# Understanding social robots: A user study on anthropomorphism

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# Understanding Social Robots: A User Study on Anthropomorphism

Frank Hegel[1], Sören Krach[2,3], Tilo Kircher[2], Britta Wrede[1], Gerhard Sagerer[1]

*Abstract*– **Anthropomorphism is one of the keys to understand the expectations people have about social robots. In this paper we address the question of how a robot's actions are perceived and represented in a human subject interacting with the robot and how this perception is influenced only by the appearance of the robot. We present results of an interaction-study in which participants had to play a version of the classical Prisoners' Dilemma Game (PDG) against four opponents: a human partner (HP), an anthropomorphic robot (AR), a functional robot (FR), and a computer (CP). As the responses of each game partner were randomized unknowingly to the participants, the attribution of intention or will to an opponent (i.e. HP, AR, FR or CP) was based purely on differences in the perception of shape and embodiment. We hypothesize that the degree of human-likeness of the game partner will modulate what the people attribute to the opponents – the more human like the robot looks the more people attribute human-like qualities to the robot.**

## I. INTRODUCTION

As machines become fixtures in the home and workplace, our interactions with them will become more sophisticated and inevitable. Within this context it has been proposed that social robots serve as an interface between humans and technology [1] with the supposition that the more anthropomorphic a robot looks like the more the user will expect the robot to behave like a human being. We assume that a human-like behaving robot is the easiest to use interface simply because humans are highly skilled in having natural interaction with and communication to other humans. Furthermore, users would not have to learn a new technical vocabulary in order to reach a goal when interacting with technical devices. However, these assumptions have barely been tested in a systematic way. Is it indeed the case that the more anthropomorphic a robot looks, the more we expect it to behave in a human-like way? How is this expectation manifested in the human cognitive system and what kinds of expectations are affected? The answers to these questions will have a severe impact on the further development of robots as they address the fundamental cognitive mechanisms underlying the interaction with robots. To address these questions we directly investigated the interaction of human participants with artificial/robotic systems with increasing degrees of human-likeness. Furthermore, participants were scanned by means of functional magnetic resonance imaging enabling us to measure cortical activation during these interactions. We expect the results of our studies to have a severe impact on the design of social robots.

Fig. 1. Setting of the briefing; from left to right: anthropomorphic robot (AR), computer partner (CP), human partner (HP) and functional robot (FR).

In the experiment participants had to play a version of the classical Prisoners' Dilemma Game (PDG), a paradigm commonly used in social psychology to study aspects of interpersonal behaviour. PDG matrices are used in functional imaging scenarios, because they enable to investigate implicit perspective taking without having confounding influences due to social desirability. First (see Figure 1), the subjects were briefed to play in a face-to-face scenario against a human player (HP), the anthropomorphic robot BARTHOC Jr. (AR), a functional robot (FR) designed with two Lego Mindstorm sets, and a computer player (CP). Afterwards the participants passed on to the MR-scanner located in a neighbouring room and were instructed to play the game during the next 30 minutes. Finally, the participants had to fill out several questionnaires about the interaction with the different robots.

The responses of the interactors (HP, AR, FR and CP) were randomized in advance, thus ensuring that the subjects' differences in reactions were purely based on the different expectations and perceptions of their interactors. According to

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[1] Faculty of Technology, Applied Computer Science, Bielefeld University, Universitätsstr. 25, 33615 Bielefeld, Germany. E-Mail: (fhegel, bwrede, sagerer)@techfak.uni-bielefeld.de

[2] Department of Psychiatry, RWTH Aachen University Hospital, Pauwelsstr. 30, 52074 Aachen, Germany. E-Mail: skrach@ukaachen.de

[3] Central Service Facility, Functional Imaging at the ICCR-Biomat, RWTH Aachen University Hospital, Pauwelsstr. 30, 52074 Aachen, Germany

the general assumption of social robotics our hypothesis was that the human-like robot will evoke more activation of anthropomorphic attributions than a functional designed robot opponent.

In Section II we refer to appearance and anthropomorphism within the field of social robotics. Section III describes the design of our experiment. The results are presented in Section IV. In conclusion we discuss the results of the behavioural data of our experiment in Section V.

## II. RELATED WORK

In the Section 2.1 we address related work on the appearance of social robots relating to expectations users have and Section 2.2 outlines anthropomorphism, Section 2.3 the Uncanny Valley hypothesis, and Section 2.4 the embodiment of robotic characters.

### *2.1 Appearance of Social Robots*

Social robots were inspired by biology. They were basicly used to study swarms or the behaviour of insects [2]. However, later approaches treat the interaction between humans and robots. The term social in this case represents the fact that there are two or more entities within the same context [3]: Social robots are embodied agents that are part of a heterogeneous group: a society of robots or humans. They are able to recognize each other and engage in social interactions and they communicate with each other [2]. Furthermore, the robot should be able to understand us in social terms and we, in turn, should be able to understand it in the same social terms. That implies the robot to have lifelike qualities, because humans generally anthropomorphize technology and they tend to interpret behaviour as being intentional [4, 5]. Therefore, the appearance of the robot should match the expectations a user has [6, 7].

The form, i.e. the appearance of robots has also a substantial influence on the assumptions people have about specific applications and behaviours [8, 9]. Therefore, the designer of robots should guarantee that the form of a robot matches its functions. In this context DiSalvo et al. [10] suggest to consider a) an amount of robot-ness to emphasise the robot-machine capabilities and to avoid false expectations, b) an amount of human-ness such that the subjects feel comfortable, and c) a certain amount of product-ness such that the robot is also seen as an appliance.

Fong et al. [2] distinct between four broad categories of the robot's aesthetic form: anthropomorphic, zoomorphic, caricatured, and functional. An anthropomorphic appearance is recommended to support a meaningful interaction with users [4, 7], because many aspects of nonverbal communication are only understandable in similarity to a human-like body. Robots with a zoomorphic appearance are intended to behave like their animal counterparts. Robots with a caricatured appearance are used to focus on very specific attributes. Finally, functional robots are designed in a technical/functional manner to illustrate their ultimate functions.

The design of a robot's head is an important issue within human-robot interaction (HRI) because it has been shown that the most non-verbal cues are mediated through the face [11]. Without a face the robot is anonymous [12]. The physiognomy of a robot changes the perception of its human-likeness, knowledge, and sociability. Therefore, people avoid negatively behaving or looking robots and prefer to interact with positive robots [13]. Furthermore, an expressive face indicating attention [15] and imitating the face of a user [15] makes a robot more compelling to interact with. Consequently, Duffy [7] argues a robot has to have a certain degree of anthropomorphic attributes for meaningful social interaction.

### *2.2 Anthropomorphism*

Anthropomorphism entails attributing humanlike properties, characteristics, or mental states to real or imagined nonhuman agents and objects [16]. According to v. Foerster [17] we anthropomorphize because it allows us to explain things we do not understand in terms that we do understand, and what we understand best is ourselves as human beings. This is consistent with the familiarity thesis [18] which claims to understand the world based upon a mental model of the world that we are most fimiliar with.

According to the *Three-Factor-Theory of Anthropomorphism* by Epley et al. [16] the extent to which people anthropomorphize is determined by three factors: (a) Elicited Agent Knowledge: Knowledge about humans in general or self-knowledge serve as a basis for induction primarily because such knowledge is acquired earlier and is more richly detailed than knowledge about nonhuman agents or objects. The more similar in appearance or motion the nonhuman agent is, the more people are likely to use themselves as a source of induction. For example, robots are anthropomorphized more readily when given humanlike faces and bodies [10] and hummingbirds suddenly appear more deliberate and thoughtful when their natural quickness is slowed to a humanlike speed [19]. (b) Effectance Motivation: Effectance describes the need to interact effectively with one´s environment. Attribuing human characteristics and motivations to nonhuman agents increases the ability to make sense of an agent´s action and reduces uncertainty. Finally, (c) Sociality Motivation describes the need and desire to establish social connections with other humans. When people feel lack of social connection they anthropomorphize to a higher content to satisfy their motivation to be together with others.

### *2.3 The Uncanny Valley*

The Uncanny Valley hypothesis [20] is also dealing with human-likeness. The idea of the hypothesis follows from Freud's description of the uncanny (a translation of the German word 'unheimlich') [21]: "derives its terror not from something externally alien or unknown but – on the contrary – from something strangely familiar which defeats our efforts to separate ourselves from it".The Uncanny Valley represents how an object can be perceived as having enough human-like characteristics to evoke a constrained degree of empathy through one's ability to rationalize its actions and appearance. When the movements and the appearance are almost human-like but not entirely, there are too many expectations of the capabilities and the result is a negative reaction from the observer. In the end, the object becomes so human-like that it is effectively treated as a human being where it has reestablished a balance between anticipated and actual function and form to a sufficient degree that works [1].

### 2.4 Embodiment

Furthermore, the embodiment of a robot may have an effect when interacting with a robot. [22] found a facilitation effect in his study with the emotional robot eMuu. Participants acquired a higher score in a negotiation game and they put more effort into the negotiation when they interacted with the embodied robot character instead of the screen character. This may due to the feeling of social presence [23].

## III. EXPERIMENTAL PROCEDURES

### 3.1 Participants

We present preliminary data of twenty male subjects (24.47 ± 2.97 years) that participated in the study. All participants had normal or corrected-to-normal vision and were right-handed according to the Edinburgh Handedness Index [24]. Participants were excluded if they were diagnosed with a past or present psychiatric, neurological, or medical disease. Participants further underwent neuropsychological testing, including attention [25], executive functions [26] and IQ [27]. Furthermore, personality traits were investigated by means of the BFI [28]. The study was approved by the local ethical committee.

### 3.2 Setting of Briefing

All participants completed a briefing consisting of a "get-together" with their putative game partners: a computer (CP), a functional robot (FR), an anthropomorphic robot (AR) and a human confederate (HP) (see Figure 1).

### A. The Functional Robot (FR)

The functional robot with its two arms (see Figure 2) was constructed from two Lego Mindstorm sets (http://mindstorms.lego.com). Each arm consists of two servo motors and a Lego NXT controller that is a computer controlled Lego brick. The two servo motors are directly connected to the NXT controller. The movements of the servo motors are very precise (+/- one degree) so that a believable animation on a computer keyboard is warranted. The behaviour of pressing two buttons on a laptop keyboard is programmed with the Mindstorms NXT software which serves as an intuitive drag and drop programming software to design robots. The functional design represents two arms modeled after a human arm to support the idea of anthropomorphism.

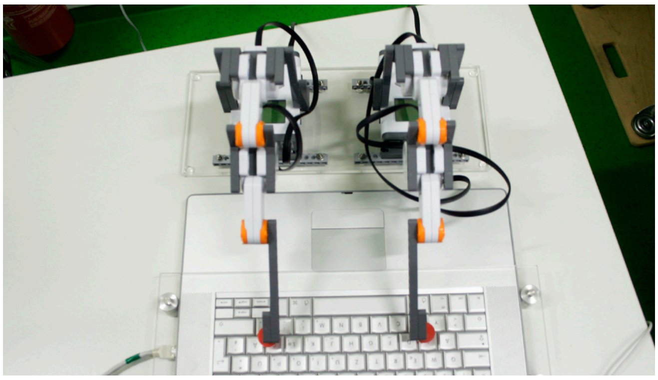

Fig. 2. Functional Robot, Lego Mindstorms

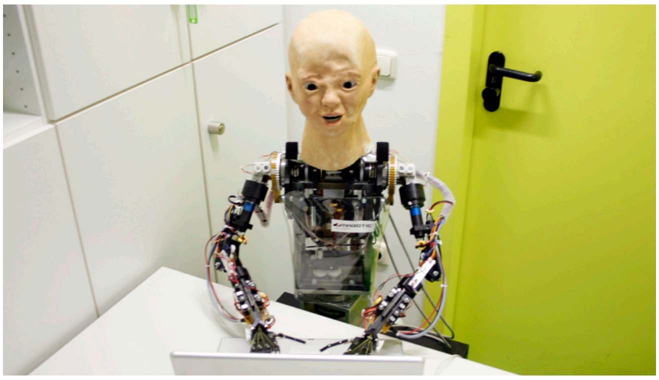

Fig. 3. Anthropomorphic Robot, BARTHOC Jr.

### B. The Anthropomorphic Robot BARTHOC Jr.

BARTHOC Jr. looks like a child at the age of five years with the size of 65 cm from the waist upwards (see Figure 3). The robot is able to move its torso which is mounted on a 65 cm high chair-like socket to the left and to the right. The socket includes the power supply, actuator controllors named iModules, and two serial interfaces to a computer. One interface controls the head and neck actuators, the other one is connected to the actuators below the neck.

In total 41 actuators consisting of DC- and servo motors move the robot. The face has ten degrees of freedom to control jaw, mouth angles, eyes, eye brows, and eye lids. Therewith, the robot is able to imitate human-like facial expressions. The eyes are vertically aligned and horizontally moveable. Each eye contains a Firewire color video camera with a resolution of 640 x 480 pixels. Furthermore, the head can be turned, tilted to its side and slightly shifted forwards and backwards. Each arm can be moved similarly to the movements of a human arm. With its five fingers on each hand BARTHOC Jr. is able to show simple grips as well as deictic gestures. The fingers use only one bending actuator, but they are autonomously controllable for believable movements. By using different facial masks which are made of latex we are able to alter the appearance of BARTHOC Jr's face. This enables us to use male and female personalities within specific settings to study gender effects. For extended experiments with an adult-like robot we use the taller robot BARTHOC [29].

After introducing participants to their opponents for the upcoming game sessions, participants were seated face-to-face with their anticipated game partners (see Figure 1). A notebook placed in front of the participant displayed the instruction of the experiment. Notebooks – placed in front of each interactor - were linked to the participant's notebook via mocked connecting cables. The keyboards placed in front of the robots were covered by a custom-made plexiglass device. This construction was equipped with a fixed two-button system allowing the robot to press only two single keys (see Figure 2).

For the briefing both robots were programmed in advance to push their keyboard buttons exactly at the same time when the subjects believed to play them. Similarly, the confederate contemporaneously pressed his buttons when the subject assumed playing the human partner. However, during the tutorial as well as during the entire experiment, the response behaviour of the subject's partners was randomized, thereby not enabling participants to really cooperate or find "a best way". By this means it will be possible to infer pure "intentional stance" associated neural activity [30, 31] as possible strategies of the putative partners are hold constant.

### *3.3 Task Design*

The briefing comprised two tutorial rounds for each condition (CP, FR, AR, HP and baseline). The task resembled decision games already applied by other research groups and can be considered as a variant of the PDG [32, 33, 34, 35, 36].

Taken together, participants always had to find a decision about cooperating or defecting with the respective interactor in a series of nine games in a row. Cooperation was signalled by pressing the left button on the computer keyboard, defection by pressing the right button, respectively. Depending on the interactor's decision, the participant immediately received a previously defined and explicitly learned pay-off feedback, making the scenario highly interactive.

The payoff feedback, as conveyed by the decision matrix (specifically developed and pre-tested) worked as follows: If both contenders were pressing the left button, both of them would be gratified with 20 points each (CC). In case that the participant would press the left button (cooperate) with the respective partner pressing the right button at the same time (defect), the participant would return with 10 points for this game, but the opponent would receive 20 points (CD). The other way around, the participant (defect) would reap 20 points, while the opponent would receive 10 points (DC). In case both contenders choose to defect, the dilemma would eventuate with both sides receiving zero points (DD). CC implies mutual cooperation, while DD involves mutual non-cooperation [26].

Games were interspersed by a low-level baseline condition enforcing participants to alternately press the right and left button when a central cross hair appeared on the computer screen. Importantly, the instruction given to the participants involved the demand to both, "win a series of games and reach a virtual highscore". As these two converse goals could, per definition, not be reached by solely pressing one button, this matrix secured an almost equal pressing of both buttons, thereby supporting the idea behind: to find a decision based upon the reasoning about the opponent's last decisions, i.e. triggering Theory of Mind (ToM). Finally, the briefing pursued two goals: firstly, familiarizing participants with the decision matrix and secondly, triggering a strong attachment of the participants to their game partners.

## IV. RESULTS

The research in this paper is mainly based on behavioural data that we recorded during the scenario and the questionnaire.

### *4.1 Neuroimaging Data*

In short, functional imaging data reveal that we succeeded in misleading all participants and that main cortical regions contributing to a perspective taking were activated during all conditions (CP, FR, AR and HP). Areas of activation circumscribe the medial prefrontal cortex (mPFC) extending into the medial superior frontal cortex (mFC) as well as the temporo-parietal junction (TPJ). For a more detailed description the reader is referred to [5, 37].

### *4.2 Behavioural Data / Questionnaire*

Directly after scanning participants were asked to filling out a questionnaire about their impressions of the task and game partners. The questionnaire mainly focused on the perception of the interaction with each individual opponent (CP, FR, AR, HP). As the behavioural responses of each partner were randomized in advance, evaluations must be attributed solely to the different outer appearances of interaction partners.

As a prerequisite to derive meaningful interpretations of the behavioural and functional imaging data on-line response behaviour and questionnaires indicated that all of the 20 participants believed in the setting, i.e. they believed to really interact with the partners on-line.

Neither reaction times nor button pressing behaviour differed significantly between conditions (reaction times: $F(1,19) = .07$; $p = .98$; button pressing behaviour: $F(1,19) = .26$; $p = .85$). Overall, participants played rather competitive with a ratio of around 60/40 (competitive/cooperative) decisions, irrespective of the partner being played.

### *A. Human-Likeness of Barthoc Jr. and Lego-Robot*

As hypothesized the subjects rated BARTHOC Jr.'s appearance as significantly more human-like as the functional robot (paired samples t-test: $t = 9.28$; $p < .0001$). Furthermore, there was a trend towards appreciating BARTHOC Jr. as more sympathetic and friendly compared to the functional robot (paired samples t-test: $t = 1.88$; $p < .10$).

### *B. Fun Experiencing the Game Partner*

The subjects experienced linearly increasing fun in the interaction the more the respective partner exhibited human-like features, i.e. CP < FR < AR < HP (linear trend of perceived fun: $F(1,19) = 19.06$; $p < .0001$) (see Figure 4).

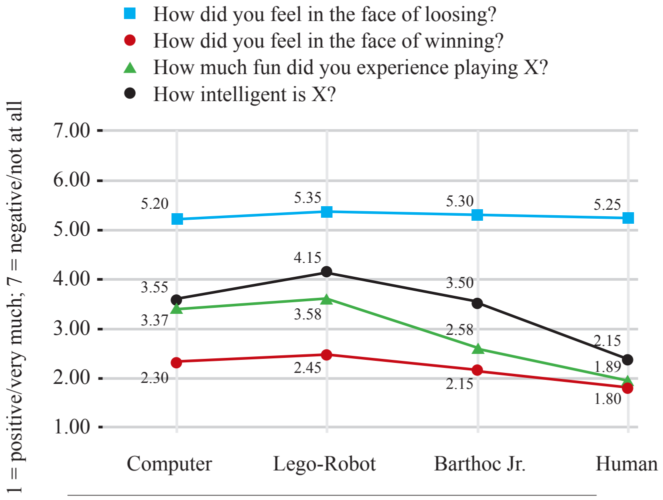

Fig. 4. Attribution of intelligence, feeling in the face of winning/loosing, fun experiencing the game

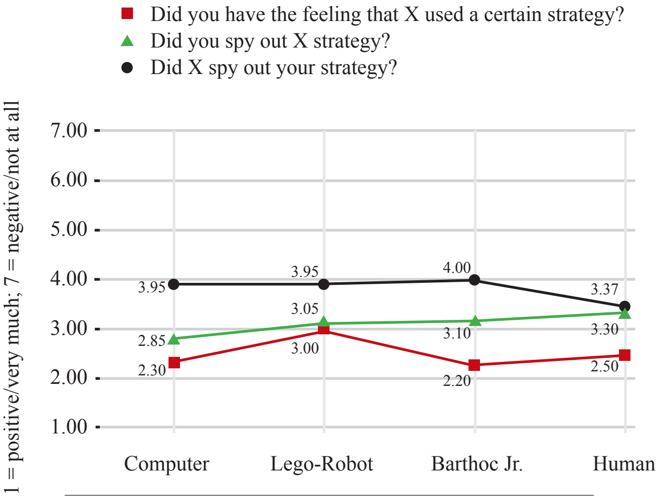

Fig. 5. Attribution of strategy

### *C. Attribution of Intelligence*

Game partners were attributed increasing intelligence the more they appeared human-like; i.e. CP < FR < AR < HP (linear trend of attributed intelligence: F(1,19) = 9.21; $p < .005$) (see Figure 4). For both calculations, quadratic and cubic trends did not reach significance.

### *D. Feelings in the Face of Winning and Losing*

Nobody liked to lose against any opponent (see Figure 4), but subjects felt best when beating the human player (1.80) (however, this effect did not reach significance). Overall, there was a significant difference in the self-estimated sensation between winning (positively valued) and losing series (negatively valued), irrespective of the actual game partner (paired samples t-tests: computer partner: $t = 9.45$; $p < .0001$; functional robot: $t = 7.86$; $p < .0001$; anthropomorphic robot: $t = 8.03$; $p < .0001$; human partner: $t = 10.80$; $p < .0001$).

### *E. Strategy of the Opponents*

It turned out that the participants acknowledged that the human partner was superior in spying out their strategy (3.37) as compared to the robots (4.00 and 3.95) or the computer (3.95) (to note, an ANOVA did not reach significance). Interestingly, inversely they rated the human partner being less predictable than the artificial systems (see figure 5; HP=3.30; anthropomorphic robot = 3.10; functional robot = 3.05; computer partner = 2.85).

## V. DISCUSSION & CONCLUSION

With the present study we provide a new methodology to analyze the basic mechanisms of mentalizing and a method to investigate the basis of acceptance and comfort factors caused by the design of robots' appearances and behaviours. On a neuronal level, we were able to demonstrate that participants tried to figure out the goals and intentions of all interactors, documented by highly significant activations of brain regions commonly associated with mentalizing. The cortical activity ($p < .05$; FWE corrected) in the medial frontal cortex as well as in the right temporo-parietal junction correlates with the increase of human-likeness of interaction partners [5, 37].

Behaviourally, the participants experienced more joy in the interaction and sympathy for the opponent the more the game partner exhibited anthropomorphic features. Furthermore the participants felt better in the face of winning and they attributed more intelligence to the opponent the more its appearance was human-like shaped. Therefore, we conclude that the participants' anthropomorphic attributions to the robots increase with the degree of human-likeness of the opponent.

Interestingly, subjects indicated that they felt being trapped by the opponents' strategy the more the ladder exhibited human-like features. On the other hand with decreasing degrees of human-likeness subjects felt superior in spying out their opponents´ strategies.

Finally, answers given in a free interview indicated that subjects not only judged the Lego-robot as less intelligent and inferior, but also witnessed him as a simple ”toy” with its ”dumb hands pushing the buttons”. In contrast, the computer was perceived as applying a ‘cold calculation’.

In summary, the experiment demonstrates that human beings implicitly attribute human-like qualities, such as mental states, to nonhuman agents. This finding was evident on a neurophysiological as well as behavioural level.

The only parameter that was modulated within the present experiment was the appearance of the opponents: thus the results indicate that perceived similarity influences the intense of the participants' attributions towards the robots. Thus, anthropomorphism plays an important role in the design of robots as it is strongly related to the perception of intelligence, fun, the attribution of intentions and thus the predictability of the robot. However, the exact interplay of anthropomorphism, perceived intelligence and attribution of intention needs to be analyzed further in more detail.

## VI. ACKNOWLEDGEMENTS

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