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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.

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

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