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Effects of form and motion on judgments of social robots' animacy, likability, trustworthiness and unpleasantness ☆

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ABSTRACT

One of robot designers' main goals is to make robots as sociable as possible. Aside from improving robots' actual social functions, a great deal of effort is devoted to making them appear lifelike. This is often achieved by endowing the robot with an anthropomorphic body. However, psychological research on the perception of animacy suggests another crucial factor that might also contribute to attributions of animacy: movement characteristics. In the current study, we investigated how the combination of bodily appearance and movement characteristics of a robot can alter people's attributions of animacy, likability, trustworthiness, and unpleasantness. Participants played games of Tic-Tac-Toe against a robot which (1) either possessed a human form or did not, and (2) either exhibited smooth, lifelike movement or did not. Naturalistic motion was judged to be more animate than mechanical motion, but only when the robot resembled a human form. Naturalistic motion improved likeability regardless of the robot's appearance. Finally, a robot with a human form was rated as more disturbing when it moved naturalistically. Robot designers should be aware that movement characteristics play an important role in promoting robots' apparent animacy.

1. Introduction

Robot applications are moving away from isolated factory settings and are becoming more integrated into peoples' daily lives. Robots can be found in environments like hospitals, museums, and schools. However, people are social creatures. As robots become more prevalent in typical human environments, it is increasingly important that they are able to interact socially. This has led robot designers to develop *social robots*, which interact and communicate with humans by following behavioral norms (Bartneck and Forlizzi, 2004). These robots are designed to achieve a human–robot interaction (HRI) similar to a human–human interaction. They succeed when people consider them as partners to live, interact, or communicate with. This is possible only when robots are seen not as a bunch of hardware, but rather as agents with whom we can establish social relations. Therefore, animacy—understood as the quality to be perceived as a living entity rather than an inert object (New Oxford American Dictionary, 2010), is one of the most important features for a social robot.

The first step in any social interaction is recognizing that your partner is alive. We automatically attend to objects that we have categorized as animate (New et al., 2007). Furthermore, animacy detection is a prerequisite to higher-level social functions such as mentalizing and communication (Thalia Wheatley and Alex Martín, 2009). A great deal of work in social robotics has therefore been devoted to creating the illusion of animacy. Making a robot look animate, however, has presented a major challenge to robot designers because judgments of animacy are influenced by many factors. A robot's apparent animacy is a function of its size, its appearance, its responsiveness to stimuli, the appropriateness of its responses and the diversity of its behavioral repertoire, as well as a myriad of other factors.

Robot designers have often used anthropomorphism as a means of increasing apparent animacy. For example, Bartneck et al. found that robots are deemed more animate when they generate rich and contextually appropriate facial expressions

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(Bartneck et al., 2009). Indeed, one of the most common ways to make a robot look animate is to endow it with a life-like face (Spexard et al., 2007). An extreme example is Isiguro's Geminoids[1] (Ishiguro, 2013).

Experimental psychologists also have long been interested in the visual features that induce percepts of animacy (Michotte, 1963). In psychology, multiple lines of research have converged on the importance of another visual animacy cue, which has received relatively little attention in the field of social robotics—movement characteristics. Objects that do not look alive when they sit still appear animate if they move in ways that are characteristic of living creatures (Heider and Simmel, 1944; Gao et al., 2009, 2010; Schultz and Bulthoff, 2013). In addition, research on "biological motion perception" has shown that a human form can be recovered from a sparse arrangement of dots if the dots' motion is consistent with the structure of an underlying human body (Johansson, 1973). Scrambled variants of these stimuli also look somewhat alive, suggesting that sensations of animacy can arise from analysis of pure motion signals, independent of form processing (Chang and Troje, 2007). Thus research in psychology makes an interesting prediction for applied research in robotics: perhaps the perceived animacy of a robot depends on its movement characteristics as much as or even more than its bodily appearance.

In addition, the combination of the bodily appearance and motion characteristics may result crucial for a robot interacting with people. People can attribute certain mental states and qualities to a robot based on its form but these could be altered due to its motion features, and vice versa.

The present experiment explored how different visual features influence judgments of robots' animacy. In particular, we were interested in whether a robot's movement, in addition to its bodily appearance, influences how animate it seems. We hypothesized that participants in HRIs attribute higher levels of animacy, agency and intentionality to robots that move naturalistically. We predicted that participants would attribute more mental states to a robot that moved naturalistically during a competitive game.

Bodily appearance and manner of movement, individually, have been identified as key features to animate lifeless objects. We explored how the manipulation of both features simultaneously can boost attributions robot animacy. To the best of our knowledge, this is the first study to evaluate how bodily appearance and manner of movement can be combined to alter the humans' perception of robots while interacting.

Participants played several games of Tic-Tac-Toe with a robot. The robot's bodily appearance was either (1) with only one arm visible to the participants (*low anthropomorphism*, Fig. 1a), or (2) with two arms, a torso, and a head (*high anthropomorphism*, Fig. 1b). While playing with the participants, the robot's arm moved either (1) smoothly, along rational trajectories, or (2) mechanistically, along trajectories which were relatively disjointed and indirect. We measured participants' impressions of the robot in four domains: animacy, likability, unpleasantness, and trustworthiness.

Evaluating a robot's animacy can be difficult if the robot seems completely inanimate. Because the effects of lifelike form and motion might be obscured by a floor effect in participants' animacy ratings, we included a manipulation to promote the robot's apparent animacy. Past research has shown that people display a greater level of social engagement and make more mental state attributions during HRIs in which the robot cheats (Short et al., 2010). Accordingly, in the present study, the robot cheated during one game of Tic-Tac-Toe.

2. Related works

Bodily appearance and animacy. Past research has examined how the bodily appearance of a robot (often referred to as its "embodiment") influences attributions of animacy and likeability. In one experiment, androids (robots that closely resemble human beings) were judged to be more animate and more likeable than robots with less naturalistic bodies (Ishiguro, 2008). In a follow-up experiment, participants played a bargaining game with four opponents: a computer agent, a robot with a slightly humanoid appearance, an android, or a human (Nishio et al., 2012). When participants considered only their opponent's appearance, there were no differences in their attributions of animacy and likeability. However, after having a short conversation with the opponent (the same in all cases), participants rated the android and the human similarly in terms of likeability and animacy, while the computer agent and humanoid robot were judged to be less likeable and less animate. In addition to these effects of bodily appearance on attributions of likeability and animacy, participants are likely to attribute human-like qualities to robots with anthropomorphic features (Hegel et al., 2008).

The effects of anthropomorphism on judgments of robots' likeability and animacy have been confirmed in a number of applied contexts. Robots with a human-like appearance provide a stronger sense of social presence and enable more enriching social HRIs than robots whose form is instead purely functional (Kwak, 2014). The bodily appearance of robots can also influence moral behavior. Kim et al. (2014) found that participants were more willing to donate to a nonprofit fundraising organization when interacting with an anthropomorphic robot than when interacting with a functional robot (Kim et al., 2014). In healthcare, researchers have used highly lifelike robots in therapy for autism spectrum disorder (Scassellati et al., 2012). These scientists posit that lifelike robots can faithfully mimic social behavior, and that they can be used in therapy to address the social symptoms associated with autism.

Movement characteristics and animacy. While robot designers have focused mainly on bodily appearance in creating illusions of animacy, researchers in experimental psychology have considered another factor which influences animacy attributions: movement characteristics. This was first demonstrated in a classic experiment by Heider and Simmel (1944). In this study, participants were asked to interpret an animation featuring three moving geometric shapes. Most participants described the animation by attributing goals and mental states to the shapes, indicating that attributions of animacy do not always depend on objects' having animate bodily appearances. Subsequent research has attempted to isolate and further study the motion cues that cause objects to appear animate.

Several groups have claimed that "self-propelledness" is an important factor contributing to the perception of animacy (Schultz and Bulthoff, 2013). Objects are judged to be alive when their motion cannot be explained by appeal to external forces. Tremoulet and Feldman (2000) argued that, under certain circumstances, the following two cues can give the impression of self-propelledness/animacy: (1) change in speed and (2) change in direction. Gaur and Scassellati (2006) agreed that these factors play a role, but added an energy metric based on simple models of objects' kinematic and potential energies. According to them, changes in speed, direction and energy are the three major features used to identify a moving object as animate or inanimate. In some cases, however, the perceived animacy of an object may arise

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[1] Geminoids are androids that closely resemble humans. http://www.geminoid.jp

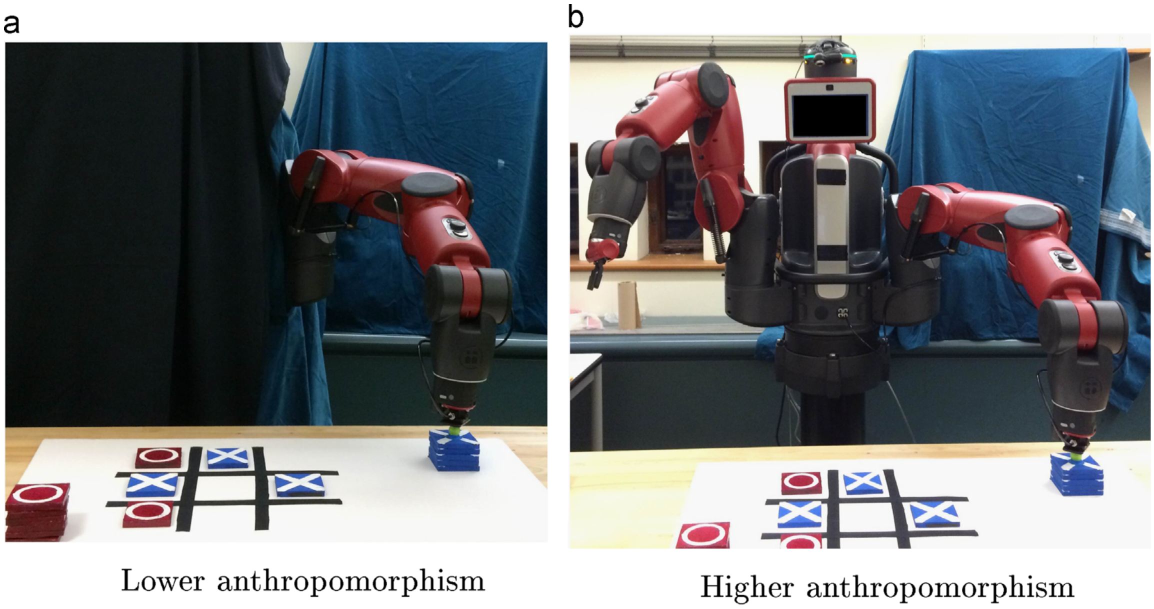

Fig. 1. Robot's bodily appearances during the experiments.

from the detection of movements which betray its status as an intentional agent (e.g. chasing). For example, Gao et al. (2010) reported that randomly moving shapes which keep their fronts oriented toward a target are perceived as animate by virtue of their apparent goal-directedness.

Another relevant line of psychological research is concerned with the mechanisms by which we perceive moving bodies. This literature is descended from Gunnar Johansson's initial report that observers easily perceive the movements of other people, even when these movements are depicted in a degraded stimulus made by affixing 12 point lights to the actor's joints (Johansson, 1973). Some of the more recent research on "biological motion perception" considers whether distinguishing between animate and inanimate point light displays depends on one's ability to discern a body structure among the dots (Lange and Lappe, 2006). Although biological motion perception may normally involve such form processing, there is evidence that local motion cues are sufficient to discriminate animate from inanimate displays (Chang and Troje, 2007).

Animators and visual artists have also become quite adept at using motion cues to induce the perception of animacy. However, their discoveries have not been translated into robotics for two reasons. First, robots are constrained by physical structures and mechanical design in a way that animations are not. Second, robots must automate the process of generating appropriately lifelike movement, whereas animators use their creative talent to determine the appropriate motion characteristics.

Although roboticists have yet to directly apply psychologists' findings to the task of making robots look alive, some have independently begun to take an interest in motion cues to animacy. For example, Van Breemen (2004) considered how several principles of cartoon animation (Johnson and Johnson, 1981) can be applied to making robots look alive. For example, non-rigid motion looks more animate than rigid motion, and actions are easier to identify when they start and begin with easily recognizable poses. He suggested that pre-programmed movements based on these principles might be combined with reactive movements (movements responding to stimuli in the robot's environment) to create more verisimilitudinous illusions of animacy. Since the publication of Van Breeman's paper, several robotics researchers have employed these principles (e.g. Ribeiro and Paiva, 2012; Takayama et al., 2011; Saldien et al., 2014). A tenet of particular relevance to the current project is the principle of "arcs", which posits that living organisms generally move their limbs in arc-shaped trajectories, rather than along straight lines. The present work tested directly whether arc-shaped limb movements can be used to enhance impressions of robots' animacy.

While the above research examined how movement characteristics can be used to evoke the perception of animacy per se, social robotics researchers more often manipulate movement in order to create the illusion that a robot is in a particular mental state and measure subjects' responses to this exhibited mental state. In one representative experiment, robots which moved in ways that suggested caution and interest were more effective at calming victims of disasters (Bethel and Murphy, 2010). Harris and Sharlin (2011) studied people's emotional responses to a robot when it moved in different ways. They found that the robot's motion influenced observers' emotional reactions and their engagement with the robot. This experiment used an unfamiliar robotic interface (a stem-like robot), which exhibited two patterns of movement: mechanical (a set of simple, repetitive motions varying in frequency and direction) and organic (pre-recorded sequences designed to represent mental states such as curiosity and restlessness). Regardless of the condition, relationships between certain types of motion and emotional attributions were found (e.g. fast movements towards the participant were perceived as approach-aggression). Participants in the mechanical condition evinced boredom more often. In the organic condition, participants considered themselves to be interacting with the robot; in the mechanical condition, participants felt like pure observers.

Saerbeck and Bartneck (2010) assessed how movement characteristics influenced the perceived affect of two different robots (a cat-like robotic talking head, and a disc-shaped Roomba vacuum cleaner). The authors manipulated the acceleration and the curvature of the robots' movements and found a strong relationship between these parameters and perceived affect. In particular, perceived arousal was negatively associated with acceleration. Participants' responses were related to these motion patterns across different robot embodiments, suggesting that the affective state conveyed by the robots' motion was analyzed independently from their form.

Although observers typically judge robots with naturalistic bodies to be more animate, these judgments are radically altered if the robot moves mechanistically. Saygin et al. (2012) studied the role of human-like appearance and biological movement in humans' perception of robots. They performed functional magnetic resonance imaging as participants watched videos of humans and robots carrying out actions. The experiment had three conditions: human (biological appearance and movement), robot (mechanical appearance and movement), and android (biological appearance and mechanical movement). There was a distinct neural response in the android condition, which may be related to the fact that this condition featured a mismatch between the agent's bodily appearance and its movements. The authors suggest that the neural response in the android condition reflects the prediction error associated with seeing an agent that appears human, but does not move naturalistically. They propose that this response is a neural correlate of the uncanny valley *phenomenon*[2] (Mori, 1970).

Although bodily appearance and manner of movement are both known to influence judgments of robots' animacy, their effects on animacy attributions during direct HRI have never been investigated within the same study. We ran an experiment in which participants played a game against a robot, and we systematically manipulated the robot's appearance and manner of movement in order to determine how these factors affect attributions of animacy, likability, trustworthiness and disturbingness.

We were concerned that our robot would be judged as completely inanimate if it played the game without showing further signs of intentionality. Past work in our lab indicates that cheating behavior is a powerful cue to animacy. A robot that cheats in an interactive game is judged to be more lifelike, as this behavior signals cleverness and a desire to win (Short et al., 2010; Litoiu et al., 2015). In the experiments run by Short et al., authors observed that a cheating behavior made a substantial difference towards the perception of animacy. However, in this experiment, the robot made additional movements while cheating. In a later experiment, Litiou et al. confirmed that the cheating behavior itself caused the attributions, but not the additional movements. Considering the previous results about cheating behavior, we therefore programmed our robot to cheat once per session as a methodological manipulation in order to avoid a possible floor effect in subjects' animacy ratings.

Using the Short et al.'s questionnaire, we evaluated the impact of these two features on participants' attributions of animacy, likeability, trustworthiness, and unpleasantness during HRI.

3. Experiments

In this experiment, participants played Tic-Tac-Toe with a robot. Participants stood at a table, across from the robot Baxter. Each participant played 10 rounds of Tic-Tac-Toe against Baxter. They were given a piece of paper and instructed to record the results (*I won*/*I lost*/*We tied*) of each round. During the experiment, two cameras recorded the interaction. After the experiment, participants completed a computer-based questionnaire in which they answered questions about their session. Each experimental session took around 30 min in total.

Fig. 2. Baxter, the robotic platform used for the experiments.

3.1. Baxter

Baxter is an industrial robot created by Rethink Robotics (Fig. 2). This robot has been designed to perform a wide variety of repetitive tasks around people.

The robot was anchored to a stand located across the table from the participant, and the table obstructed their view of the lower-body. The robot was equipped with two articulated industrial robot arms with grippers as end effectors. Under this configuration, the robot was 1′77 m high and 138 kg.

The bodily appearance of the robot was manipulated using a curtain. In the one-arm (low anthropomorphism) condition, the curtain occluded most of Baxter's body, except Baxter's left arm. In the full-body condition, Baxter was fully visible (with two arms, a torso, and a head).

The robot's movements were autonomously determined and controlled by the algorithms running on Baxter. Thus, the movements were identical between subjects in the same conditions.

The beginning of the game and the change of turns were determined by experimenters, Wizard-of-Oz-style. Under this style of control, a hidden human operator (the experimenter) remotely supervised the robot. The intervention of the operator was twofold: (i) it sent the command to start each game once the board is clear and the tokens are in the initial stacks; and (ii) signal the end of the participant's turn and hence the beginning of Baxter's turn. The operator was hidden behind a curtain to ensure that the participant was not aware of this situation.

3.2. The Tic-Tac-Toe scenario

Tic-Tac-Toe is a two-player board game where players take turns placing colored tokens in a 3 × 3 grid. The first player to

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[2] As an agent's appearance is made more human-like, people's disposition toward it becomes more positive, until a point at which increasing human-likeness leads to the agent being considered strange, unfamiliar and disconcerting.

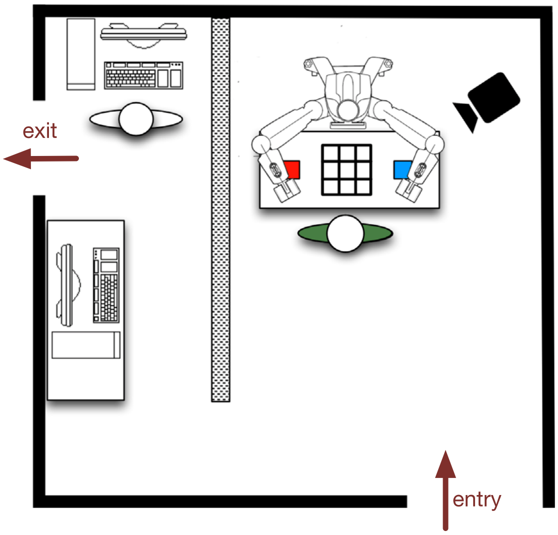

Fig. 3. Sketch of the scenario.

place three tokens of the same color in a row (vertical, horizontal, or diagonal) wins the game.

The task area (Fig. 3) contained of a high table. The robot was located on one side of the table, and the participant stood on the opposite side of the table facing the robot. At the beginning of the experiment, a game board and stacked colored tokens were placed on the table. The game was monitored via an overhead camera.

Before entering the task area, the participant was informed about the interactive game, the estimated duration, and the compensation ($5 per participant). The experimenter escorted the participant to the task area. They entered the task area from the bottom entry in Fig. 3, so that they did not see the robot operator hidden behind a curtain on the left. The robot and the details of the game were then introduced. The participant was told about the position of the cameras. After that, the experimenter left the task area, joining the robot operator behind the curtain. During the experiment, participants were not aware of the robot operator.

Once the robot and the participant were alone in the task area, the robot welcomed the participant and gave some brief instructions. Then, the robot said "*I start the game*" and the game began. The robot and the participant alternated turns placing tiles on the board; after each turn, the robot announced "*it's my turn*" or "*it's your turn*" as appropriate. Each participant played at least ten full games of Tic-Tac-Toe.

In every condition, except the control condition, the robot cheated to win on the 5th game by placing one of its tiles on top of one of the participant's tiles in order to get three tiles of its own in a row (see strategy outlined below). Sometimes the robot won the 5th game fairly (i.e., without cheating), in which case it attempted to cheat on the following game. Once the robot unfairly won a game, it completed five more *fair* games.

As mentioned previously, cheating was included to elicit intentionality in the robot, which keeps the robot from appearing too inanimate. This avoids a floor effect in which the robot's animacy is rated at the minimum across all experimental conditions. Following previous work on robot cheating in games (Short et al., 2010), we kept a low frequency of cheating rounds to normal game play rounds.

The strategy followed by the robot on each turn consisted of the following steps:

(1) If there is an empty cell that the robot can use to win, then place a tile in it.
(2) Else, if this is a cheating round and there is an occupied cell that the robot can use to get three in a row, then move a tile to that cell.
(3) Else, if there is an empty cell that the opponent can use to win, then make a defensive move by placing a tile in it.
(4) Else, randomly choose an empty cell to place a tile.

At the end of each game, the robot said "*I win*", "*You win this time*", or "*That's a tie*!" based on the result and asked the participant to move all tiles back to the initial stacks. After the final round, the robot indicated that the game was over, thanked the participant, and returned to its initial position.

The experimenter then returned and asked the participant to complete a brief questionnaire.

3.3. *The questionnaire*

The questionnaire used in this experiment is based on the Interactive Experiences Questionnaire (Lombard et al., 2000). Lombard et al. (2000) developed it as a standardized survey for testing presence, specifically for feelings of presence with film. Later, Kidd and Breazeal (2004) used this questionnaire as a test of the perceived social presence of a set of characters in an interaction: a human, a robot and a cartoon. Later on, many researchers have used it in robotics (Litoiu et al., 2015; Hayes et al., 2014; Short et al., 2010; Bainbridge et al., 2008).

In this work, the questionnaire was modified from Short et al. (2010), and it consisted in 20 seven-level Likert scale questions assessing participants' impressions of the robot and of the interaction. Finally, participants rated the applicability of 24 adjectives to Baxter, using 7-level Likert scales (from "Describes poorly" to "Describes well").

3.4. *Conditions*

There were 5 between-subject conditions in our experiment. The conditions were defined using the following three parameters:

Cheating vs. Fair. Evaluating a robot's animacy can be difficult if the robot seems completely inanimate. Because the effects of lifelike form and motion might be obscured by a floor effect in participants' animacy ratings, we included a manipulation to promote the robot's apparent animacy. Past research has shown that people display a greater level of social engagement and make more mental state attributions during HRIs in which the robot cheats (Short et al., 2010). Accordingly, in the present study, the robot cheated during one game of Tic-Tac-Toe. The robot played fairly for all games in the control condition, and it cheated in one game in the rest of the conditions.

Bodily appearance: full-body vs. one-arm. Baxter was presented in two different configurations. In the one-arm configuration (Fig. 4a) only Baxter's left arm was visible and the rest of its body was hidden under a curtain. In the full-body configuration, Baxter was fully visible (Fig. 4b). Anthropomorphism refers to an innate human tendency to ascribe human form or attributes to a non-human entity (Hutson, 2013). Here we focus on the form and, considering that the full-body configuration is closer to a human shape than the one-arm configuration, we refer to them as high and low anthropomorphism respectively.

Movement type: mechanistic vs. smooth. Baxter's arm moved in one of two ways. In the mechanistic condition the arm did not follow the most efficient (diagonal) trajectory to its goal. Instead, it executed a series of short, perpendicular movements. In the smooth condition, the arm followed a relatively efficient trajectory toward its goal-a shallow arc, similar to the movement that would

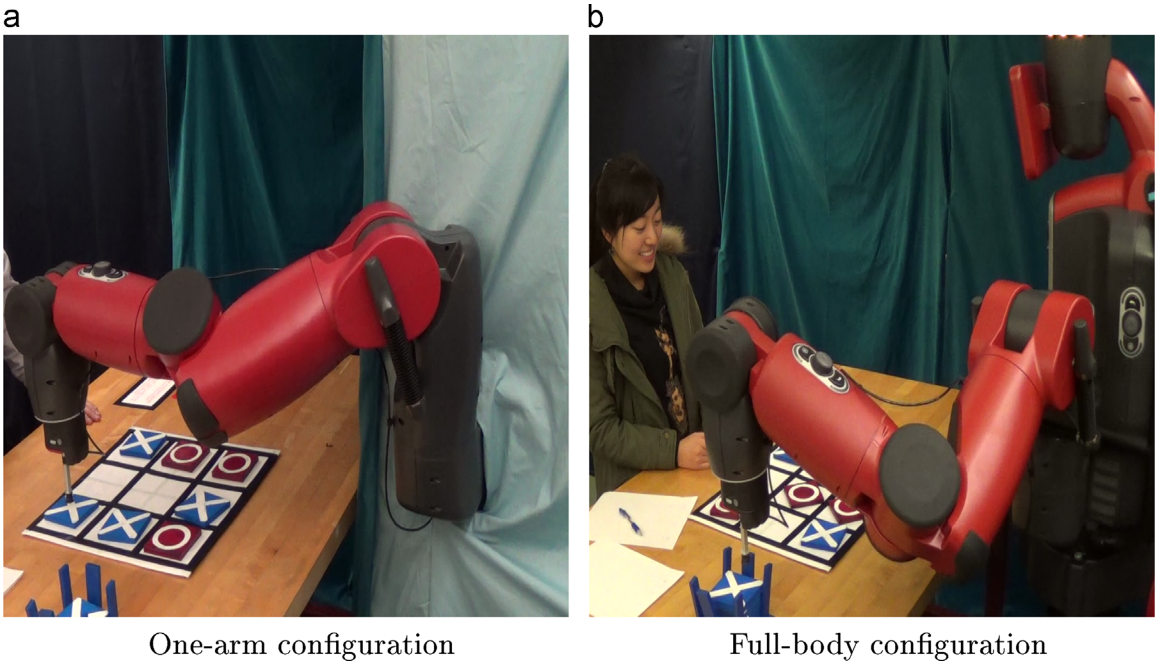

Fig. 4. Manipulation of Baxter's bodily appearance during the experiments.

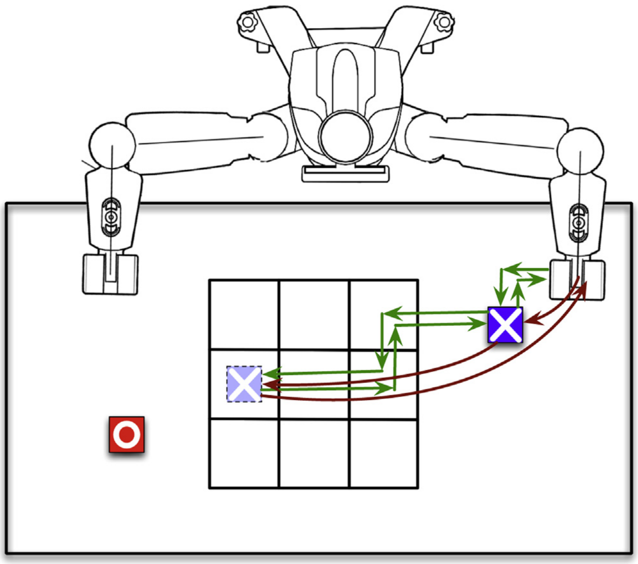

Fig. 5. Manipulation of Baxter's movements: green lines depict a mechanistic trajectory and red arrows depict a smooth trajectory. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

be performed by a human arm. An example of these two types of motion is shown in Fig. 5.

Trajectories were defined as a set of points (i.e. position and orientation) that have to be consecutively reached by Baxter's end effector. The velocity and acceleration during each segment of the trajectory (the motion between two consecutive points) were scaled to keep a smooth acceleration and deceleration. Multiple joints were involved in the motion of each segment and all of them started and ended at the same time.

The five conditions are summarized in Table 1.[3]

Table 1
Our 2 (one-arm vs. full-body) × 2 (smooth vs. mechanistic movement) design yields four primary experimental conditions. In order to check whether the cheating behavior (present in all aforementioned conditions) constituted an effective manipulation, we included an additional "control" condition in which the robot had one arm, moved mechanistically and did not cheat.

	Bodily appearance	
Movement	One-arm-mechanistic	Full-body-mechanistic
	Control	
	One-arm-smooth	Full-body-smooth

3.5. Participants

Fifty-six participants were recruited through fliers, social media, and mailing lists. Data from 13 of them were discarded due to technical issues. Another participant's data was excluded from analysis since s/he failed to answer most of the questions in the questionnaire. Data from 42 participants (64% female, age range from 18 to 58) were used in the analysis.

The number of participants in each condition is listed in Table 2. Each participant was randomly assigned to one of the five conditions.

4. Statistical analysis

To measure different aspects of participants' impressions of Baxter, we first categorized the items in the questionnaire into four subscales using a typical psychological scale construction procedure. We found four subscales: likability, animacy, unpleasantness, and trustworthiness. These names of the subscales were decided based on the questions that form each one (Appendix A). During this preprocessing stage, data from all conditions were collapsed together. Then, based on the identified subscales, we

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[3] In order to provide a clear understanding of the different conditions in relation with the type of movement and the bodily appearance, several videos are available: (i) mechanistic full-body (https://youtu.be/P3sZRHGZh-4), (ii) smooth full-body (https://youtu.be/6LXd9rvBBjk), (iii) mechanistic one-arm (https://youtu.be/kkREIZ9oqyk), and (iv) smooth one-arm (https://youtu.be/3QIxK1Vo53Y).

Table 2
Size of the condition groups.

Condition	Sample size
Control	8
One-arm-mechanistic	7
One-arm-smooth	9
Full-body-mechanistic	9
Full-body-smooth	9

analyzed and compared responses on these subscales to assess differences in participants' reactions to Baxter across conditions.

4.1. Data preparation

Three items ("*Was it easy to play the game*?", "*frustrating*" and "*annoying*" in the section "*For each word give your overall impressions of Baxter by selecting one number for each characteristic*") were reverse-coded since they correlated negatively with most of the other items.

To make sure that the questions were sufficiently sensitive, we calculated the standard deviations for each item and confirmed that all of them were larger than 1. Bivariate correlations between all items were conducted (with pairwise deletion as missing data treatment), and none of the items showed coefficients larger than 0.9, indicating that the questions were not redundant.

To identify proper categorization, an exploratory factor analysis with rotation was performed with listwise deletion as missing data treatment. The first four components extracted were able to explain over 50% of variance (before rotation). Based on the loadings of these components, we categorized all of the questions into four subscales, which we labeled *likability*, *animacy*, *unpleasantness*, and *trustworthiness*. In this step, several items were deleted and not included in the four subscales.

To confirm the categorization of each item, we looked for ambiguous items by running bivariate correlations between all items. We found that the item "*For each word give your overall impressions of Baxter by selecting one number for each characteristic: convincing*" correlated with items in both the likability and unpleasantness subscales, and therefore excluded it from further analysis.

Finally, to confirm the internal consistency of the subscales, Cronbach's alphas were calculated for each subscale. We compared each subscale's overall Cronbach's alpha to Cronbach's alpha after one of the items in the subscale was deleted. In this manner, we identified four items that decreased the internal consistency of their subscales ("*I would like to talk with Baxter*", and "*responsive*", "*aggressive*", and "*credible*" in the section of "*For each word give your overall impressions of Baxter by selecting one number for each characteristic*"). These items were excluded from further analysis.

We ended up with 25 items (12 questions and 13 adjectives) classified in the four subscales. Appendix A contains the final set of scales used in subsequent analyses.

4.2. Data analysis

The average ratings from the four subscales were treated as four dependent variables. Unequal variances were found between different conditions in the trustworthiness subscale, and the items in this subscale were therefore log-transformed before any comparisons were made.

As a manipulation check, we compared trustworthiness and animacy ratings in the control condition (one-arm, mechanistic movement, and no cheating) to those in the one-arm, mechanistic condition (with cheating) with a within-subject t-test.

We evaluated the influence of movement and bodily appearance characteristics on participants' impressions of Baxter using four 2 (bodily appearance) × 2 (movement type) between-subject analyses of variance (ANOVAs), for likability, animacy, unpleasantness, and trustworthiness.

The hypotheses we evaluated with the four two-way ANOVAs are:

- H_1: The attributions of likability, animacy, unpleasantness, and trustworthiness will differ between one-arm and full-body configurations.
- H_2: The attributions of likability, animacy, unpleasantness, and trustworthiness will vary depending on the type of motion (smooth or mechanistic).
- H_3: There is an interaction between the form and motion of Baxter

The control condition was excluded from these ANOVAs because it would introduce an additional independent variable, *cheating*, and we focused on the effects of bodily appearance and movement type. Cheating was used across all conditions used in the ANOVA as a method to avoid a floor effect (see Section 3.4).

4.3. Results

Participants trusted Baxter less in the one-arm-mechanistic condition (with cheating; $M=2.32$, $SD=1.46$, before log-transformation) than in the control condition (one-arm-mechanistic movement, without cheating; $M=4.50$, $SD=1.68$, before log-transformation), $t(13)=2.59, p=0.023$, (this t-test was run after log transformation, however the results were the same when no log-transformation was performed). This suggests that participants noticed the Baxter's rule-breaking behavior and considered it to be untrustworthy behavior. To our surprise, there was no effect of cheating on animacy ratings.

However, animacy ratings were numerically higher with cheating ($M=3.40, SD=0.92$) than without ($M=2.63, SD=0.99$), $t(13)=1.57, p=0.142$.

The results of the ANOVAs for each subscale are summarized in Table 3. There was a statistically significant difference between groups in the four domains: likability ($F(4,37)=3.886, p=0.010$), animacy ($F(4,37)=3.003, p=0.030$), unpleasantness ($F(4,37)=3.894, p=0.010$), and trustworthiness ($F(4,37)=3.406, p=0.018$).

Table 3
Results of the ANOVA on the different domains: likability, animacy, unpleasantness, and trustworthiness.

Domain	Sum of squares	df	Mean square	*F*	Sig.
Likability					
Betweengroups	16.082	4	4.020	3.886	0.010
Within groups	38.282	37	1.035		
Total	54.364	41			
Animacy					
Between groups	12.790	4	3.197	3.003	0.030
Within groups	39.397	37	1.065		
Total	52.187	41			
Unpleasantness					
Between groups	9.799	4	2.450	3.894	0.010
Within groups	23.280	37	0.629		
Total	33.079	41			
Trustworthiness					
Between groups	29.052	4	7.263	3.408	0.018
Within groups	78.853	37	2.131		
Total	107.905	41			

The descriptive statistics in the four domains for all conditions are shown in Appendix B.

We did not find main effects of bodily appearance. Hence, we cannot accept H_1. This means that we cannot state that differences in Baxter's bodily configurations altered people's attributions of animacy, likability, trustworthiness, and unpleasantness to the robot.

There were main effects or marginal main effects of movement type on likability, animacy and unpleasantness (Fig. 6), for likability, $F(1, 30)=12.09$, $p=0.002$; for animacy, $F(1, 30)=3.98$, $p=0.055$; for unpleasantness, $F(1, 30)=3.72$, $p=0.063$. Regardless of bodily appearance, smooth arm movements increased ratings of likability ($Ms=4.88$, $SDs=0.96$; $Mm=3.73$, $SDm=0.90$), animacy ($Ms=3.55$, $SDs=1.11$; $Mm=2.76$, $SDm=1.07$), and unpleasantness ($Ms=2.20$, $SDs=1.04$; $Mm=1.61$, $SDm=0.72$). Therefore, considering the main effects found due to the movement type, H_2 was confirmed. That is, attributions of the robot's likability, animacy, and unpleasantness were significantly higher when arm movements were smooth than when arm movements were mechanistic.

For likability, no interaction effect was found. The effect of movement type was present independently of the robot appearance (Fig. 7).

In the case of animacy, a marginal interaction was found between movement type and bodily appearance, $F(1, 30)=4.11$, $p=0.052$ (Fig. 8). Here the effect of movement type was driven by the full-body condition, $t(16)=3.29$, $p=0.005$; participants who interacted with a full bodied robot exhibiting mechanistic movement gave lower animacy ratings ($M=2.27$, $SD=0.94$) than participants who saw a full-bodied robot which moved smoothly ($M=3.71$, $SD=0.92$). In the one-arm condition, there was no effect of movement type on animacy ratings, $t(14)=0.02$, $p=0.985$. Interestingly, participants provided lower animacy ratings in the mechanistic-full-body condition ($M=2.27$, $SD=0.94$) than in the mechanistic-one-arm condition ($M=3.40$, $SD=0.92$).

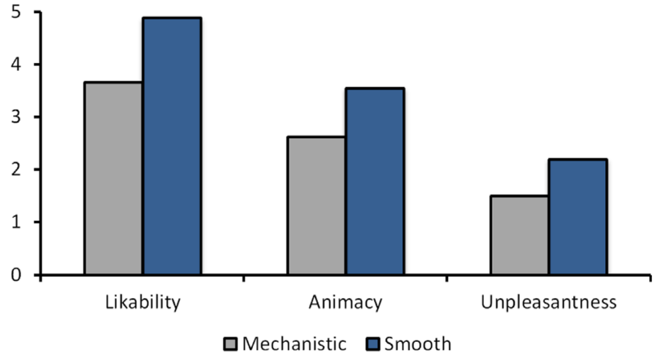

Fig. 6. Effect of movement-type on ratings of Baxter's likeability, animacy and unpleasantness. Regardless of its bodily appearance, when the robot exhibits smooth movement, subjects liked it more, and perceived it more animated and more unpleasantness.

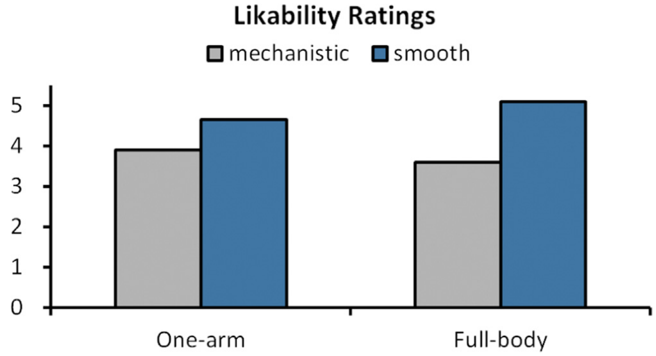

Fig. 7. Effects of bodily appearance and movement type on likability ratings. The robot performing smooth movements was rated as more likable in all conditions.

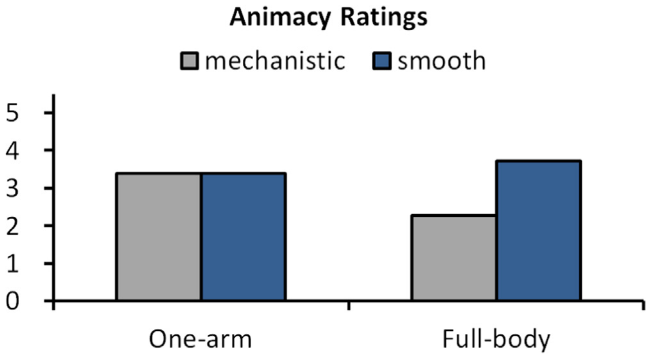

Fig. 8. Effects of bodily appearance and movement type on animacy ratings. The robot was rated as particularly inanimate in the full-body-mechanistic condition. There were no differences in animacy ratings between any of the other conditions.

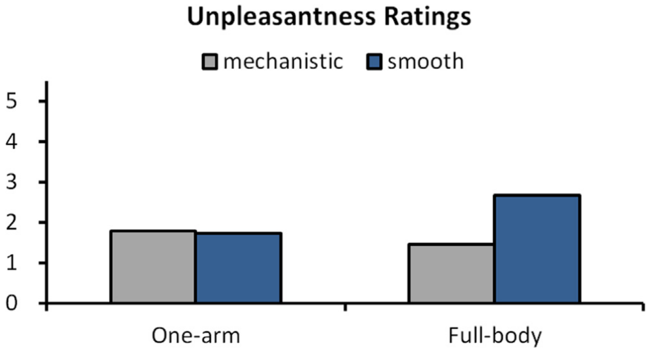

Fig. 9. Effects of bodily appearance and movement type on unpleasantness ratings. The robot was rated as particularly unpleasant in the full-body-smooth condition. There were no differences in unpleasantness ratings between any of the other conditions.

In the case of unpleasantness, the effect of movement type was again driven almost entirely by the full-body condition, evinced by an interaction effect, $F(1, 30)=4.65$, $p=0.039$ (Fig. 9). In the full-body condition, unpleasantness ratings were higher when the robot exhibited smooth movement ($M=2.67$, $SD=1.12$) than when it exhibited mechanistic movement ($M=1.47$, $SD=0.48$) condition, $t(16)=2.95$, $p=0.009$. No movement type effect was found in the one-arm condition, $t(14)=0.16$, $p=0.877$. No effect of movement type or bodily appearance was found on trustworthiness.

Taking into account the interaction effects just mentioned, H_3 was accepted. Thus, there was interaction between the form and motion of Baxter.

5. Discussion

In this experiment, a social robot's bodily appearance and movement characteristics influenced participants' impressions of its likeability, animacy, trustworthiness and unpleasantness. We found that (a) a robot that moved naturalistically was more likable regardless of whether its full body was visible, (b) naturalistic movement boosted a robot's perceived animacy only when its full body was visible, and (c) people found the most animate-looking robot (a full-bodied robot which moved smoothly) most disturbing.

5.1. Effects of bodily appearance and movement type on likeability and animacy

When the robot moved smoothly, it was judged to be more likeable and more animate (although, in the latter case, the effect of movement was restricted to the full-body condition). These findings accord with the principle of “arcs” (Van Breemen, 2004) discussed in Section 2. According to this postulate, cartoon characters look more alive when they move their limbs along arc-shaped trajectories. Similarly, our robot was judged to be more animate when it moved its arm along smooth (arc-shaped) trajectories. It is worth considering, however, that subjects were not responding to the arc shape per se, but rather to the fact that trajectories in the smooth condition were more direct (i.e. more rational).

Baxter was rated as equally animate in the one-armed-mechanistic, one-armed-smooth and full-body-smooth conditions, while it was judged to be *particularly inanimate* in the full-body-mechanistic condition. We believe that participants judged the robot to be animate based on its ability to communicate and play the game rationally. However, participants in the full-body-mechanistic condition may have been surprised by the mismatch between the robot's relatively human-like body and its mechanistic movement, and this may have translated into lower animacy ratings. Clearly both movement and bodily appearance are important to creating the illusion of a “living machine”.

It is important to mention that in this work animacy and social interaction are closely related. As mentioned in the Introduction, before any social interaction happens, we need to identify that our partner is alive (New et al., 2007). Then, if the robot is perceived as an interactive partner, we can say that it is perceived as a living entity too. Therefore, some questions in the animacy subscale are related to the type and quality of the Baxter–subject interaction.

Even considering that both terms are different, we believe that social interaction and animacy are closely related: a person just interacts socially with something that is alive. Consequently some of the questions of the animacy subscale were related to “interaction”. Besides, the term animacy was decided by the authors trying to summarize all the questions included in this subscale.

It is worth noting that our study had many other features that likely influenced animacy attributions. Subjects were aware that they were completing a study in a social robotics lab. Baxter played the game rationally, and it cheated to win. In addition, the robot's utterances may have increased its apparent animacy. These factors, which were not present in all the other studies, made our study significantly different from others in the literature.

5.2. Effect of cheating

The present findings support previous claims that a cheating robot is considered less trustworthy than a robot that does not cheat in an interactive game (Short et al., 2010). An arm that moved mechanistically and cheated received lower trustworthiness ratings than an arm that moved mechanistically and played fairly. However, in contrast to Short et al.'s finding, the effect of cheating on animacy ratings did not reach statistical significance. Given that the numerical trend was in the same direction as observed in Short et al, with a cheating robot appearing slightly more animate, it is possible that we simply did not have enough power to find this effect with our sample size.

Participants who played against the cheating robot may have interpreted its behavior in terms of (i) an underlying intention to win (untrustworthy motives), or (ii) a software malfunction (untrustworthy software). That animacy ratings did not differ significantly between cheating and non-cheating conditions indicates that participants may have given the latter interpretation. It is possible that cheating behavior evokes mental state attributions only when the actor already possesses some animacy attributes (e.g. a lifelike bodily appearance or lifelike motion). Further experiments are required to test this possibility.

5.3. Effects of bodily appearance and movement type on unpleasantness

The robot's manner of movement interacted with its bodily appearance in influencing ratings of its unpleasantness. Although movement-type did not influence unpleasantness ratings in the one-arm condition, smooth movement caused the robot to look more disturbing when its full body was visible. It is possible that participants in this condition considered the robot to be a physical threat; smooth movements were completed more quickly than mechanistic movements. In line with this idea, other possible explanation is related to the size of the robot. Baxter is considerably larger than any of our participants and it has a shoulder width and height that would make it potentially imposing. In the one-arm condition, most of the robots are hidden and the *threatening* effect of Baxter's physical features consequently vanishes.

A more interesting possibility is that the relative discomfort of participants in this condition was due to the confluence of perceptual animacy cues exhibited by the robot. A mechanistically moving robot will look disturbing when it closely resembles a human form (Mori, 1970; Saygin et al., 2012). We propose that smooth, naturalistic movement may also look “uncanny” when executed by a robotic agent-a hitherto undiscovered variant of the uncanny valley *phenomenon* (Matsui et al., 2005). However, our data indicate that this sensation arises only when the actor possesses a vaguely humanoid form.

This result initially appears at odds with our finding that participants rated the robot as more likeable when it moved smoothly. We think participants preferred naturalistic motion because it was more stimulating than mechanistic movement. Thus, although participants may have found a full-bodied robot executing naturalistic motion uncanny, this was still more likeable than a one-armed or full-bodied robot exhibiting relatively boring, mechanistic motion.

5.4. Limitations

This experiment has some limitations that constrain the results obtained.

The perception of a robot in HRI is constrained by the background of subject. The participants in this experiment were from the environment of the Yale University. Usually these subjects have particular social and cultural circumstances that could limit the results to other groups of people. A larger sample with more diversity would have benefited our results.

One of the main limitations was the sample size of the five conditions. Though bigger size of the groups for each condition was desirable, we have obtained significant results and interesting conclusions.

In this work, we considered two types of robot appearance (one-arm and full-body) implemented with the robot Baxter. The application of the results to a completely different robot is not clear and further experiments are needed.

In the case of the movement type, we have explored the type of trajectories (smooth vs. mechanistic). Many other factors, such as the speed or acceleration, may affect the results. Again, new experiments are required to evaluate different motion features.

6. Conclusions

We ran an experiment in which participants interacted with a robot that varied in its bodily appearance (high anthropomorphism vs. low anthropomorphism) and manner of movement (smooth vs. mechanistic). We measured how these factors influenced participants' attributions of animacy, likeability, trustworthiness, and unpleasantness during HRI.

Our main finding was that movement characteristics influenced the robot's apparent animacy, likability, and unpleasantness. Baxter was considered to be more likeable when it exhibited naturalistic, compared to mechanistic motion. Interestingly, the robot's movement characteristics interacted with its bodily appearance in influencing participants' attributions of animacy, as well as their judgments of the robot's unpleasantness. Mechanistic movement was considered particularly inanimate when performed by a full-bodied robot, and a full-bodied robot executing naturalistic movements was considered to be particularly unpleasant. These findings suggest that movement matters for HRI.

Given that naturalistic motion influences both robots' perceived animacy and their unpleasantness, we would like to propose a new direction for research in social robotics. In some applications, such as security and law enforcement, animacy cues might be a helpful means of making individuals feel uncomfortable, intimidated or wary. For such applications, we would recommend using a robot with a vaguely human form, executing naturalistic movement (a la Robocop). In other situations, animacy cues might be a means of making robots more likeable. Robotic arms performing naturalistic movements are a simple and non-threatening means of achieving this effect. Regardless of their purposes, robot designers should be aware that movement characteristics play a key role in determining people's responses during HRI.

Acknowledgments

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Appendix A. Items used in the analysis

All items (and the subscales they belong to) used in the analysis are shown in Table A1.

Appendix B. Descriptive statistics

Table B1 presents the descriptive statistics for all conditions in the four subscales: likability, animacy, unpleasantness, and trustworthiness.

Table A1
Items used in the analysis.

Subscale	Item
Likability	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Likable
	Would you like to play Tic-Tac-Toe with Baxter again?
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Satisfying
	How much fun was playing with Baxter?
	I like Baxter.
	I would like to see Baxter again.
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Enjoyable
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Entertaining
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Good
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Compelling
Animacy	How often did you feel that Baxter was really alive and interacting with you?
	To what extent did you feel you could interact with Baxter?
	How natural was the interaction with Baxter?
	Baxter is a lot like me.
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Lifelike
	How much control over the interaction did you feel you had?
Unpleasantness	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Menacing
	How often did you feel awkward in front of the robot?
	Did you feel fear while playing with Baxter?
	Did you perceive Baxter as threatening?
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Dangerous
Trustworthiness	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Honest
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Trustworthy
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Reliable
	For each word give your overall impressions of Baxter by selecting one number for each characteristic: Fair

Table B1
Descriptive statistics in the five conditions for likability, animacy, unpleasantness, and trustworthiness.

Condition	*N*	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Likability								
Control	8	3.5917	1.28604	0.45468	2.5165	4.6668	1.80	5.30
1-arm M	7	3.9000	0.64550	0.24596	3.3030	4.4970	2.90	4.60
1-arm S	9	4.6605	1.09156	0.36366	3.8214	5.4996	3.40	6.30
Full M	9	3.5951	1.06241	0.36060	2.7630	4.4271	1.60	5.10
Full S	9	5.1000	0.81394	0.27131	4.4743	5.7257	3.80	6.40
Total	42	4.1960	1.15150	0.17768	3.8372	4.5549	1.60	6.40
Animacy								
Control	8	2.6250	0.93702	0.34896	1.7933	3.4502	1.00	3.67
1-arm M	7	3.4000	0.91672	0.34649	2.5522	4.2478	1.80	4.33
1-arm S	9	3.3889	1.30437	0.43479	2.3363	4.3915	2.00	5.50
Full M	9	2.2667	0.94413	0.31471	1.5409	2.9924	1.00	4.33
Full S	9	3.7130	0.92149	0.30716	3.0046	4.4213	2.17	5.33
Total	42	3.0742	1.12821	0.17409	2.7226	3.4258	1.00	5.50
Unpleasantness								
Control	8	1.3000	0.46599	0.16475	0.9104	1.6896	1.00	2.40
1-arm M	7	1.8000	0.95917	0.36253	0.9129	2.6371	1.00	3.60
1-arm S	9	1.7333	0.73485	0.24495	1.1665	2.2962	1.00	3.20
Full M	9	1.4607	0.47958	0.15968	1.0960	1.8353	1.00	2.20
Full S	9	2.6667	1.12250	0.37417	1.6036	3.5295	1.40	4.60
Total	42	1.8048	0.89822	0.13660	1.5249	2.0347	1.00	4.60
Trustworthiness (log-transformed)								
Control	8	1.4226	0.47180	0.16681	1.0282	1.8171	0.41	1.95
1-arm M	7	0.6544	0.67394	0.25473	0.0311	1.2777	0.00	1.45
1-arm S	9	0.9975	0.65993	0.21998	0.4902	1.5048	0.00	1.79
Full M	9	0.7165	0.56751	0.16917	0.2803	1.1527	0.00	1.50
Full S	9	0.8225	0.33542	0.11181	0.5647	1.0803	0.22	1.32
Total	42	0.9236	0.53997	0.09103	0.7397	1.1074	0.00	1.95

References

Bainbridge, W.A., Hart, J., Kim, E.S., Brian, Scassellati, 2008. The effect of presence on human–robot interaction, Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication, Technische Universität München, Munich, Germany, August 1–3, 2008. IEEE, pp. 701–706.

Bartneck, C., Forlizzi, J., 2004. A Design-Centred Framework for Social Human–Robot Interaction, pp. 591–594. http://dx.doi.org/10.1109/ROMAN.2004.1374827.

Bartneck, C., Kanda, T., Mubin, O., Al Mahmud, A., 2009. Does the design of a robot influence its animacy and perceived intelligence? Int. J. Soc. Robot. 1, 195–204. http://dx.doi.org/10.1007/s12369-009-0013-7, URL 〈http://link.springer.com/10.1007/s12369-009-0013-7〉.

Bethel, C.L., Murphy, R.R., 2010. Non-facial and non-verbal affective expression for appearance-constrained robots used in victim management. Paladyn 1, 219–230. http://dx.doi.org/10.2478/s13230-011-0009-5, URL 〈http://www.springerlink.com/index/10.2478/s13230-011-0009-5〉.

Chang, D.H.F., Troje, N.F., 2007. Animacy and direction from point-light displays: is there a life detector?. J. Vis. 7, 481. http://dx.doi.org/10.1167/7.9.481, URL 〈http://www.journalofvision.org/content/7/9/481.abstract〉.

Gao, T., McCarthy, G., Scholl, B.J., 2010. The wolfpack effect. Perception of animacy irresistibly influences interactive behavior. Psychol. Sci. 21, 1845–1853. http://dx.doi.org/10.1177/0956797610388814.

Gao, T., Newman, G.E., Scholl, B.J., 2009. The psychophysics of chasing: a case study in the perception of animacy. Cogn. Psychol. 59, 154–179. http://dx.doi.org/10.1016/j.cogpsych.2009.03.001, URL 〈http://linkinghub.elsevier.com/retrieve/pii/S0010028509000188〉.

Gaur, V., Scassellati, B., 2006. Which motion features induce the perception of animacy. In: Proceedings of 2006 IEEE International Conference for Development and Learning, Bloomington, Indiana. URL 〈http://www.cs.yale.edu/scaz/papers/Viksit-ICDL-06.pdf〉.

Harris, J., Sharlin, E., 2011. Exploring the affect of abstract motion in social human–robot interaction. In: Proceedings of the 2011 IEEE RO-MAN, July 31 2011-August 3 2011, Atlanta, USA. IEEE, pp. 441–448. URL 〈http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6005254〉. http://dx.doi.org/10.1109/ROMAN.2011.6005254.

Hayes, B., Ullman, D., Alexander, E., Bank, C., Scassellati, B., 2014. People help robots who help others, not robots who help themselves. In: Proceedings of the 23rd IEEE International Symposium on Robot and Human Interactive Communication, Edinburgh, Scotland, Finalist, RSJ/KROS Distinguished Interdisciplinary Research Award.

Hegel, F., Krach, S., Kircher, T., Wrede, B., Sagerer, G. 2008. Understanding social robots: a user study on anthropomorphism. In: Proeedings of the 2008, the 17th IEEE International Symposium on Robot and Human Interactive Communication, RO-MAN 2008, Munich. 1-3 August. 2008. Page(s): 574-579. IEEE, URL 〈http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4600728〉. Page(s): 574–579. ISBN: 978-1-4244-2212-8. http://dx.doi.org/10.1109/ROMAN.2008.4600728.

Heider, F., Simmel, M., 1944. An experimental study of apparent behavior. Am. J. Psychol. 57, 243–259.

Hutson, M., 2013. The 7 Laws of Magical thinking: how irrational beliefs keep us happy, healthy, and sane. Plume, New York.

Ishiguro, H., 2008. Studies on humanlike robots humanoid, android and geminoid. In: Carpin, S., Noda, I., Pagello, E., Reggiani, M., Stryk, O.v. (Eds.), Simulation, Modeling, and Programming for Autonomous Robots, Lecture Notes in Computer Science, vol. 5325. Springer, Berlin, Heidelberg, pp. 2–2. URL 〈http://link.springer.com/chapter/10.1007/978-3-540-89076-8_2〉.

Ishiguro, H., 2013. Studies on very humanlike robots. In: International Conference on Instrumentation, Control, Information Technology and System Integration (SICE 2013), Nagoya University, Aichi.

Johansson, G., 1973. Visual perception of biological motion and a model for its analysis. Percept. Psychophys. 14, 201–211. http://dx.doi.org/10.3758/BF03212378, URL 〈http://link.springer.com/article/10.3758/BF03212378〉.

Johnson, T., Johnson, O., 1981. Disney Animation: The Illusion of Life. Edición: Collectors ed., Abbeville Pr, New York.

Kidd, C., Breazeal, C., 2004. Effect of a robot on user perceptions. In: 2004 Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, (IROS 2004), vol. 4, pp. 3559–3564. http://dx.doi.org/10.1109/IROS.2004.1389967.

Kim, R.H., Moon, Y., Choi, J.J., Kwak, S.S., 2014. The Effect of Robot Appearance Types on Motivating Donation. ACM Press, New York, NY, USA, pp. 210–211. http://dx.doi.org/10.1145/2559636.2563685, URL 〈http://dl.acm.org/citation.cfm?doid=2559636.2563685〉. Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction ACM. ISBN: 978-1-4503-2658-2. http://dx.doi.org/10.1145/2559636.2563685.

Kwak, S.S., 2014. The impact of the robot appearance types on social interaction. Arch. Des. Res. 2, 81–93, URL 〈http://aodr.org/xml/01817/01817.pdf〉.

Lange, J., Lappe, M., 2006. A model of biological motion perception from configural form cues. J. Neurosci. 26, 2894–2906. http://dx.doi.org/10.1523/JNEUROSCI.4915-05.2006, URL 〈http://www.jneurosci.org/content/26/11/2894〉.

Litoiu, A., Ullman, D., Kim, J., Scassellati, B., 2015. Evidence that Robots Trigger a Cheating Detector in Humans. ACM Press, New York, NY, USA, pp. 165–172. http://dx.doi.org/10.1145/2696454.2696456, URL 〈http://dl.acm.org/citation.cfm?doid=2696454.2696456〉. In: Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction. ACM ISBN: 978-1-4503-2883-8. http://dx.doi.org/10.1145/2696454.2696456.

Lombard, M., Ditton, T.B., Crane, D., Davis, B., Gil-Egui, G., Horvath, K., Rossman, J., Park, S, 2000. Measuring presence: a literature-based approach to the development of a standardized paper-and-pencil instrument. In: Proceedings of the Presence 2000–3rd Annual International Workshop on Presence, March 27–28, 2000, Delft, The Netherlands. URL 〈https://ispr.info/presence-conferences/previous-conferences/presence-2000/〉 ISBN: 90-386-1571-X.

Matsui, D., Minato, T., MacDorman, K.F., Ishiguro, H., 2005. Generating natural motion in an android by mapping human motion. In: Proceedings of the 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, (IROS 2005), 2–6 August 2005. Alberta, Canada. IEEE, pp. 3301–3308. URL 〈http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1545125.〉 ISBN: 0-7803-8912-3. http://dx.doi.org/10.1109/IROS.2005.1545125.

Michotte, A., 1963. Manual of modern psychology, The Perception of Causality. Basic Books, Oxford, England, URL 〈http://psycnet.apa.org/psycinfo/1964-05029-000〉.

Mori, M., 1970. The uncanny valley. Energy 7, 33–35, URL 〈http://www.movingimages.info/digitalmedia/wp-content/uploads/2010/06/MorUnc.pdf〉.

New, J., Cosmides, L., Tooby, J., 2007. Category-specific attention for animals reflects ancestral priorities, not expertise. In: Proceedings of the National Academy of Sciences, vol. 104, pp. 16598–16603. URL 〈http://www.pnas.org/content/104/42/16598.short〉.

New Oxford American Dictionary, 2010. Animacy, third ed. Oxford University Press, New York, USA.

Nishio, S., Ogawa, K., Kanakogi, Y., Itakura, S., Ishiguro, H., 2012. Do robot appearance and speech affect people's attitude? Evaluation through the ultimatum game. In: 2012 IEEE RO-MAN, Paris, 9–13 September 2012. IEEE, pp. 809–814. URL 〈http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6343851〉. 2012. ISSN: 1944-9445. ISBN: 978-1-4673-4604-7. http://dx.doi.org/10.1109/ROMAN.2012.6343851.

Ribeiro, T., Paiva, A., 2012. The illusion of robotic life: principles and practices of animation for robots. In: Proceedings of the Seventh Annual ACM/IEEE International Conference on Human–Robot Interaction, ACM, New York, NY, USA. pp. 383–390. URL 〈http://dl.acm.org/citation.cfm?id=2157814〉. ISBN: 978-1-4503-1063-5. http://dx.doi.org/10.1145/2157689.2157814.

Saerbeck, M., Bartneck, C., 2010. Perception of Affect Elicited by Robot Motion. In: Proceedings of the 5th ACM/IEEE international conference on Human-robot interaction. ACM Press, pp. 53–60, URL 〈http://portal.acm.org/citation.cfm?doid=1734454.1734473〉 http://dx.doi.org/10.1145/1734454.1734473 IEEE Press, Piscataway, NJ, USA. ISBN: 978-1-4244-4893-7.

Saldien, J., Vanderborght, B., Goris, K., Van, M., Lefeber, D., 2014. A motion system for social and animated robots. Int. J. Adv. Robot. Syst. 11 http://dx.doi.org/10.5772/58402. URL 〈http://www.intechopen.com/journals/international_journal_of_advanced_robotic_systems/a-motion-system-for-social-and-animated-robots〉.

Saygin, A.P., Chaminade, T., Ishiguro, H., Driver, J., Frith, C., 2012. The thing that should not be: predictive coding and the uncanny valley in perceiving human and humanoid robot actions. Soc. Cogn. Affect. Neurosci. 7, 413–422. http://dx.doi.org/10.1093/scan/nsr025, URL 〈http://scan.oxfordjournals.org/lookup/doi/10.1093/scan/nsr025〉.

Scassellati, B., Admoni, H., Matarić, M., 2012. Robots for use in autism research. Annu. Rev. Biomed. Eng. 14, 275–294. http://dx.doi.org/10.1146/annurev-bioeng-071811-150036, URL 〈http://www.annualreviews.org/doi/abs/10.1146/annurev-bioeng-071811-150036〉.

Schultz, J., Bulthoff, H.H., 2013. Parametric animacy percept evoked by a single moving dot mimicking natural stimuli. J. Vis. 13, 15. http://dx.doi.org/10.1167/13.4.15, URL 〈http://www.journalofvision.org/lookup/doi/10.1167/13.4.15.

Spexard, T., Hanheide, M., Sagerer, G., 2007. Human-oriented interaction with an anthropomorphic robot. IEEE Trans. Robot. 23, 852–862. http://dx.doi.org/10.1109/TRO.2007.904903, URL 〈http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4339549〉.

Short, E., Hart, J., Vu, M., Scassellati, B., 2010. No fair!! An interaction with a cheating robot. In: 2010 5th ACM/IEEE International Conference on Human–Robot Interaction (HRI), pp. 219–226. http://dx.doi.org/10.1109/HRI.2010.5453193.

Takayama, L., Dooley, D., Ju, W., 2011. Expressing thought: improving robot readability with animation principles. In: Proceedings of the 6th international conference on Human-robot interaction. ACM Press, New York, NY, USA, pp. 69–76. http://dx.doi.org/10.1145/1957656.1957674, URL 〈http://portal.acm.org/citation.cfm?doid=1957656.1957674〉 ISBN: 978-1-4503-0561-7. http://dx.doi.org/10.1145/1957656.1957674.

Thalia, Wheatley, Alex, Martín, 2009. The neuroscience of social interaction. In: Kaplan & Sadock's Comprehensive Textbook of Psychiatry, ninth ed. Lippincott Williams & Wilkins, pp. 345–353.

Tremoulet, P.D., Feldman, J., 2000. Perception of animacy from the motion of a single object. Perception 29, 943–951. http://dx.doi.org/10.1068/p3101, URL 〈http://www.perceptionweb.com/abstract.cgi?id=p3101〉.

Van Breemen, A.J.N., 2004. Bringing robots to life: applying principles of animation to robots. In: Proceedings of the International Conference for Human-computer Interaction, CHI2004, Vienna, Austria, Citeseer. URL 〈http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.125.8136&rep=rep1&type=pdf〉.