Not Too Close and Not Too Far: Comfort-Distance Towards Virtual Humans and Anthropomorphic Robot

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Abstract. Nowadays, machines like humanoid and non-humanoid robots no longer belong to an imagined futuristic scenario but to many real contexts of our time. This leads to the reconsideration of the relationship between humans and machines from a human-centered perspective. Indeed, despite the fact that evidence has shown that people perceive robots as social beings and that robots are designed to ensure a pleasant and positive atmosphere, little is known about the human comfort (i.e. positive or negative proxemics preferences) in interacting with human-like machines. More specifically, here we wondered whether the robot's appearance could serve as a socio-emotional cue to influence individuals' proxemics preferences. The present study tried to address this issue considering the Interpersonal-comfort space (IPS) as a reliable measure of the quality of social interactions. To this end participants were asked to provide the comfort-distance judgement while being approached by an anthropomorphic robot, a non-anthropomorphic robot and male and female virtual confederates showing positive or negative facial expressions. Results suggest that participant's comfort distance can be ideally ordered along a line from a negative pole with non-anthropomorphic robot and angry humans to a positive pole with neutral and happy humans. It is interesting to note that the comfort distance from the anthropomorphic robot seems to be between these two poles.

Keywords: Human-Robot Interaction, Comfort space, IVR, Anthropomorphic Characteristics.

1 Introduction

The rapid and wide spread of modern technologies and solutions (e.g., virtual assistants, chatbots, machines learning, AI models etc.) in our daily life let us to deal with an unedited scenario of new advantages, possibilities, limits and changes [1]. This becomes more relevant if we look at the evidence that entities like robots, both anthropomorphic and non-anthropomorphic, no longer belong to an imagined futuristic scenario, but to many real contexts of our time [2, 3]. Nowadays, indeed, robots are used in industries, offices, domestic environments as well as they have a role of welcoming in variety of services including retail, hotels, public transport and so forth [4–6]. As a consequence, the co-existence of humans and robots in the same environment has to be taken into account and reviewed from a human-centered perspective, because people and robots have to effectively (and pleasantly) interact [2].

According to proxemics studies, the use of space during interactions is a good measure of the quality of social interactions [7]. The IPS represents the optimal distance between ourselves and others, that is our emotional ‘private space’ [8]. In the social psychology literature, a typical task to assess the size of interpersonal space is based on comfort-distance judgments provided through the ‘stop-distance’ paradigm: participants have to stop the interactant at the point where they still feel comfortable with the other’s proximity [8–10]. Usually, people react by increasing the IPS in uncomfortable/threatening situations and by reducing the IPS in comfortable/safe situations [8, 11]. In line with proxemics studies, evidence has demonstrated that IPS is modulated by the socio-emotional characteristics of the interactant such as age, gender, and facial expression also when the interactant is a virtual character (e.g. [12, 13]). Similar to IPS among humans, people tend to maintain their personal/private zone when interacting with robots [14, 15] or virtual robots [16, 17]. Although several human-related and robot-related factors can affect proxemics in Human-Robot interaction (HRI) (e.g. individuals’ familiarity with robots and the robot’s form), previous studies have emphasized the role of robot appearance in proxemics preferences (e.g. [15, 18]). Indeed, a higher degree of anthropomorphism is linked to higher expectations of adherence to human proxemics norms (e.g. [18]). Although there are many studies on robots [18, 19], to our knowledge no study has investigated how much the anthropomorphic appearance in itself can represent a socio-emotional value in proxemics terms.

Here we wondered if, based on the anthropomorphic appearance, individuals tend to consider robots as friendly interlocutors to get in touch with or as potentially unpleasant/threatening interlocutors to stay away from. A possible way to address this issue is to compare individual's comfort-distance when interacting with human confederates showing positive, negative, or neutral emotions and with anthropomorphic and non-anthropomorphic robots. Comparing humans with facial expressions with the two different robots allowed us to better understand how people conceive proxemically the anthropomorphic appearance. To this end, we devised an IVR study in which participants were asked to determine the comfort-distance (distance people prefer from other persons) while being approached by anthropomorphic and non-anthropomorphic robots and virtual confederates with happy, angry or neutral facial expressions. The IPS sensitivity to social cues could be revealing of subjective dispositions towards the interactant (virtual human, robot) [13, 20].

We expect that the humanoid appearance should induce participants to reduce the distance compared to the non-anthropomorphic robot. However, we cannot hypothesize to what socio-emotional value (facial expression) the anthropomorphic appearance can be considered similar (e.g. [13]).

2 Materials and Methods

2.1 Participants

Thirty-one participants (16 females), were recruited (mean age = 23.03, SD= 3.03). In this study all participants had normal or correct to normal vision. Nobody claimed discomfort or vertigo during the immersive virtual reality (IVR) experience. Participants gave their written consent to take part in this study. Experiment and testing were in conformity with the 2013 Declaration of Helsinki and the in accordance with the criteria established by the Local Ethics Committee (Dept. of Psychology, University of Campania L. Vanvitelli).

2.2 Immersive Virtual Reality (IVR) equipment and Setting

The experiment was conducted in the Laboratory of Cognitive Science and Immersive Virtual Reality (CS-IVR), Department of Psychology, University of Campania L. Vanvitelli-Caserta (Italy). The IVR was installed in a rectangular room (5 m x 4 m x 3 m) and includes the Vizard Virtual Reality Software Toolkit 4.10 (WorldViz, LLC, USA) with the Oculus Rift DK2 as head-mounted display (HMD), having two OLED displays for stereoscopic depth (images = 1920 x 1080; 90° horizontally, 110° diagonally). The IVR system allowed for the continuous tracking and recording of participant's position by means of a marker placed on the HMD; visual information was updated in real time. Graphics modelling of all virtual stimuli were created with the 3D Google Sketch Up 7.0 free software and 3DS Max (Autodesk). The position and orientation tracking systems allowed the participants to realistically experience dynamic and stereoscopic visuo-motor input as if they were in front of natural stimuli.

2.3 Virtual stimuli and Virtual environment

The virtual room (3 x 2.4 x 3 m) consisted of green walls, white ceiling, and a grey floor with a 3 m white dashed line from the initial position of the participants to the end of the virtual room.

A total of six confederates (half female) with angry, happy, and neutral facial expression were selected among a colony of highly realistic virtual humans (Vizard Complete Characters, WorldViz; USA). The emotional expression of the face was obtained by modelling the virtual faces with 3DS Max (Autodesk) following the KDEF database [21]. The sample of virtual confederates was selected on the basis of a previous pilot study [13] in which 14 participants rated, on a 9-point Likert scale, how much the faces presented on the PC appeared happy/unhappy, friendly/threatening, angry/peaceful, and annoying/quite. Following this evaluation, twelve virtual confederates were selected whose facial expressions were: happy (two males and two females) angry (two males and two females) and neutral (two males two female) (Fig. 1).

The selected virtual confederates represented male and female adults aged about 30 years and perceived as representation of typical Italian citizens. The virtual confederates kept their arms extended along the body (see in Fig.1). An anthropomorphic robot and non-anthropomorphic robot were also used (Fig.1). The height of the virtual stimuli (that is, male and female virtual confederates, anthropomorphic/non-anthropomorphic robot) was 175 cm. Walking speed (0.5 ms -1) and approach trajectory was constant for all virtual stimuli [22].

Fig. 1. Examples of virtual stimuli. On the left the panel shows the anthropomorphic and non-anthropomorphic robots and a virtual confederate with neutral facial expression. On the right, an example of angry (top) and happy (bottom) facial expressions of virtual man and woman. All the experimental stimuli are shown according to participants' perspective.

3 Procedure

After presenting the IVR devices and an initial exploration of the virtual world to familiarize with the IVR equipment and the environment all participants received written instructions about the comfort-task. These instructions were also then orally repeated by the experimenter. Participants wore the HMD and invited to freely explore the virtual room. Through the HMD, participants could see the virtual stimuli fully immersed in the virtual scene. After this familiarization phase, participants were guided by the experimenter to a pre-marked starting position holding a key-press device in their dominant hand. Throughout the entire experimental session, participants were with their arms extended along the body, like the posture assumed by the virtual confederates and the anthropomorphic robot.

The experimental flow comprised a four-trial training session to allow the participant to familiarize with the task. After that, the tasting phase began again with a short presentation of the instructions (2 s) followed by a fixation cross (300 ms) then a virtual stimulus (i.e. a male/female virtual confederate, an anthropomorphic or non-anthropomorphic robots) appeared. Participants stood still and saw each virtual stimulus moving towards them at a constant speed, until they stopped it by pressing the button. Indeed, the comfort-task instructions were: "Press the button as soon as the distance between you and the virtual stimulus makes you feel uncomfortable". After the button press, the virtual stimulus disappeared, and the next trial was presented. Each virtual stimulus was randomly presented (i.e., virtual human confederate showing happy, angry, and neutral facial expression 4 times each, anthropomorphic and non-anthropomorphic robot 4 times each; total of 32 trials).

4 Data analysis

The distance at which the participants stopped the virtual stimuli was measured (cm). The participant's arm length was then subtracted from the average distance.

A one-way ANOVA for within-subject design was used to analyze mean distance (cm) between the participants and the virtual stimuli as a 5-level factor (Non-anthropomorphic Robot, Anthropomorphic Robot, Angry, Neutral, Happy). Data points outside M±2.5 SD (0.04%) were discarded. The Tukey post-hoc test was used. The magnitude of significant effects was expressed by partial eta-squared (η^2_p).

5 Results

The results showed a significant main effect of Virtual stimuli, F (4,30)= 4.50, $P<0.01$, $\eta^2_p = 0.14$. The Tukey post-hoc test showed that participants preferred a significantly larger comfort distance from the non-anthropomorphic robot than virtual humans looking happy (P=0.01) or with a neutral expression ($P<0.5$). Similarly, they preferred a larger comfort distance from virtual humans looking angry than happy (P=0.01) or with a neutral expression ($P<0.5$). There was no significant difference between angry virtual humans and non-anthropomorphic robot (P= 1). The only virtual stimulus that showed no significant difference from the non-anthropomorphic robot and the humans was the anthropomorphic robot. As shown by the related means, the comfort distance can be ideally ordered along a line going from a negative pole with non-anthropomorphic robot (mean= 169.23, SD= 50.96) and angry humans (mean= 168.89, SD= 32.13) to a positive pole with neutral (mean= 142.94, SD= 53.80) and happy (mean= 137.48, SD= 24.05) humans. As also shown in Fig.2, the comfort distance from the anthropomorphic robot seems in between these two poles (mean= 154.07, SD= 65.52).

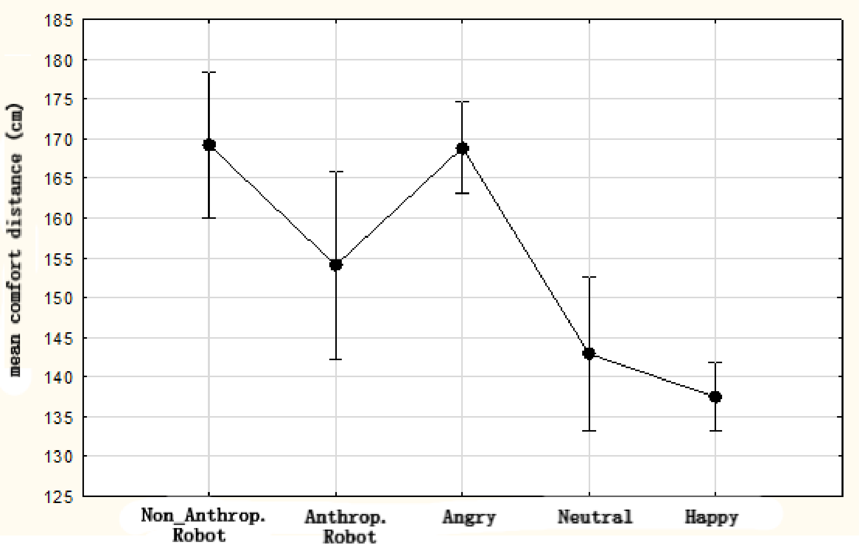

Fig. 2. Participant-virtual stimulus comfort-distance. The graph shows the mean comfort distance (cm) as a function of the type of virtual stimulus (anthropomorphic/non-anthropomorphic robot and happy, angry, and neutral virtual confederates). Error bars represent the standard error.

For explorative purposes, four t-tests for dependent samples (corrected for multiple comparisons, α= 0.0125) were performed contrasting the factor "Robot" with all others. The analyses showed that only the comparison that approached significance was between the anthropomorphic and the non-anthropomorphic robot (t (30) = -0.545, P= 0.016. In contrast, no significant difference from all human stimuli emerged.

6 Discussion

To our knowledge, despite the fact that Human-Robot Interaction (HRI) researchers studied a variety of opening encounters and factors that can influence human proxemics preferences towards robots, no study has investigated how much the anthropomorphic characteristic can represent a socio-emotional value in proxemics terms [1, 2, 23, 24]. Namely, here we wondered if people treat robots as pleasant and friendly interactant or as disturbing/unpleasant interactant when sharing the same social environment on the basis of their anthropomorphic appearance. Therefore, we considered the IPS comfort-distance as a reliable measure of the quality of social interactions [7], measured by asking participants to determine interpersonal comfort-distance while interacting with an anthropomorphic robot, virtual confederates expressing happy, angry or neutral facial expressions and a non-anthropomorphic robot.

In line with the literature, the results showed that the comfort-distance was larger with angry virtual confederates and the non-anthropomorphic robot compared to happy and neutral ones [16, 13]. More interestingly for our purposes, results revealed that participants' preferred comfort-distance towards the anthropomorphic robot lies between angry confederates, non-anthropomorphic robot and the virtual humans exhibiting neutral and happy facial expressions. In other words, in proxemics terms participants kept the anthropomorphic robot to a distance in between negative (i.e. angry confederates and non-anthropomorphic robot) and positive (i.e. happy and neutral confederates) virtual stimuli. Therefore, our data reflect the social and safety components of the IPS [16, 13]. Compared to non-anthropomorphic robot, the humanoid appearance evoked a more human-like interaction [15]. Indeed, the necessity to humanizing the robot refers to the tendency of individuals to see non-human agents as human beings and to attribute to them intentions, motivations, or goals similar to human ones. This strongly influences the way people treat these agents [25].

This pattern of results suggests that each social interaction implies approach and avoidance behaviors that provoke the optimal regulation of interpersonal distance [26]. In line with the goal of the present study, our results would indicate that during human-robot interaction the anthropomorphic appearance plays a relevant socio-emotional role in regulating the optimal IPS distance. As in human-human interaction it is common for individuals to form quick impressions about their unknown interactant, in Human-Robot interaction people tend to have the same idea about their interactant and the robot's appearance has proved particularly important [18]. Indeed, the anthropomorphic characteristics increase the robot's familiarity and the perception to be in touch with a "human-social entity" [27].

To conclude, the present findings may contribute to better understand the human necessity to create "socially interactive robots" with human-like characteristics [28].

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