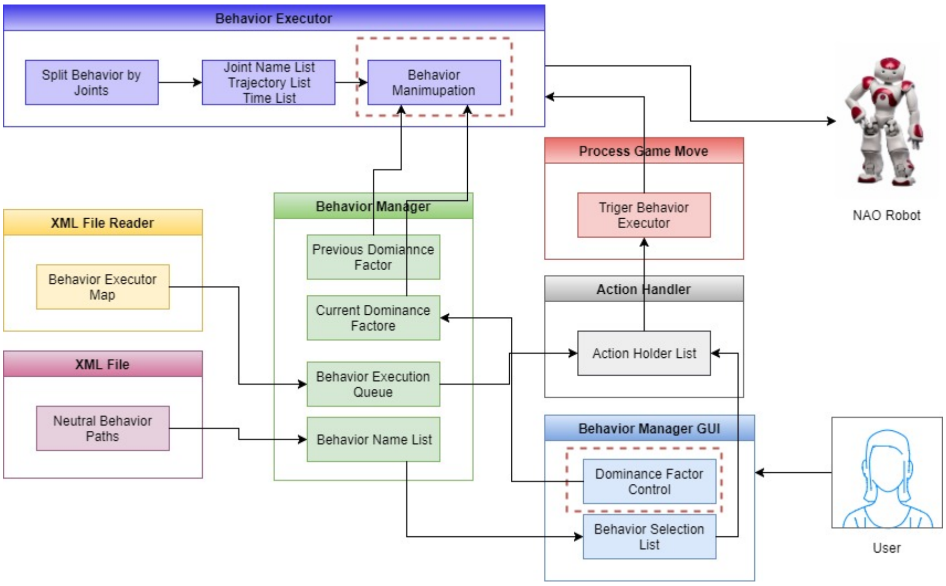


Figure 5.1: The architecture of Behavior Manager.

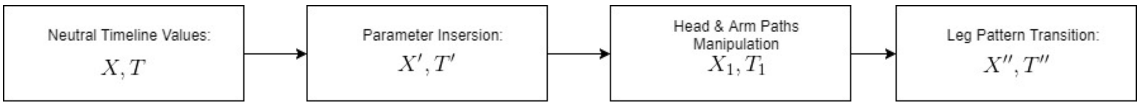


Figure 5.2: The manipulation procedure.

a timed interpolation function which sends a sequence of joint trajectory values and a corresponding sequence of times. These two lists decide the path and execution time for a behavior. The path information for all implemented behaviors is stored in a XML file which is imported to the system through XMLFileReader. The imported angle sequence and time sequence are two arrays. We define the original behavior path imported from the XML file is the neutral movement. The neutral behaviors is created in *Choreographe*, the desktop application for creating animations, behaviors and dialogs [37]. We used *Choreographe* to generate the keyframes of the original (neutral) behaviors. Then we manipulate the relative dominance expression to this neutral one based on the input dominance factor.

For a specific behavior, there are multiple joints moving parallel. The path of joint i is described as:

$$\begin{cases} \boldsymbol{x}_i = & (x_{i0}, x_{i1}, \cdots, x_{in_i}) \\ \boldsymbol{t}_i = & (t_{i0}, t_{i1}, \cdots, t_{in_i}) \end{cases}, \tag{5.1}$$

where x_{ij} is the trajectory value of joint i at t_{ij} time. Let n be the maximum value of n for all m joints. The path for the entire behavior will be described as two $m \times n$ matrices: $X_{m\times n}$ and $T_{m\times n}$.

5.3.1. Parameter Insersion

The bodily factors we want to manipulate are related to the movement of different body component. For a better understanding of the manipulation, we define two matrices to represent the path information for each behavior.

However, not every behavior involves the movement of all the joints, before the manipulation, we need to check whether $X_{m\times n}$ and $T_{m\times n}$ contain the path of the joints that are related to the dominant expression. For example, if the original behavior does not contain the movement of the head, the neutral motion path will not contain the values for HeadPitch. If the neutral behavior does not contain the paths of the required joints, the path of the missing joints need to be inserted before the manipulation. As described in the previous section, all behaviors will end in a final position. Since these joints do not need to perform any movement, the movement for these joints is a point-to-point path about the change of the end position. Therefore, the inserted trajectory values for these joints are the same as the trajectory values of the same joints of the end position, which is provided in Appendix A. Assume there are k joints need to be inserted, there will be k arrays

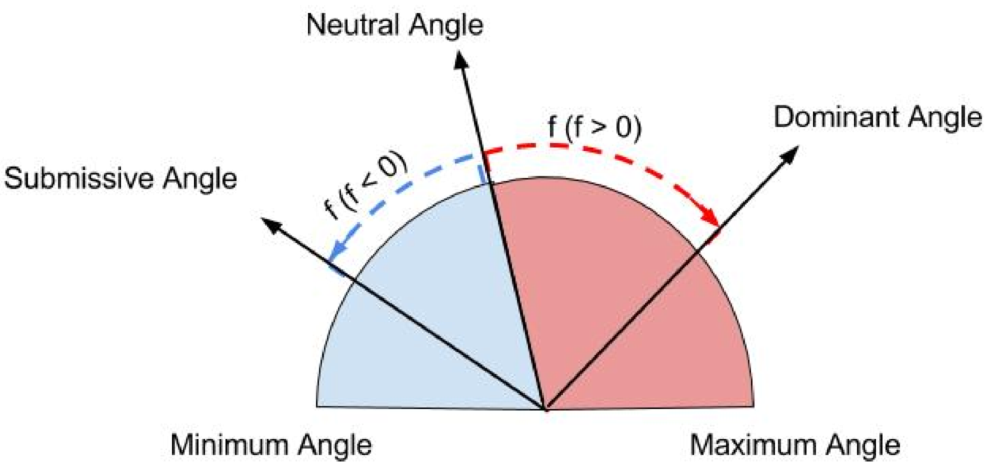


Figure 5.3: The manipulation of the head pitch angle and the left/right shoulder roll angle.

inserted in each path matrix. If we define the inserted arrays as $N_{k\times n}$ and $L_{k\times n}$, the path matrix will be:

$$X'_{(m+k)\times n} = \begin{pmatrix} X_{m\times n} \\ Y_{k\times n} \end{pmatrix}, T'_{(m+k)\times n} = \begin{pmatrix} T_{m\times n} \\ L_{k\times n} \end{pmatrix} \tag{5.2}$$

5.3.2. Head and Arm Movement

The movements of the head and the arms are usually related to the expression of the head pitch and the body expansiveness, the joint trajectories need to be manipulated are: `HeadPitch, LShoulderRoll, RShoulderRoll`. And since these are the only joints related to the dominant factors, they can be executed and manipulated parallel with other joints on the head and the arms. The description of all the joints trajectories on NAO is provided in Appendix B. The linear function we used for the manipulation is defined as below:

$$J(f) = \begin{cases} x_{Neutral} + (x_{Max} - x_{Neutral}) \times f & , f > 0 \\ x_{Neutral} - (x_{Neutral} - x_{Min}) \times f & , f < 0 \end{cases} \tag{5.3}$$

x_{Max} and x_{Min} are two reference values of a joint. They are the extreme positions of the joint. As shown in Figure 5.3, the manipulation is between the neutral angle and the limit positions. The red area is the space for increasing dominance degree and the blue space is for decreasing dominance degree. The dominance factor f is the proportion of the increased area to the entire reachable area (the blue or the red area). For example, the minimum reachable angle of `LShoulderRoll` in radian is -0.3142. If the neutral position of this joint for one behavior is 0.2013, then the range for reducing dominance is [-0.3142, 0.2013]. Given a dominant factor of -0.6, the new position will be: $0.2013 - (0.2013 - (-0.3142)) \times 0.6$, which is 0.1080. The limited positions of `HeadPitch, LShoulderRoll` and `RShoulderRoll` are listed in Appendix B.

Assume the three joints related to the head and the arm movement are $\boldsymbol{x}_0 \sim \boldsymbol{x}_2$, from 5.3, the new trajectory of $\boldsymbol{x}_0 \sim \boldsymbol{x}_2$ is derived as:

$$\boldsymbol{x}'_i = \left(J(x_{i0}, f), J(x_{i0}, f), \cdots, J(x_{in}, f)\right) \tag{5.4}$$

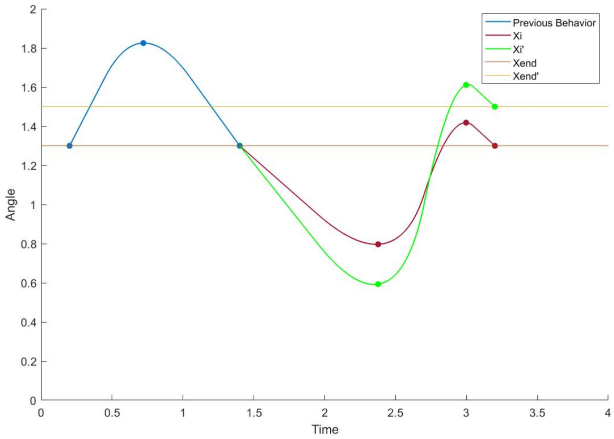
Let

$$\boldsymbol{X}_1 = \left(\boldsymbol{x}'_0, \boldsymbol{x}'_1, \boldsymbol{x}'_2\right)^T \tag{5.5}$$

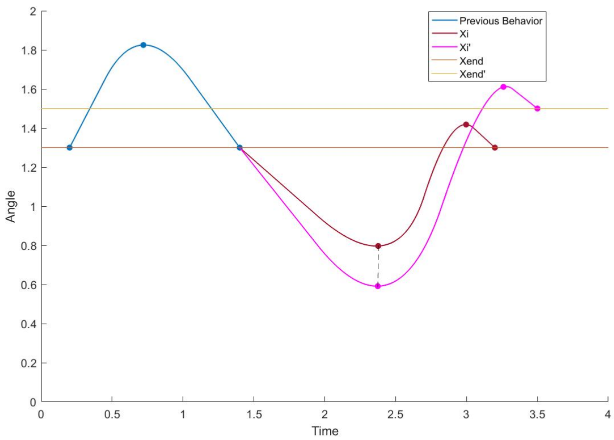
, the first three rows of the trajectory matrix will be $\boldsymbol{X}_1$.

5.3.3. Timestamp Adjustment

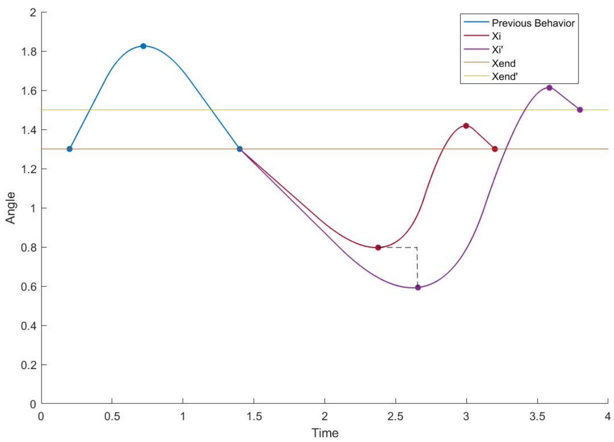
In Figure 5.4 (a), the blue dots and red dots represent the path of the original movement of one arm or head joint, which consists of two behaviors. Suppose that after the first (blue) behavior finished, the dominance factor changed, so the path of the second (red) behavior changed to the new path, which is the green line,



(a) Without time adjustment



(b) Time adjustment after 5.6



(c) Initial time adjustment under 5.7

Figure 5.4: The procedure of time adjustment.

after the manipulation of the trajectories defined in 5.3. As we can see, the gradient in the red and the green curves are different because the angle values are changed but the time values stay the same. In order to keep the motor works with a similar velocity and acceleration, the corresponding timestamp values of the arms and the head joint should also be adjusted. The purpose of this adjustment is to ensure the new motion will not exceed the maximum motor speed of the NAO robot and keep the behavior as natural as the original (neutral) one. One existing problem is that the motor movement conditions of the NAO robot under the `angleInterpolation` command are unknown. We do not know how the low level motors move under this condition. Hence, we cannot give a concrete analysis for the velocity and acceleration change. However, since we make the time and the trajectory increase by the same proportion, the average speed will stay unchanged after manipulation. Therefore, the percentage increase for each time interval should be the same as the percentage increase of the trajectory. When the dominance factor f is positive, from 5.3 we can get:

$$x'_{ij} = x_{ij} + \left(x_{max} - x_{ij}\right) \times f$$

$$x'_{i(j-1)} = x_{i(j-1)} + \left(x_{max} - x_{i(j-1)}\right) \times f$$

Then we get the angle displacement:

$$x'_{ij} - x'_{i(j-1)} = (x_{ij} - x_{i(j-1)}) \times (1 - f)$$

The change in proportion $\frac{x'_{ij}-x'_{i(j-1)}}{x_{ij}-x_{i(j-1)}}$ will be (1-f). Therefore, the new j time for joint i is calculated by:

$$t'_{ij} = t'_{i(j-1)} + \left(t_{ij} - t_{i(j-i)}\right) \times \left(1.00 - f\right) \tag{5.6}$$

The profile of this result is described in Figure 5.4 (b). As mentioned in previous sections, each behavior will finally reach the end position. Hence, every behavior is designed to start from a fixed position. In Figure 5.4 (b) we can see that if the starting time of the behavior does not change, there is also a risk of exceeding the maximum velocity in the first segment of the motion. So the first time value t'_{i0} needs to be changed with:

$$t'_{i0} = t_{i0} \times \frac{x'_{i0} - x'_{endPrevious}}{x_{i0} - x_{end}} \tag{5.7}$$

Since the neutral end position x_{end} is known and the changed end position of the previous behavior $x'_{endPrevious}$ can be calculated by 5.3, we need to record the previous dominance factor in order to generate the whole time sequence. Combine 5.6 and 5.7, we got 3 new time arrays for `HeadPitch, LShoulderRoll and RShoulderRoll` and let them be $G_{3\times n}$, then we got the first 3 rows in the time matrix:

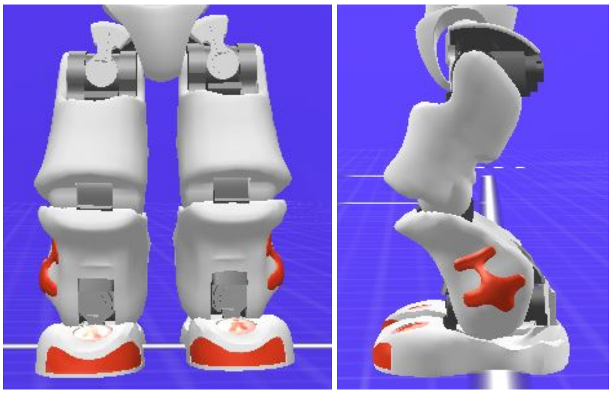
$$\boldsymbol{T}_1 = \left(\boldsymbol{t}'_0, \boldsymbol{t}'_1, \boldsymbol{t}'_2\right)^T \tag{5.8}$$

5.3.4. Leg Movement

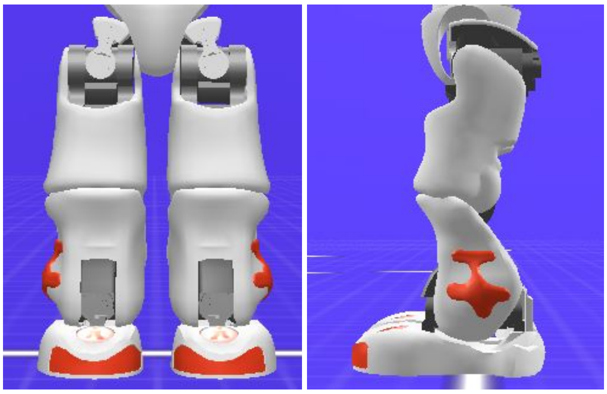
The leg positions and movements are linked to the expression of the body expansiveness and the body extension. But the parameters of the leg positions are highly constrained by the balance problem. Due to the lack of the modulation of the balance constraint of the NAO robots, it is hard to obtain a continuous function which can be used to get the target joint trajectory with a specific dominance factor value like we did with the manipulation of the arms and the head. It is related to a lot of mechanical problems which are definitely beyond the scope of this thesis. However, in many scenarios of the socially interactive robot, there are a lot of behaviors that do not contain the movement of legs. For example, during a lecture, the teacher may walk around, or stay in a fixed position while speaking. Therefore, for a robot designed for the educational use, although we cannot manipulate the walking movements, the manipulation of the standing posture can also let the robot express different dominant levels.

Therefore, we create three patterns of the standing postures with different expansiveness and extension which is shown in Figure 5.5. As shown in Figure 5.5, the three leg postures are created manually by adjusting various joints of a real NAO robot. The relation between the dominance factor and the leg patterns is described as:

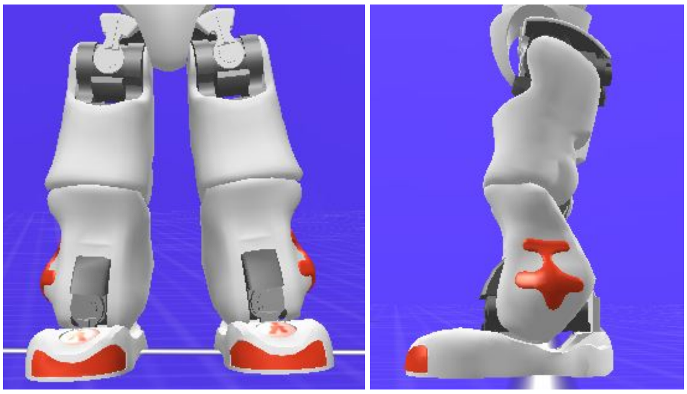
$$StandingPattern(f) = \begin{cases} Pattern_{sub} & , -1.00 \le f < -0.33 \\ Pattern_{neu} & , -0.33 \le f \le 0.33 \\ Pattern_{dom} & , 0.33 < f \le 1.00 \end{cases} \tag{5.9}$$



(a) Submissive Pattern: low expansiveness and low extension



(b) Neutral Pattern: low expansiveness and high extension



(c) Dominant Pattern: high expansiveness and high extension

Figure 5.5: Patterns of leg positions.

Hence, there are 3 levels of the dominant expression through the leg control. If the dominance factor changes between the phases, a transition movement will take place within the next behavior to change the pattern of the legs. The transition movement is executed parallel with the hand and the head movements in the next behavior. Otherwise, the legs will stay still with the current pattern.

Assume the 3rd to 12th rows in X' and T' are the path for the legs joints. Then these values need to be replaced with the new leg pattern. And we define these new values as two $10 \times n$ matrices $\boldsymbol{X}_2$ and $\boldsymbol{T}_2$. Therefore, we got the final path for this behavior:

$$\boldsymbol{X}'' = \begin{pmatrix} \boldsymbol{X}_1 \\ \boldsymbol{X}_2 \\ \boldsymbol{X}_r \end{pmatrix}, \boldsymbol{T}'' = \begin{pmatrix} \boldsymbol{T}_1 \\ \boldsymbol{T}_2 \\ \boldsymbol{T}_r \end{pmatrix} \tag{5.10}$$

$\boldsymbol{X}_r$ and $\boldsymbol{T}_r$ are paths of the rest unchanged joints.

6
Experiment

In order to test the performance of the dominance manipulation strategy we described in Chapter 4, a human-robot interactive experiment is conducted. This chapter will show the experimental procedure and also the result.

6.1. Experiment Overview

With implementation of dominant manipulation, the *Behavior Manager* is capable to generate behaviors in different dominant levels. Experiments are required to check whether the robot can perform as we expect and whether people can perceive the emotions we want to convey through the robot.

Based on the experimental purpose, we establish the following hypothesis:

1. Observers have different feelings towards behaviors manipulated with different dominance factors.

2. The behavior manipulated under a high dominance factor will be regarded as more dominant than the behavior manipulated under a low dominance factor.

3. The behavior manipulated under a low dominance factor will be regarded as less dominant than the neutral one. And the behavior manipulated under a high dominance factor will be regarded as more dominant than the neutral one.

6.2. Method

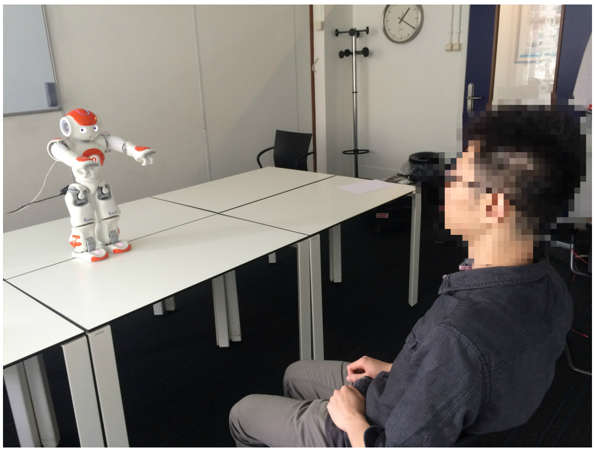
6.2.1. Experimental Design

Similar to the experiment in Chapter 3, we use repeated measurement for different dominant levels. There are 3 groups of behaviors with different dominant degrees: -1.00, 0 and 1.00. 10 behaviors are selected from the `XML` file (the behavior library). Based on the manipulation strategy, these dominant degrees represent submissive, neutral and dominant manipulations respectively. Therefore, each testing group contains 10 behaviors. The behaviors in every group are the same motions but with different manipulations.

Each participant will be assigned one group of behaviors. Behaviors will be displayed in a random order. After the execution of each behavior, the observer need to rank their perception towards this behavior in a 9-point scale Self-Assessment Manikins (SAM) questionnaire. SAM is a non-verbal pictorial assessment technique that directly measures the pleasure, arousal, and dominance associated with a person's affective reaction to a wide variety of stimuli [7]. The SAM questionnaire and the experiment introduction is shown in Appendix C.

For each behavior, the participant needs to select a picture that has the most similar impression of the robot behavior . If the participant cannot make their decision between two pictures, they can select the number in between. During the experiment, the participant are allowed to ask for the repetition of the behavior in case the behavior is too short to perceive an emotion. The next behavior will be shown after the observer finished answering the current one.

(a)



(b)

Figure 6.1: Experiment setup.

Table 6.1: Repeated measures ANOVA

Source	SS	df	MS	F	P
Posture	416.443	6.201	67.157	16.556	<0.001
Manipulation	59.364	2	29.682	4.407	0.022
Posture * Manipulation	36.777	12.402	2.965	0.731	0.724
Error(Posture)	704.287	173.629	4.056		
Error(Manipulation)	188.604	28	6.736		

6.2.2. Setup

As we tested in Chapter 3, the height and the observation angle do not affect people's perception of dominance. So in this experiment, the robot is placed on a 1.1-meter tall table. The observer sits in a chair at a distance of 1.5 meters to the robot, which is a comfortable distance for observation and it is close enough for detecting the behavior of the robot clearly. An example is shown in Figure 6.1.

6.3. Result

There are 31 participants in this experiment in total. They are all students or staff in TU Delft with up to 8 nationalities and aged from 23 to 60. The numbers of participants in each group are: 11 in the submissive group, 10 in the neutral group and 10 in the dominant group. The perception of the dominance is represented by the response value of SAM. To verify the performance of our manipulation, a Repeated Measures ANOVA is applied on the result by using SPSS.

In this case, the within-subject variable is the tested 10 postures and the between-subject factor is the dominance manipulations. As shown in Table 6.1, the ANOVA within-subject test result with Greenhouse-Geisser correction shows the mean dominance for different postures are statistically significantly different ($F(6.201, 173.629) = 16.556, P < 0.001$). This suggests that, similar to the experiment with static stimuli, the dynamic behaviors themselves have an impact on the dominance perception. Behaviors differ in the expressed dominance degrees and some behaviors are regarded as more dominant than the other one no matter it is displayed with or without the manipulation. Our manipulation also has an statistically significant effect on the dominance perception ($F(2, 28) = 4.407, P = 0.022$), which means the observer's perception of dominance highly depends on the type of the manipulation. Moreover, there is no interaction between the posture and the manipulation with the P value larger than 0.05. Our manipulation doesn't have an effect on increasing the dominance perception.

Tukey's HSD test is also used to verify the differences between groups. Results in Table 6.2 show that the dominant and the submissive group are statistically significantly different with P < 0.05, a significant difference at 0.05 and a confidence interval not including zero.

Same conclusions are also indicated in Figure 6.2. Comparing Figure 6.2 (b) and Figure 6.2 (c), we can see that the overall shape of the lines are very similar. Under the identical manipulation condition, some behaviors always have a higher dominance expression than others. For a specific behaviors, the manipulation can change the dominance perception degree. But the manipulation does not interact with the behaviors. It will not make a less dominant behavior convey a higher dominant feeling than a dominant one. Figure 6.2 (a) and Figure 6.2 (c) show the performance of our manipulation. In Figure 6.2 (a), the overall dominance expression of these groups are different and the relation is as we expected. In Figure 6.2 (b), the difference between the neutral and the dominant group are not significant, which is consistent with the result in Table 6.1.

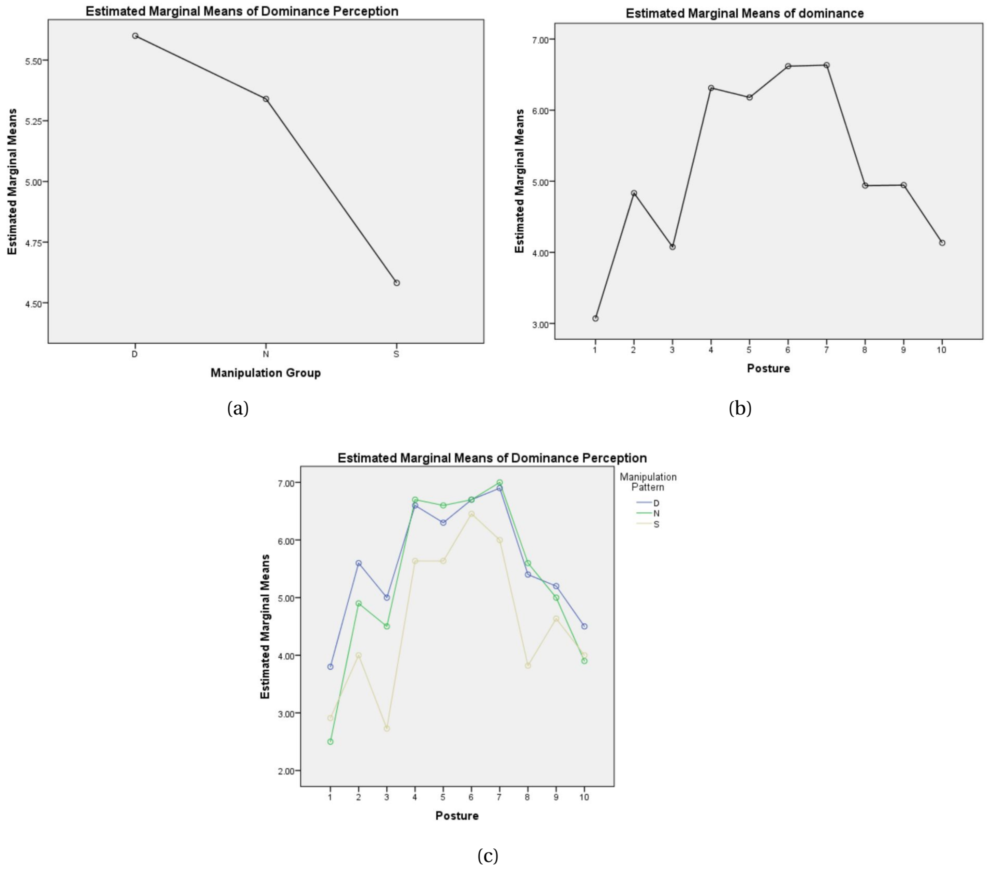
6.4. Conclusion

On overall, our solution succeeds in distinguishing submissive behaviors with dominant behaviors. Given a neutral behavior, it is capable to show a submissive version and a dominant version of the same movement. And this manipulation does not affect the original characteristics of the behaviors. If behavior A is more dominant than behavior B, then after the same manipulation, the behavior A will still be more dominant than behavior B.

The experiment result shows that the difference between the neutral group with the dominance and the submissive groups are not significant. This consequence may be caused by:

Table 6.2: Tukey HSD test result.

Pattern (I)	Pattern (J)	Mean Difference (I-J)	Std. Error	P	95% CI LB	95% CI HB
Dominant	Neutral	0.260000	0.367038	0.760595	-0.648181	1.168181
	Submissive	1.018182	0.358599	0.021987	0.130882	1.905482
Neutral	Dominant	-0.260000	0.367038	0.760595	-1.168181	0.648181
	Submissive	0.758182	0.358599	0.105077	-0.129118	1.645482
Submissive	Dominant	-1.018182	0.358599	0.021987	-1.905482	-0.130882
	Neutral	-0.758182	0.358599	0.105077	-1.645482	0.129118



(a)

(b)

(c)

Figure 6.2: Patterns of leg positions.

- Compared to the experiment in Chapter 3, the amount of the participants in this experiment is relatively small. This may result in an insufficient sample size.
- The SAM questions used in this experiment has only 9 discrete levels. The limited amount of available choices probably result in the experiment failed in distinguishing the neutral group.
- As described in Chapter 4, we use the neutral position to the limit positions as the range of the range of the manipulation. This makes it possible to use all the reachable position of the NAO robot to manipulate the behaviors. However, during the experiment, we notice there is a possibility that the manipulated may result in a distortion of the behavior. For example, if the arms of the robot are adjusted to a very high position, the new movement will probably become unnatural and not similar to the original behavior. It may look like a completely new movement rather than a different version of the original one.

7

Conclusion and Prospects

7.1. Conclusion

The objective of this thesis is to find a way to let the NAO robot express different levels of dominance by using bodily expressions. We first proposed the idea to make robots mimic the dominant symbols of human. Literature studies are carried out to explore the potential factors that may affect the expression of dominance: the head pitch and the body expansiveness. Then, a static online experiment proves these factors also have an impact on humanoid robots. For the NAO robot, the manipulations of these parameters is represented by changing the angles of related joints. The manipulation of these body features is implemented on the PAL project. Finally, a perception experiment is explained to evaluate the performance. The result shows our bodily manipulation has a statistically significant effect on the perceived dominance.

Overall, we succeed in the generation of submissive and dominant expressions. The manipulation still requires more efforts to present the differences between the submissive / dominant expressions with the neutral expressions. The innovation of this method is it can be applied on any neutral behaviors theoretically without the requirement for the manual creation or modification of the new behaviors. Given a developed neutral behavior, it is capable to manipulate the dominant perception to an expected degree by setting the dominance factor in the application. Compared to the approaches used in previous studies, our solution significantly reduces the effort required for developing and evaluating new behaviors. Moreover, this approach can be adopted by a wide range of humanoid robots. Because it only requires the movement of limbs and head. For robots which does not support leg movement, like Pepper, it is also possible to use the manipulation of the head and the arms. Furthermore, this method can also be used in combination of other possible manipulations. For example, once the manipulation of the warmness is developed, it is possible to manipulate the warmth and the dominance on the same behavior in the meantime because this manipulation does not affect the characteristics of movements.

7.2. Future Work

Given the current results, several avenues remain open for the future work:

- The sample size of the second experiment is small, which may affect the statistic analysis. Moreover, PAL project aims to build a pedagogical agent for children. People at different ages have different feelings towards the same behaviors [45]. The bodily symbols which work for adults may not have the same effect on children. So more experiments are necessary for the evaluation.

- One preliminary assumption is the original behaviors are neutral. But the actual dominance levels of behaviors in the behavior library we used in PAL project is unknown. As shown in Figure 4.3 and Figure 6.2, some original behaviors are already have a dominant or submissive impression. This may limit the manipulation for a more dominant / submissive expression.

- As discussed in Chapter 5, since we use the full range of the reachable position in the manipulation, it is possible to cause the distortion of the behavior. The range of the manipulation should be adjusted depends on the characteristic of each behavior.

- As we discussed in Chapter 2, the emotion perception highly depends on the observer's cultural background. Therefore, if we have enough participants, it is necessary to apply statistic analysis by nationalities.
- In this thesis, we test the static image stimuli as well as the dynamic movement. However, the design purposes of SIR require the experiment based on a more interactive scenario. In the next step, the experimental stimuli will be an interactive application, for example, lectures consist of the same behaviors with different dominance levels.
- In Chapter 1, we introduced the concept of Interpersonal Circumplex and the importance of nonverbal behaviors. And our goal is to manipulate the robotic emotions. Therefore, the manipulation of the horizontal dimension, the warmth, as well as the manipulation of verbal behaviors still requires exploration. This will bring many motivations to the further research:
    1. What is the overall effect when the manipulation of bodily expressions is used together with verbal behaviors?
    2. How to manipulate the warmth (the x axis in Interpersonal Circumplex) of humanoid robots?
    3. Can the manipulation of the warmth and the dominance work together? What is the overall effect after the two manipulations?
    4. It is possible to reach all positions in the space of Interpersonal Circumplex and generate different emotions by using parameterized manipulations?

A

Potential Nonverbal Cues of Human Dominance

Table A.1: Parameters that are related to dominance perception

Factor	Description	Synonyms	Tipical expressions	Dominance effects
Openness	Keeping limbs open or closed (Carney and Cuddy, 2010)		Palm towards/outwards body	More openness represents higher dominance;Expansive but Closed Body Posture Increases Submissive Behavior[5]
Expansiveness	Taking up more or less space (Carney and Cuddy, 2010)	Large body size	Strenched arms and legs	More expansiveness represents higher dominance;Expansive but Closed Body Posture Increases Submissive Behavior[5]
Frequency of gesture using	(Burgoon & Le Poire, 1999)		Frequent hand movement during communication	High frequency of gestures represents high dominance
Eye contact	The frequency of direct eye gaze between speakers and listeners	Gaze	Twist head and look at listeners	More eye contacts help to build social power
Self touch	The frequency of performer touching his/her body		Hands on face/body	Less self touch is associated with higher dominance[22]
Interpersonal distance	The distance between the speaker and the listener			Smaller distances were perceived as higher dominance[22]
Gesture	The hand position and movement		Pointing; Waving hand	Higher frequency of gesturing using while speaking will result in higher dominance perception[22]
Body Lean	Leans forward toward the interaction partner		High power individuals were perceived to lean forward[22]	

B

Joints of NAO

B.1. Joints

All joints and their names are shown in Figure B.1. The NAO robot has a symetric structure, so the joints are also identified by a prefix letter. For example, `LShoulderRoll` and `RShoulderRoll` represent the `ShoulderRoll` joints on the left and the right side of the body respectively.

B.2. Motion Range of Manipulated Joints

Joint Names	Minimum Value (radians)	Maximum Value (radians)
HeadPitch	-0.6720	0.5149
LShoulderRoll	-0.3142	1.3265
RShoulderRoll	-1.3265	0.3142

B.3. The Position Information of Legs Patterns

Joint Names	Submissive Pattern	Neutral Pattern	Dominant Pattern
LAnklePitch	-0.345127	0.005618	0.083065
LAnkleRoll	-0.008000	-0.008114	-0.13
LHipPitch	-0.443734	0.008114	0.13
LHipRoll	0.00624	0.006242	0.092294
LHipYawPitch	-0.000237	-0.000237	-0.169103
LKneePitch	0.690254	-0.005618	-0.083065
RAnklePitch	-0.345127	0.005618	0.083065
RAnkleRoll	0.008115	0.008114	0.13
RHipPitch	-0.443734	0.008114	0.13
RHipRoll	-0.006242	-0.006242	-0.092294
RHipYawPitch	-0.000237	-0.000237	-0.169103
RKneePitch	0.690254	-0.005618	-0.083065

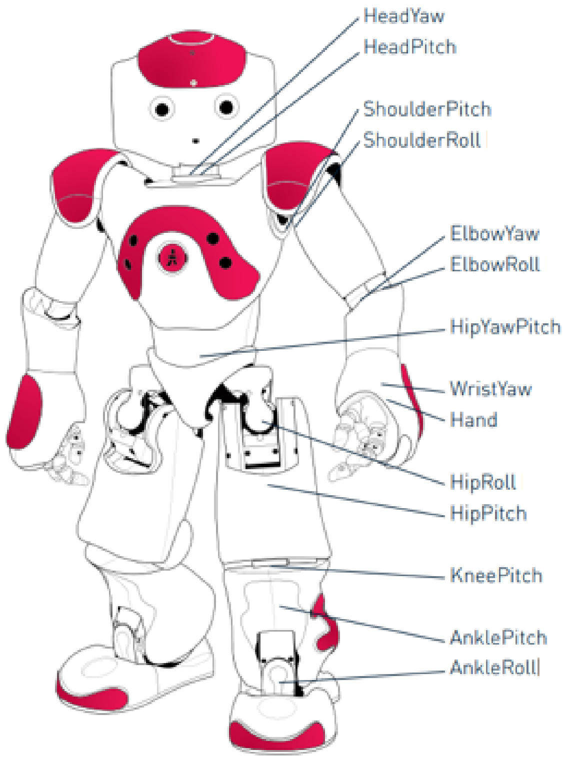


Figure B.1: Kinematic structure of NAO.

C
SAM Questionnaire

C.1. Experiment Instruction

Before the experiment, an instruction is provided to participants with the purposes and the procedure of the experiment. The instruction is shown in Figure C.1.

C.2. Questionnaire

The participants are required to rate their feelings through SAM questions as shown in Figuer C.2.

The Self Assessment Manikin Experiment of the Dominance Expression of Humanoid Robots

Thank you for agreeing to participate in today's experiment. This experiment aims to investigate people's perception towards the behaviors of NAO robots. You will be shown **10** different behaviors (postures and movements) one by one and required to rank your feeling from **three** different aspects for each behavior:
Pleasure: valence of an individual's intent (friendliness, liking, joy).
Arousal: an individual's ability to act on and deliver those intentions (skill, respecting, motivation).
Dominance: an individual's disposition to assert control over interactions (power).

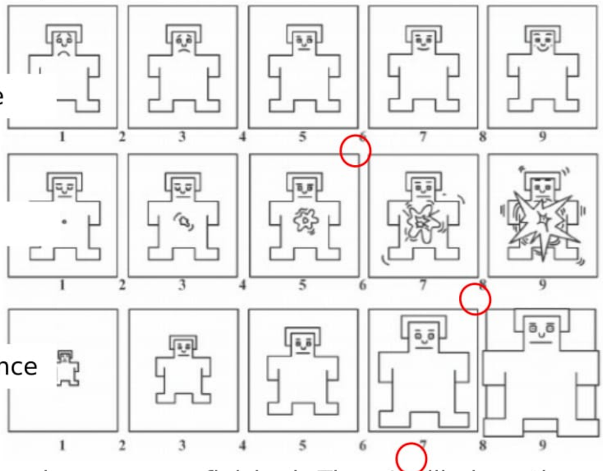
For each behavior test, there three image rating questions in the questionnaire.
You need to select the picture which gives you the most similar feeling you get from the robot. You can also select the number in between when the two pictures are all close to the robot behavior.
For example, the expected experiment procedure would be like:

1. The experiment conductor (me) display a robot behavior to you.
2. The participant observes the robot behavior. You can inform me to repeat the robot performance until you get a comprehensive perception.
3. The participant circle the corresponding number to rate the perception, for example:

Pleasure

Arousal

Dominance



4. Inform me when you are finished. Then I will show the next behavior for you.

Figure C.1: The experiment instructions.

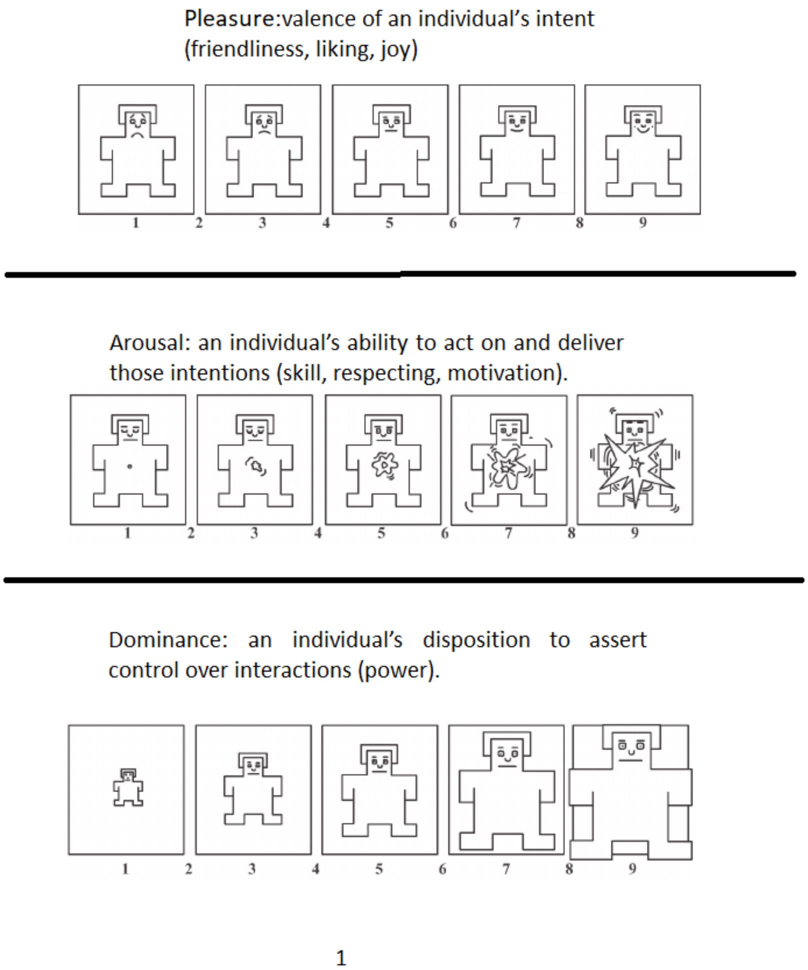


Figure C.2: The Self Assessment Manikin questions.

Bibliography

[1] M Anderson. Nonverbal communication. 1987.

[2] Aryel Beck, Brett Stevens, Kim A Bard, and Lola Cañamero. Emotional body language displayed by artificial agents. *ACM Transactions on Interactive Intelligent Systems (TiiS)*, 2(1):2, 2012.

[3] Nikolaus Bee, Colin Pollock, Elisabeth André, and Marilyn Walker. Bossy or wimpy: expressing social dominance by combining gaze and linguistic behaviors. In *Intelligent virtual agents*, pages 265–271. Springer, 2010.

[4] Fabiane Barreto Vavassori Benitti. Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education*, 58(3):978–988, 2012.

[5] Olga Bialobrzeska and Michal Parzuchowski. Size or openness: Expansive but closed body posture increases submissive behavior. *Polish Psychological Bulletin*, 47(2):186–194, 2016.

[6] Vanessa K Bohns and Scott S Wiltermuth. It hurts when i do this (or you do that): Posture and pain tolerance. *Journal of Experimental Social Psychology*, 48(1):341–345, 2012.

[7] Margaret M Bradley and Peter J Lang. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry*, 25(1):49–59, 1994.

[8] Cynthia Breazeal. Emotion and sociable humanoid robots. *International Journal of Human-Computer Studies*, 59(1):119–155, 2003.

[9] Pablo Briñol, Richard E Petty, and Benjamin Wagner. Body posture effects on self-evaluation: A self-validation approach. *European Journal of Social Psychology*, 39(6):1053–1064, 2009.

[10] C. Lathan K. Dakhane K. Edwards J. M. Vice C. Plaisant, A. Druin and J. Montemayor. A storytelling robot for pediatric rehabilitation. *Proceedings of the fourth international ACM conference on Assistive technologies*, page 50–55, 2000.

[11] Dana R Carney, Judith A Hall, and Lavonia Smith LeBeau. Beliefs about the nonverbal expression of social power. *Journal of Nonverbal Behavior*, 29(2):105–123, 2005.

[12] Dana R Carney, Amy JC Cuddy, and Andy J Yap. Power posing: Brief nonverbal displays affect neuroendocrine levels and risk tolerance. *Psychological science*, 21(10):1363–1368, 2010.

[13] Dana R Carney, Amy JC Cuddy, and Andy J Yap. Review and summary of research on the embodied effects of expansive (vs. contractive) nonverbal displays. *Psychological Science*, 26(5):657–663, 2015.

[14] Joseph Cesario and Melissa M McDonald. Bodies in context: Power poses as a computation of action possibility. *Social Cognition*, 31(2):260–274, 2013.

[15] Iris Cohen, Rosemarijn Looije, and Mark A Neerincx. Child's perception of robot's emotions: effects of platform, context and experience. *International Journal of Social Robotics*, 6(4):507–518, 2014.

[16] Amy JC Cuddy, Caroline A Wilmuth, Andy J Yap, and Dana R Carney. Preparatory power posing affects nonverbal presence and job interview performance. *Journal of Applied Psychology*, 100(4):1286, 2015.

[17] Kerstin Dautenhahn. Socially intelligent robots: dimensions of human–robot interaction. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 362(1480):679–704, 2007.

[18] David Feil-Seifer and Maja J Mataric. Defining socially assistive robotics. In *Rehabilitation Robotics, 2005. ICORR 2005. 9th International Conference on*, pages 465–468. IEEE, 2005.

[19] Julia Fischer, Peter Fischer, Birte Englich, Nilüfer Aydin, and Dieter Frey. Empower my decisions: The effects of power gestures on confirmatory information processing. *Journal of Experimental Social Psychology*, 47(6):1146–1154, 2011.

[20] Marina Fridin. Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education. *Computers & education*, 70:53–64, 2014.

[21] Michael B Gurtman. Exploring personality with the interpersonal circumplex. *Social and Personality Psychology Compass*, 3(4):601–619, 2009.

[22] Judith A Hall, Erik J Coats, and Lavonia Smith LeBeau. Nonverbal behavior and the vertical dimension of social relations: a meta-analysis., 2005.

[23] Markus Häring, Nikolaus Bee, and Elisabeth André. Creation and evaluation of emotion expression with body movement, sound and eye color for humanoid robots. In *Ro-Man, 2011 Ieee*, pages 204–209. IEEE, 2011.

[24] Jochen Hirth, Norbert Schmitz, and Karsten Berns. Towards social robots: Designing an emotion-based architecture. *International Journal of Social Robotics*, 3(3):273–290, 2011.

[25] Li Huang, Adam D Galinsky, Deborah H Gruenfeld, and Lucia E Guillory. Powerful postures versus powerful roles: Which is the proximate correlate of thought and behavior? *Psychological Science*, 22(1): 95–102, 2011.

[26] M. L. Walters B. Robins H. Kose-Bagci N. A. Mirza K. Dautenhahn, C. L. Nehaniv and M. Blow. Kaspar – a minimally expressive humanoid robot for human–robot interaction research. *Applied Bionics and Biomechanics*, 369, 2009.

[27] Shuuji Kajita, Kenji Kaneko, Fumio Kaneiro, Kensuke Harada, Mitsuharu Morisawa, Shin'ichiro Nakaoka, Kanako Miura, Kiyoshi Fujiwara, Ee Neo, Isao Hara, et al. Cybernetic human hrp-4c: A humanoid robot with human-like proportions. *Robotics Research*, pages 301–314, 2011.

[28] Timothy Leary. Interpersonal diagnosis of personality. *American Journal of Physical Medicine & Rehabilitation*, 37(6):331, 1958.

[29] Albert Mehrabian et al. *Silent messages*, volume 8. Wadsworth Belmont, CA, 1971.

[30] Johannes Michalak, Judith Mischnat, and Tobias Teismann. Sitting posture makes a difference—embodiment effects on depressive memory bias. *Clinical psychology & psychotherapy*, 21(6): 519–524, 2014.

[31] Alain Mignault and Avi Chaudhuri. The many faces of a neutral face: Head tilt and perception of dominance and emotion. *Journal of nonverbal behavior*, 27(2):111–132, 2003.

[32] Shwetha Nair, Mark Sagar, John Sollers III, Nathan Consedine, and Elizabeth Broadbent. Do slumped and upright postures affect stress responses? a randomized trial. *Health Psychology*, 34(6):632, 2015.

[33] Gabriele Paolacci, Jesse Chandler, and Panagiotis G Ipeirotis. Running experiments on amazon mechanical turk. 2010.

[34] M. A. Neerincx R. Looije and F. Cnossen. Persuasive robotic assistant for health self-management of older adults: Design and evaluation of social behaviors. *International Journal of Human Computer Studies*, 68:386, 2010.

[35] M. A. Neerincx R. Looije and F. Cnossen. O. a. b. henkemans, b. p. bierman, j. janssen, m. a. neerincx, r. looije, h. van der bosch, and j. a. van der giessen. *Using a robot to personalise health education for children with diabetes type 1: A pilot study*, 92:174, 2013.

[36] Boris Reuderink. The influence of gaze and head tilt on the impression of listening agents. *Manuscript, University of Twente*, 2006.

[37] Aldebaran Robotics. Nao h25 datasheet. `https://www.ald.softbankrobotics.com/en`, 2012. [Online].

[38] Nicholas O Rule, Reginald B Adams Jr, Nalini Ambady, and Jonathan B Freeman. Perceptions of dominance following glimpses of faces and bodies. *Perception*, 41(6):687–706, 2012.

[39] James A Russell. Core affect and the psychological construction of emotion. *Psychological review*, 110 (1):145, 2003.

[40] Sabine Stepper and Fritz Strack. Proprioceptive determinants of emotional and nonemotional feelings. *Journal of Personality and Social Psychology*, 64(2):211, 1993.

[41] I. Nourbakhsh T. Fong and K. Dautenhahn. A survey of socially interactive robots. *Robotics and autonomous systems*, 42(3):143–166, 2003.

[42] Keith M Welker, David E Oberleitner, Samantha Cain, and Justin M Carré. Upright and left out: Posture moderates the effects of social exclusion on mood and threats to basic needs. *European Journal of Social Psychology*, 43(5):355–361, 2013.

[43] Jerry S Wiggins. A psychological taxonomy of trait-descriptive terms: The interpersonal domain. *Journal of personality and social psychology*, 37(3):395, 1979.

[44] Jerry S Wiggins. *Paradigms of personality assessment.* Guilford Press, 2003.

[45] Lorna Wing and Judith Gould. Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification. *Journal of autism and developmental disorders*, 9(1):11–29, 1979.

[46] Liu Xin, Xie Lun, Wang Zhi-liang, and Fu Dong-mei. Robot emotion and performance regulation based on hmm. *International Journal of Advanced Robotic Systems*, 10(3):160, 2013.

[47] Junchao Xu, Joost Broekens, Koen Hindriks, and Mark A Neerincx. *Mood expression through parameterized functional behavior of robots.* IEEE, 2013.

[48] Andy J Yap, Abbie S Wazlawek, Brian J Lucas, Amy JC Cuddy, and Dana R Carney. The ergonomics of dishonesty: The effect of incidental posture on stealing, cheating, and traffic violations. *Psychological Science*, 24(11):2281–2289, 2013.

[49] Massimiliano Zecca, Yu Mizoguchi, Keita Endo, Fumiya Iida, Yousuke Kawabata, Nobutsuna Endo, Kazuko Itoh, and Atsuo Takanishi. Whole body emotion expressions for kobian humanoid robot—preliminary experiments with different emotional patterns—. In *Robot and Human Interactive Communication, 2009. RO-MAN 2009. The 18th IEEE International Symposium on*, pages 381–386. IEEE, 2009.