Shaping Robot Gestures to Shape Users' Perception: The Effect of Amplitude and Speed on Godspeed Ratings

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Abstract— **This work analyzes the relationship between the way robots gesture and the perception that human users develop about them. In particular, this work shows how the Godspeed scores - collected during an experiment over 45 stimuli that has involved 30 observers - change with amplitude and speed of a given gesture. The results suggest that shaping gestures aimed at manifesting the inner state of the robot (e.g., cheering or showing disappointment) tends to change the perception of Animacy (the dimension that accounts for how driven by endogenous factors the robot is perceived to be), while shaping gestures aimed at achieving an interaction effect (e.g., engaging and disengaging) tends to change the perception of Anthropomorphism, Likeability, and Perceived Safety (the dimensions that account for the social aspects of the perception).**

I. INTRODUCTION

This work investigates the interplay between the gestures that a humanoid robot displays and the perception of the users, i.e., the tendency of these latter to attribute the robots certain characteristics rather than others. The main difference with respect to most previous works in the area is that the approach proposed in this article does not take into account only the gestures that the robot displays, but also the way they are displayed. In particular, the experiments investigate the association between variations of *amplitude* and *speed* - two major parameters that characterize any natural and synthetic gesture - and variations of the users' perception measured with the Godspeed questionnaire [1].

In most cases, the main reason for focusing on gestures is that "gestural expression is intimately involved in acts of spoken linguistic expression" [2], meaning that speech and gestures are processed as a bimodal unit at neural [3], cognitive [4] and psychological [5] level. In particular, speech and gestures have been shown to mutually enhance one another to make an agent more effective in achieving communicative goals [6].

However, the experiments of this work revolve around the interaction between people and robots in public spaces and, more specifically, in environments in which the level of acoustic noise tends to be high enough to make it difficult to hear and understand speech. In such a situation, according to the indications of biology [7], [8], multiple modalities do not enhance one another, but rather generate redundancy by carrying the same message. In this way, the failure of one modality (e.g., speech cannot be heard due to high noise) can be compensated by the other modalities (e.g., gestures can be seen irrespectively of acoustic noise). This is the main reason why the experiments of this work take into account isolated gestures that do not accompany or interact with spoken messages.

During the experiments, 30 independent human observers have been asked to watch 45 different gestures performed by *Pepper* - a robotic platform manufactured by Softbank Robotics - and to fill, for each of them, the Godpseed questionnaire [1]. The main particularity of the gestures is that they are variants of 5 animations selected in the standard library available with the robot (see Section III-A for more details). The 9 variants of each core gesture have been obtained by manipulating two parameters, namely *speed* and *amplitude*. In this way, it is possible to investigate whether there is an association between the way a gesture is performed and the perception of the users. The motivation behind the choice of speed and amplitude is that they are related to energy and spatial extension, respectively, two characteristics that have been shown to play a crucial role in the expressiveness of artificial agents [9].

Overall, the results show that changing the way a gesture is performed is associated, to a statistically significant extent, to changes in the perception of the users. However, this does not happen in the same way for all gestures and for all the perception dimensions that the Godspeed questionnaire measures. In particular, no effects have been observed for a gesture like Pointing that, in general, is expected to exchange spatial knowledge and not to achieve interactional goals or to convey the impression of an inner state [10]. Gestures designed to achieve an interactional goal like Engaging and Disengaging interplay with most dimensions and, in particular, with Likeability, the most socially oriented dimension of the Godspeed questionnaire. Finally, shaping gestures aimed at conveying the impression of an inner state like Cheering and Head-Touching is associated with changes in the perception of Animacy, the dimension that accounts for the perception of inner processes and motivations in the robot.

The rest of this article is organized as follows: Section II surveys previous work in the area, Section III describes the experimental approach, Section IV presents experiments and results, and the final Section V draws some conclusions.

II. SURVEY OF PREVIOUS WORK

Many of the most popular social robots—such as Soft-Bank's Nao and Pepper—have few moving parts in their faces, and are therefore not equipped to display facial expressions. Also, as mentioned above, often the acoustic context can make spoken interaction problematic, particularly

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in uncontrolled public spaces. Thus, the use of gestures and other bodily enacted cues play a critical role in managing social human-robot interaction [11]. Purely emotional body expressions of a social robot—such as raising the hands to show emotions such as joy, anger, or fear—have been successfully used in a range of robot contexts [12], [13], [14]. When it comes to the systematic analysis of robot gestures, Table I shows the classification into five categories proposed in [15]. In the current context of socially intelligent robots in public spaces, it is anticipated that the robot may exhibit all five of these gesture classes, with gestures in classes 3–5 particularly relevant to this article, where the goal is to modify communicative gestures to incorporate user perception of the robot.

TABLE I
NEHANIV'S CLASSIFICATION OF GESTURES [15]

Class	Name	Characteristics
1	Irrelevant/ Manipulative Gestures	- Manipulation of objects, side effects of motor behaviour, body motion - Neither communicative nor socially interactive
2	Side Effect of Expressive Behaviour	- Associated to communication or affective states of human e.g. persons talk excitedly raising and moving their hands in correlation with changes in voice prosody or emphasis of speech.
3	Symbolic Gestures	- Communicative of semantic content, e.g. waving down; use of a conventional hand signals; nodding 'yes'; waving a greeting 'hello' or 'goodbye'
4	Interactional Gestures	- Used to initiate, maintain, regulate, synchronise, organise or terminate various types of interaction e.g. raising the hand toward the partner inviting them or send them away
5	Referential/ Pointing Gestures	- Pointing to all types of effectors: referential, attention-directing e.g. presenting objects, persons, directions or locations by pointing

A number of previous studies have examined how various parameters can influence users' reactions to the non-verbal behaviour of a virtually or physically embodied conversational agent. The model proposed in [16], for example, transforms neutral animations into emotional animations using "emotional transforms" which affect the speed and spatial amplitude of the animation. In [17], the authors defined a set of rules for modifying basic motions of a virtual character to express basic emotions such as joy and sadness, and found that amplitude, position, and speed were the main parameters. The approach described in [14] explored how controlling the size, velocity, and frequency of robot gestures could affect user perception of the robot's personality; it was found that all of these factors had an effect on the perceived robot personality, and that this factor in turn affected users' subjective impressions of the robot.

The model developed in [18] for gesture expressivity adopts six parameters, including spatial extent, temporal extent, fluidity, power, overall activation, and repetition. In perceptual tests, the six parameters were found to be recognizable and also to combine to produce movements with different qualities. The work in [19] proposes a parametrized behavior model with specific behavior parameters for bodily mood expression and applied the model to two concrete behaviors—waving and pointing—of the Nao robot. The most important parameters for creating readable mood expressions were found to be hand height and amplitude, head position, and motion speed [20]. The experiments described in [21] found that various levels of exaggeration in motion of a humanoid robot correlate to human expectations of robot-like, human-like, and cartoon-like motion. Use of exaggerated motion enhanced the interaction through increased levels of engagement and perceived entertainment value.

In a work that is particularly relevant to the current study [22], the authors have recently updated their robot-independent model for upper-body gestures of a social robot [23], [24] to add the ability to modulate functional gestures such as pointing to incorporate affective content. In their system, the speed and amplitude of a functional gesture are modified with the goal of projecting a particular affective impression, as expressed by valence and arousal. The choice of those two specific parameters and the definition of their relationship to valence and arousal were based on findings from the literature mentioned above [17], [25]; however, the resulting gestures have not yet been formally evaluated to determine whether the target affective state was successfully projected.

While the previous studies listed above considered a range of gesture parameters, all included speed and amplitude in some form. This is not surprising, as these are two dimensions that have been shown to be crucial for controlling gestures for artificial agents [9]—and indeed, these are also the two dimensions that are considered in the current study.

III. EXPERIMENTAL APPROACH

The goal of this work is to investigate the way the perception of the users changes depending on the gestures that a robot displays. This section describes the way the gestures adopted in the experiments have been generated (see Section III-A) and the approach adopted to investigate the interplay between users' perception and gestures (see Section III-B).

A. The stimuli

This section describes the process aimed at synthesizing the 45 gestures - the *stimuli* hereafter - used in the experiments of this work. The first step is the selection of 5 standard gestures - the *core stimuli* hereafter - available in the library accompanying the *Pepper* robot. The selection targeted gestures that, according to the criteria underlying the taxonomy proposed in [15], are relevant to the scenario addressed in this work, i.e., the interaction between people and robots in public spaces. The names that the robot's manufacturer has given to the selected gestures are as follows (see Figure II) [1]:

- Disengaging / Send-away;
- Engaging / Gain attention;
- Pointing / Giving Directions;
- Head-Touching / Disappointment;
- Cheering / Success.

The second step of the process is the synthesis of 9 variants for each of the core stimuli above. Three variants were generated by adopting three different values of the speed λ per core stimulus: 15, 25 and 35 *frames per second* (*fps*), where 25 *fps* is the original speed of the core stimuli. For each of the 15 resulting gestures, another three stimuli can be obtained by modifying the differences $\Delta_i(t) = \theta_i(t) - \theta_i(t-1)$, where $\theta_i(t)$ is the angle between the two mechanical elements connected by joint i at frame t. In particular, the values of the $\Delta_i(t)$ were multiplied, for all values of i and t, by a factor α - the *amplitude* hereafter. Three different values of α were adopted, namely 0.50, 0.75 and 1.00. In the first two cases, the result is a dampened version of a core stimulus, in the last case, the $\Delta_i(t)$ are left unchanged.

As a result of the process above, the 9 variants of a given core stimulus correspond to 9 pairs (α, λ), and the pair where $\lambda = 25$ and $\alpha = 1.00$ is the core stimulus itself. The versions of the core stimuli corresponding to the different values of α are portrayed in Table II.

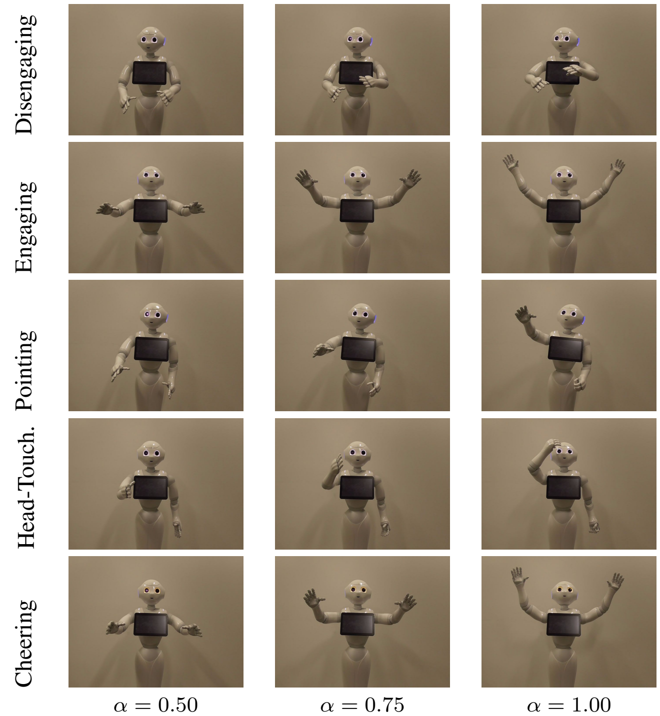

TABLE II

THE FIGURES SHOW, FOR EACH OF THE FIVE CORE STIMULI, THE EFFECT OF THE PARAMETER α. THE RIGHTMOST COLUMN ($\alpha = 1.00$) CONTAINS THE CORE STIMULI.

B. Perception Effects Analysis

The question addressed in this work is whether users perceive differently robots that display different gestures and, if yes, how the perception changes following the characteristics of the gestures. During the experiments, $N = 30$ human observers have filled the Godspeed questionnaire [1] after watching each of the 45 stimuli described in Section III-A (all observers have observed and rated all stimuli). The Godspeed questionnaire is widely accepted as a standard measurement tool for Human Robot Interaction and aims at quantifying the following tendencies underlying users' perception:

- *Anthropomorphism*: tendency of human users to attribute human characteristics to a robot;
- *Animacy*: tendency of human users to consider the robot alive and to attribute intentions to it;
- *Likeability*: tendency of human users to attribute desirable characteristics to a robot;
- *Perceived Intelligence*: tendency of human users to consider intelligent the behavior of a robot;
- *Perceived Safety*: tendency of human users to consider safe the interaction with a robot.

Filling the questionnaire results into five scores that measure the tendencies above: the higher the score, the more pronounced the tendency (see [1] for full details).

For a given stimulus, the administration of the Godspeed leads to a matrix $S = \{s_{ik}\}$, where s_{ik} is the score of observer i (where $i = 1, \dots, N$) for tendency k (where $k = 1, \dots, 5$). Thus, the following sum:

$$c_j = \sum_{i=1}^{N} s_{ij} \tag{1}$$

can be interpreted as the total number of points that the observers have accumulated for tendency j. Correspondingly, for tendency j, the total number of points accumulated over all variants of the same core gesture can be calculated as follows:

$$T_j = \sum_{\alpha} \sum_{\lambda} c_j^{\alpha\lambda} \tag{2}$$

where the sums extend over all values of parameters α and λ (see Section III-A) and $c_j^{\alpha\lambda}$ is the value of c_j obtained for a particular pair (α,λ), i.e., a particular variant of the core stimulus under exam.

The expressions above allow one to define the following χ^2 variable [26]:

$$\chi^2 = \sum_{\alpha} \sum_{\lambda} \frac{(c_j^{\alpha\lambda} - E)^2}{E}, \tag{3}$$

where $E = \frac{1}{9} T_j$. In other words, $c_j^{\alpha\lambda}$ plays the role of the observed number of points for a given variant (α, λ), while the value E plays the role of the expectation that, in this

[1] The animations associated to the core stimuli are available on the version 1.6B of Pepper in the following directories: "`animations/Stand/Gestures/No_3`" (Disengaging), "`animations/Stand/Gestures/Hey_2`" (Engaging), "`animations/Stand/Emotions/Negative/Hurt_1`" (Pointing), "`animations/Stand/Gestures/Far_3`" (Head-Touching) and "`animations/Stand/Emotions/Positive/Happy_1`" (Cheering).

Fig. 1. Experimental Setting. The observers sit at a distance of roughly 1.5 meters from the robot and provide their ratings using a tablet.

Age Range	18-22	23-25	26-30	31-35	36-40	¿40
No. of Subjects	11	6	6	3	1	3

TABLE III
AGE DISTRIBUTIONS OF THE SUBJECTS INVOLVED IN THE EXPERIMENTS.

	Ant		Ani		Lik		Int		Saf	
Core Stimulus	α	λ	α	λ	α	λ	α	λ	α	λ
Engaging	↑	↑	↑	↑	↑	↑				
Disengaging					↓	↓			↓	↓
Pointing										
Head-Touching			↑	↑						
Cheering			↑	↑						

TABLE IV
THE SYMBOLS "↑" AND "↓" ACCOUNT FOR STATISTICALLY SIGNIFICANT EFFECTS. THE SYMBOL "↑" MEANS THAT INCREASING AMPLITUDE OR SPEED CORRESPONDS TO OBSERVING HIGHER GODSPEED SCORES. THE SYMBOL "↓" MEANS THAT DECREASING AMPLITUDE OR SPEED CORRESPONDS TO OBSERVING LOWER GODSPEED SCORES. EMPTY CELLS CORRESPOND TO CASES IN WHICH NO STATISTICALLY SIGNIFICANT EFFECTS HAVE BEEN OBSERVED.

case, corresponds to a uniform distribution of points across the different variants. The χ^2 variable above allows one to test whether the observed distribution of the points deviates from the uniform distribution to a statistically significant extent. When this is the case, it is possible to say that the Godspeed tendency associated to column j in S is more or less pronounced depending on the particular gesture being displayed.

IV. EXPERIMENTS AND RESULTS

The experiments of this work have involved $N = 30$ observers that have been asked to watch the 45 stimuli described in Section III-A and, for each of them, to fill the Godspeed questionnaire (see Section III-B). All observers have performed the tasks above for all stimuli. These latter have been presented in random order (the same order for all observers) in three separate sessions (15 stimuli per session). The sessions were held in three consecutive days to limit possible tiredness effects due to the repetition of the tasks over extended periods of time. The 30 observers were split into groups of 3 people each that have been asked to participate in the same sessions while still working independently of one another. Figure 1 shows the experimental setting: the observers involved in the same session have filled the questionnaires while sitting in front of the robot at a distance of roughly 1.5 meters. The questionnaires have been filled through a software interface running on a tablet.

The 30 observers have been selected randomly from a pool of subjects available at the university where the experiments have been performed, 20 of them are female and 10 are male. The age distribution is available in Table III and the participants are of different ethnic and national origin. Only 3 observers have interacted with a robot before participating in the experiments of this work. The participants have received a payment corresponding to the minimum legal hourly wage in the United Kingdom, the country where the experiments have been performed.

The rest of this section presents the results of the analysis performed according to the approach presented in Section III.

A. *Gestures and Perception*

Table IV shows the cases in which the distribution of the Godspeed scores across the multiple variants of the same core stimulus deviates, to a statistically significant extent, from the uniform distribution (see Section III-B for details about the data analysis approach). Furthermore, when the deviation is statistically significant, the table shows whether increasing amplitude and speed of a gesture corresponds to higher or lower Godspeed scores. A deviation from the uniform distribution is considered statistically significant when a χ^2 test results into a p-value lower than 0.05. The *False Discovery Rate* (FDR) correction [27] has been applied to tackle the multiple comparisons problem.

For the Disengaging gesture, the effects take place in correspondence of Likeability and Perceived Safety. In the former case, the scores tend to decrease when α and λ increase, while in the latter case the scores tend to increase when α and λ decrease, respectively. The possible explanation behind the Likeability effects is that the gesture aims at increasing the physical distance between the robot and its users. Given that physical and social distances have been shown to be equivalent (the longer the former, the longer the latter) [28], increasing the energy of the gesture might look like an attempt of the robot to push people towards distances that, according to proxemic theories [29], correspond to less friendly and more formal relationships. For what concerns the interplay with the Perceived Safety, the probable explanation is that slower movements (lower λ) that do not extend far from the robot's body (lower α) are less likely to harm the users.

In the case of the Engaging gesture, statistically significant effects have been observed for Anthropomorphism, Animacy and Likeability. In all three cases, increasing amplitude and speed corresponds to higher Godspeed scores. For what concerns Anthropomorphism, one possible explanation is that the human brain has been shown to be more anthropomorphic - meaning that it is more prone to process artificial agents like it processes human ones - when synthetic movements are more similar to those displayed by humans [30]. Lowering α and λ actually produces gestures that, at least in the case of the Engage core stimulus, are less similar to those performed by humans. The possible explanation for the Animacy effects is that higher speed and amplitude result into higher energy and motor activation, two factors that play a crucial role when it comes to consider alive an agent [1]. Finally, the increase of the Likeability scores is likely to depend on the correlation between Anthropomorphism and positive judgments about the robots that has been observed earlier in the literature [31]. Overall, the three effects observed for the Engaging gesture are an advantage in those scenarii in which the robot is expected to proactively start the interaction with the users. The reason is that the effects provide indications on how to make the perception of the users more positive - a prerequisite towards successful interactions with machines that display human-like behaviour (see, e.g., [32]) - at the very moment they enter in contact with the users.

There is no statistically significant effect for the Pointing gesture. A possible explanation is that deictic gestures are meant to convey information about spatial knowledge [10] - in particular when it comes to the position of an object of interest in the environment - and not about the social and psychological phenomena underlying the items of the Godspeed questionnaire [1]. Finally, both the Head-Touching and Cheering gestures show significant effects in correspondence of Animacy. The main probable reason is that both gestures, when displayed by people, tend to convey information about one's inner state. In particular, Head-Touching is typically associated to a situation of confusion [33], [34] while Cheering tends to be displayed as a sign of success and satisfaction [6]. This means that a robot displaying the two gestures above can elicit the attribution of the same inner states and, ultimately, of Animacy, defined as the very property of being alive [1].

For both Head-Touching and Cheering, the Animacy scores tend to increase when both α and λ increase. For what concerns α, the probable reason is that lowering the parameter leads to gestures that have a morphology different from the core stimulus and, hence, fail in conveying the same impression. For what concerns λ, the probable reason is that movements have been shown to play a crucial role in the attribution of Animacy, the very difference between animate beings and inanimate objects [1]. Thus, increasing the movement's energy (proportional to speed) tends to attract higher Animacy scores.

V. Conclusions

This article has presented experiments on the interplay between the way a gesture is performed and the perception of the users. The results show that, at least in some cases, there is an association between speed and amplitude of a gesture - two parameters that account for energy and spatial extension - and Godspeed scores [1]. Overall, the coherent picture that emerges is that gestures expected to achieve a social goal - Engaging and Disengaging - show effects in correspondence of the Godspeed dimensions that better account for social aspects of Human Robot Interaction, namely Anthropomorphism (the tendency to attribute human characteristics to the robot) and Likeability (the tendency to attribute desirable characteristics to the robot). Similarly, gestures designed to simulate an "inner state" - Head-Touching and Cheering - show effects in correspondence of Animacy, the Godspeed dimension that captures the tendency to consider the robot alive and, hence, capable to experience the world. Finally, there are no effects for Pointing that, unlike the other stimuli used in the experiments, aims at sharing knowledge about the environment more than at conveying information about the dimensions underlying the Godspeed questionnaire.

The above suggests that the stimuli have been designed correctly and, most importantly, it shows that the Godspeed scores tend to be different in correspondence of different values of amplitude and speed. The main implication of such an observation is that it is not sufficient to decide what gestures a robot should display during an interaction, but also how the gestures are performed. In particular, the same gesture should be displayed with different amplitude and speed depending on how much the tendencies underlying the Godspeed scores should be pronounced.

The experiments revolved around isolated gestures that have been shown without the support of other modalities. The reason is that the gestures will be used in public spaces where the acoustic noise is high and, hence, gestures aim at compensating the difficulties in hearing and understanding spoken messages, in line with the indications of biologists about the use of multiple modalities in noisy environments [7], [8]. However, future work will aim at investigating how the findings of this work can possibly change when the gestures is accompanied by speech, like it is the most frequent case in everyday interactions [2], [6]. Furthermore, future work will investigate the interplay between the gestures and other characteristics that users can attribute to the robot like, e.g., the Big-Five personality traits.

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