Sharing Spaces with Robots in a Home Scenario – Anthropomorphic Attributions and their Effect on Proxemic Expectations and Evaluations in a Live HRI Trial

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Abstract

This paper presents results from an HRI study that involved participants interacting with robots of different appearances. The particular focus of this paper is how anthropomorphic attributions impacted the proxemic expectations of the robots' behaviour as well as the post-experimental evaluations of the robot. The results suggest that a higher degree of anthropomorphic attribution is linked to higher expectations of adherence to human proxemic norms. The post-experimental evaluation of the robots' violations of these expectations suggests an effect in which the reward-value of interacting with a robot which is considered more anthropomorphic counteracts the impact of the deviation from social expectation.

Introduction

Populations in the affluent industrialised nations are ageing rapidly, to the extent at that on a world wide basis, the relative number of over-60s is projected to double in the next 50 years (United Nations, 2002). This demographic shift poses serious challenges for the caring industries. Kovner et al (2002) highlight a number of issues that need to be addressed in geriatric care including that of further research into the organisation of care within health services providing care for the elderly

Such research considers the further implementation of technology to organise and deliver care to an ageing population. Robotics technology, utilising information technology along with the possibility of spatially and physically interacting with individual users in their environment and to deliver practical assistance as well as possible companionship, promises a wide range of possible ways to alleviate some of the challenges facing the workforce in the caring professions. Roy et al. (2000) argue that the falling cost of computational power as well as sensor technology brings the notion of widespread applications of assistive robotics in eldercare into the realms of feasibility. Tsui & Yanco (2007) outline some of these possible applications and attitudes towards them amongst members of the healthcare professions.

Drawing on the perspective of the user populations which may require assistance, Harmo et al. (2005) surveyed potential user groups for assistive robotics involving the elderly as well as carers, and relating the different needs expressed by these group to existing technology and technology which is currently being researched. Some of the needs presented by Harmo et al., such as security, the need for guidance in terms of navigation, dispensing medicine, mobility issues and cognitive prosthetics, can be met through the use of mobile robots with varying degrees of autonomy. Mobile robots can alleviate the need for movement, for example by assisting in fetch and carry tasks as exemplified in Hüttenrauch & Severinson-Eklundh (2002), as well as provide active guidance for users with vision impairment (Montemerlo et al., 2002) and remind users of tasks or events that they need to respond to (Roy et al., 2000). Mobile robots may also safeguard the health of its users by alerting carers of medical emergencies (Cesta et al., 2007; Roy et al., 2000).

However, mobility and perceived autonomy is not without its problems. Mobile robots have a physical and social embodiment due to their perceived autonomy and mobility that other assistive technological devices typically lack. The results from the fetch and carry study mentioned above (Hüttenrauch & Severinson Eklundh, 2002), specifically refer to the issue of space negotiation in its description of the impact of the mobile robot in a human-centred office environment. One can only assume that these issues will be even more pertinent in domestic environments, which are likely to be more cramped and cluttered than an office environment. Also, as noted in the social sciences, space negotiation is of paramount importance in human-human interactions (Hall, 1966;

Kendon, 1990). Violations of spatial preferences are often associated with feelings of discomfort (Aiello et al., 1977), even in short-term interactions. As such, care must be made when introducing mobile robots into home-environments so that they do not cause spatial discomfort of their users. This is of particular importance when the introduction of a technology into a domestic environment may not be initiated by the end user. The cost of assistive robotics may put it out of the reach of the private consumer, and as such, the decision to insert these technologies into the individual household may be based on the policy of healthcare authorities, rather than individual preferences (Swann, 2006). As such, this differs from adoption of other domestic robotics products as the Sony AIBO or the Roomba. Existing surveys (Sung et al., 2008; Friedman et al., 2003) regarding their adoption and use may not be applicable to assistive robotics. In particular, users of assistive robotics may be less 'forgiving' of changes in their everyday experience due to the introduction of new technology.

Spatial Comfort - Proxemics

In human-human interactions, the role of personal space and its negotiation is dependent on several factors (Albas, 1991; Burgoon & Walther, 1990; Gillespie & Leffler, 1983; Hartnett et al., 1970; Strube & Werner, 1984), including, but not limited to, threat, relative status and expectations related to situation and actors. Idiosyncratic factors such as personality and gender have also been reported to have an effect on proxemic expectations and perceptions of violations of these (Hartnett et al., 1970; Krail & Leventhal, 1976; Williams, 1971).

In our previous work we have considered the issue of human-robot proxemics, both in terms of specific scenarios (Koay et al., 2007; Walters et al., 2005) as well as in terms of individual differences (Syrdal et al., 2006; Syrdal et al., 2007; Walters et al., 2005). We have also reported some results on the role of robot appearance in proxemic preferences (Syrdal et al., 2007; Koay et al., 2007).

The role of robot appearance in HRI Proxemics

In human interactions, it is common for participants to form quick and lasting impressions of capabilities and personality traits of other humans with limited information available. Often such impressions are formed on the basis of appearance alone (Albright et al., 1988; Zebrowitz et al., 2002). While there are most certainly qualitative differences between how humans perceive other humans and how humans may perceive a robot companion, the appearance of a robot has been shown to be important with regard to how participants describe it, both in terms of their impressions of its capabilities as well as the attribution of anthropomorphic personalities to the robots (Lee & Kiesler, 2005; Walters et al., 2008).

Previously, we suggested that robot appearance may play an important role in human-robot proxemics (Syrdal et al., 2008). As suggested in (Gillespie & Leffler, 1983), human reactions to proxemic behaviour consists of two main mechanisms. The first is the formation of *expectations*, the second is an *evaluation* of the particular behaviour, both in light of previously held expectation as well as the reward or status of the originator of the behaviour.

According to Reeves and Nash (1996), there are similarities in how humans perceive and respond to computational artefacts and other types of technology and how they perceive and interact with other humans. This effect is referred to as ‘the Media Equation’. It is therefore likely that expectations as to the proxemic behaviour of an autonomous robot will be based on expectations humans have of other humans in the same situation. However, the Media Equation is not a consistent effect across different interactions (Bartneck et al., 2005) or computational artefacts.

How participants perceive and form expectations regarding a particular robot may depend on several factors. Kiesler & Goetz (Kiesler & Goetz, 2002) suggest the framework of *mental models* to measure and understand how humans view robots. Mental models are collections of concepts which may be applied to robots and other computational artefacts. These mental models may incorporate aspects of anthropomorphic mental models, models which we use to perceive, interpret and predict human behaviour. The degree of anthropomorphism in a participant’s mental model may thus influence the proxemic expectations of a robot. Kiesler & Goetz, showed an impact of robot appearance in terms of anthropomorphism in participants' mental models. A similar effect was also demonstrated in Hinds et al., 2004, in which participants responded more politely to a robot with a more human-like appearance than one who was more mechanical looking.

The results from these studies suggest that human users will form stronger expectations as to the proxemic behaviour of a human-looking robot, than that of a mechanical-looking one.

In terms of post-experimental evaluation of proxemic behaviour, our previous studies have shown an effect based on (1) the deviation from expected behaviour and (2) the reward of the behaviour (Syrdal et al. 2008). In this paper we investigate the hypothesis that anthropomorphic attributions towards a robot may mediate this effect.

Hinds et al (2004), as well as our previous studies (Walters et. al 2008), report that participants express more liking towards humanoid looking robots when compared to robots with a more mechanical appearance. This suggests that participants may enjoy interactions with a robot for which they have a more anthropomorphic mental model, than other robots. This enjoyment may add to the reward of the interaction and so mitigate the impact of violations of proxemic expectations.

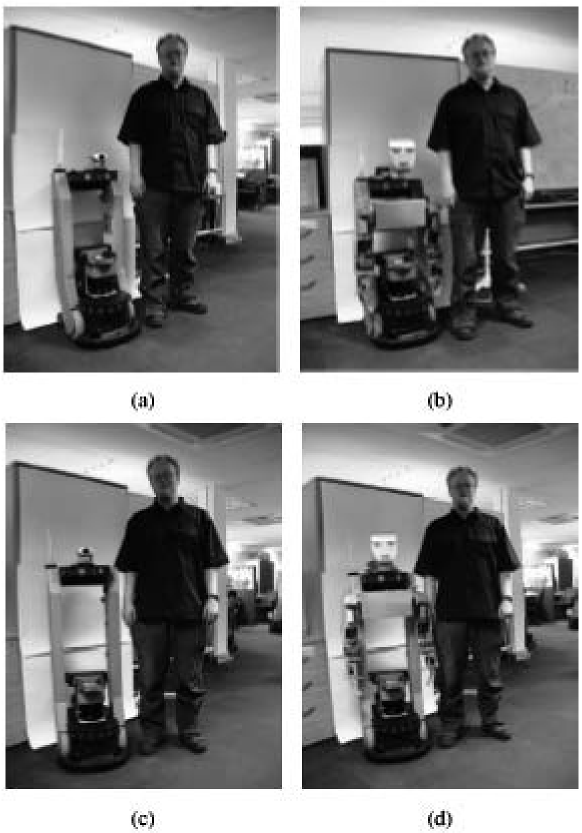


Figure 1 The different robot appearances. Shown here are (a) short mechanoid, (b) short humanoid, (c) tall mechanoid and (d) tall humanoid.

Towards this study

The purpose of this study was to investigate the role of anthropomorphic attributions in determining proxemic expectations in an experimental HRI study. We have previously examined anthropomorphic attributions of personality towards robots based on appearance in video studies (Walters et al., 2008). We have also demonstrated that robot appearance has an impact on both in-situ proxemic expectations (Koay, Syrdal et al., 2007) as well as on post-experimental evaluation of proxemic behaviour (Syrdal et al., 2008). However, the results from Walters et al. (2008) also suggest a need for consistency between appearance and behaviour. As such, the anthropomorphic attributions may be reduced due to similarity of behaviour. Secondly, if the expectations and evaluations of the robots' behaviour can be linked to the participants' mental models of the robots in terms of anthropomorphism, rather than the particular appearance of the robot used in this study, this will potentially increase the replicability of these results along a wider range of interactions with different robots.

Based on these issues, this study aims to answer whether or not expectations based on anthropomorphic attributions based on robot appearance are responsible for the differences in proxemic preferences.

Research Questions:

1. *Is the effect we have previously demonstrated in video studies for robot appearance in terms of anthropomorphic attribution, present in a live study?*

2. *Is there a direct link between these anthropomorphic attributions and in-situ proxemic preferences?*

3. *Is there a direct link between anthropomorphic attribution and post-experimental evaluation of robot proxemic behaviours?*

Method

Apparatus/ Setting

The robots used in this study were two Peoplebots[tm] (Commercially available from ActivMedia Robotics). One of the robots was modified so that its height was lower than the original model. Also, a set of removable arms as well as a head was constructed and attached to the robot in order to manipulate the human-likeness of the robots. Four different robot appearances were used: (a) short mechanical-looking (mechanoid), (b) short human-looking (humanoid), (c) tall mechanoid and (d) tall humanoid, see Figure 1 for the appearance and relative height of the robots.

In-situ proxemic preferences were recorded using the UH Subjective Feedback Device (UHSFD). The UHSFD is a small handheld device with a button. When pushed the device emits a signal to the robot. The participants were invited to try the UHSFD prior to the experiment.

Participants' evaluation of the robots' proxemic behaviour was investigated using a written questionnaire, using Likert scales to assess spatial comfort. The participants' impressions of the robots were also measured using a questionnaire. This questionnaire also included items regarding how much participants liked each robot's appearance, items measuring the 'Big Five' (Matthews et al., 2003) personality traits for each robot, as well as how human-like the participants viewed each robot (see Table 1).

Table 1 Items measuring anthropomorphic attribution

Aspect	Item
Humanlike	How Humanlike was the robot?
Extravert	How extravert/introvert was the robot?
Agreeableness	How interested/disinterested in people was the robot?
Conscientiousness	how organised & committed or disorganised/uncommitted was the robot?
Intelligence	how intelligent or unintelligent was the robot during its tasks?

The study took place in the UH 'Robot House', a private flat rented specifically for HRI studies and furnished in a manner typical for a British household, in order to create a more ecologically valid environment for participants in our studies.

Participants

33 participants took part in this study. These participants were recruited from Studynet, the University of Hertfordshire's Intranet, and were primarily students and staff at the university. Reflecting the typical population of a typical British university, they came from a variety of cultural backgrounds, including different European and Asian cultures as well as British.

Procedure

At arrival to the robot house, participants were given a brief standardised introduction to the experiment and a set of instructions. The experiment consisted of the robot approaching in 3 different scenarios, from two different directions and under two different robot control conditions. These different approach conditions were designed in order to account for a variety of use-scenarios as well as other conditions appropriate for an autonomous personal robot companion.

The three different scenarios were designed to reflect different interactions that a potential user of a personal robot may have, and were as follows:

No Interaction:

This interaction type was used in this experiment to give some insight as to how potential users may view the robots' proxemic behaviour when it is performing tasks that do not directly involve the user. In this particular scenario, the robot approached the participant before turning away.

Verbal Interaction:

This interaction type was being used to assess how potential users may respond to a robot's proxemic behaviour in interactions in which the robot and user engage in dialogue. The robot approached the user who would give the robot a series of instructions.

Physical Interaction:

This interaction type was being used to investigate the role of proxemics in interaction in which the user may need to manipulate parts of the robot, or pick up/manipulate objects carried by the robot. In this particular scenario, the robot approached the user in order for the user to pick a particular cube from its gripping tray.

There were also two different robot control conditions, reflecting situations in which the direct control a potential user might have on a robot companion might vary:

Human in Control(HiC):

In this condition the robot would approach the participant until the participant pressed the UHSFD, after which the robot would stop/turn away.

Robot in Control(RiC):

In this condition, the robot would approach the participant to its preset safety distance before stopping/turning away. The participants were still invited to use the UHSFD to indicate proxemic preference, and these responses were recorded.

Drawing on previous work on robot approach directions, which showed that participants prefer the robot to approach from the front or from an angle in full view of the participant (Woods et al., 2006) the robot approached from two different directions. It either approached directly from the front of the user, or from slightly to the right of the user.

Note, the programmes controlling the robots' behaviour were the same for the mechanoid and humanoid robot.

After participants interacted with the robot, they were invited to fill in the questionnaire evaluating the interaction, as well as the questionnaire regarding the appearance of the robots.

Research Question 1:

Research Question one was assessed using a t-test to test for differences between the robot's appearances. The results are presented in table 2 and Figure 2:

Table 2 T-tests results for anthropomorphic attribution

Aspect	Mean Diff	T-value	Significance
Humanlike	1.2	2.23(28)	**.03**
Extravert	.44	1.59(28)	**.12**
Agreeableness	.49	1.07(28)	.29
Conscientiousness	.13	.35(28)	.73
Intelligence	.77	.29(28)	.77

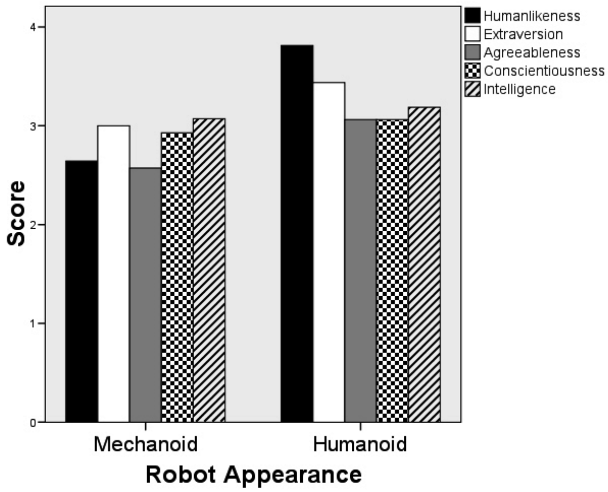


Figure 2 Mean scores for anthropomorphic attributions according to robot appearance

Table 2 and Figure 2 both suggest that the results from our previous video study could be replicated in the results from a live HRI study using the same robot appearance types. The results suggest the same trend as reported in our video study (Walters et al., 2008), namely that participants tended to rate the humanoid robot as scoring higher in both human-likeness as well as other personality traits. As in our previous paper, this result is more pronounced for Extraversion and Agreeableness, and less so for the other personality traits.

These results suggest that it is probable that participants' mental models of the robots were impacted by cues from their appearance, despite the high similarity of the robots' behaviour.

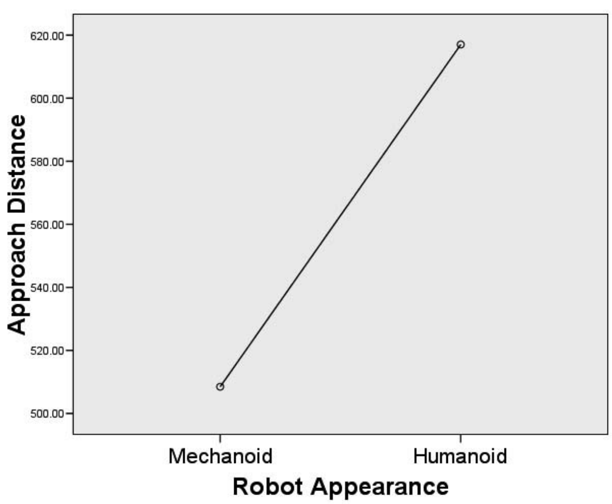


Figure 3 Approach Distances according to robot appearance.

Research Question 2:

Preliminary results from approach distance based on appearance were presented in Koay et al. (2008). For the sake of clarity, these results are summarised below. A repeated measures ANOVA found a significant main effect for robot appearance (F(1,31)=11.61, p=.002). The effect is described in Figure 3.

According to Figure 3, participants preferred the mechanoid robot to approach to a much closer distance. However, as the results from Research Question 1 show, some participants did rate the mechanoid robot appearance as humanlike, if to a lesser extent than the humanoid robot. In order to investigate Research Question 2, whether or not it was the anthropomorphic attributions rather than the particular appearance of the robot used in this study which was responsible for this effect, an ANOVA was performed, investigating the role of how human-like the robot was viewed and approach distances. We found a non-significant trend (F(1,21)=1.0,p=.33). The trend is described in Figure 4, and suggests that participants preferred robots which they viewed as more humanlike to keep a further distance.

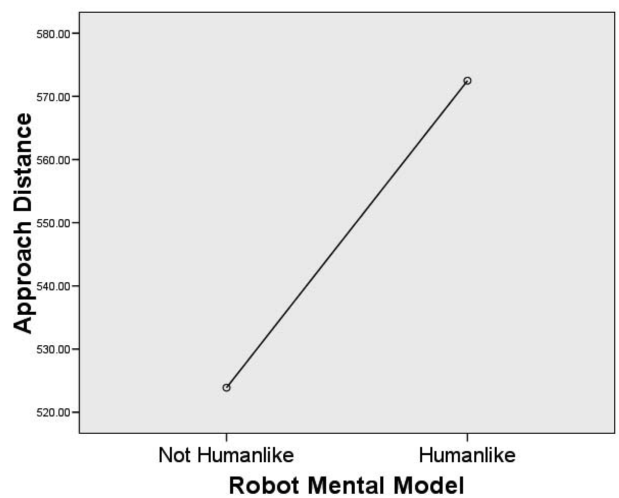
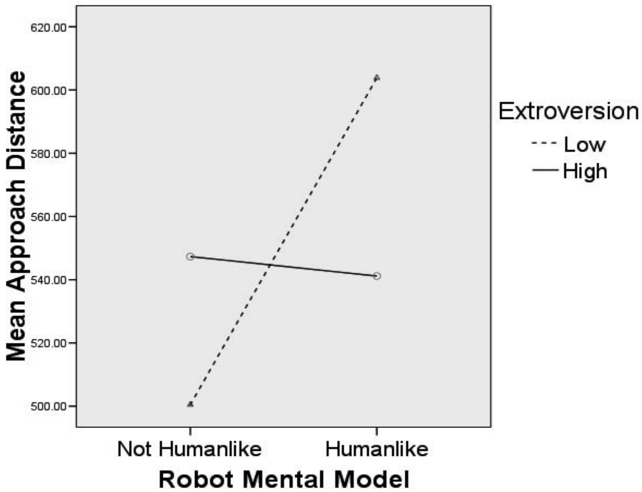


Figure 4 Approach Distances according to anthropomorphic attribution

In order to further investigate this trend, we included participants' extraversion scores into the model. As extraverts are more likely to use anthropomorphic heuristics (Luczak et al., 2003; Walters et al., 2008), and also show a greater tolerance to inappropriate proxemic behaviour (Syrdal et al., 2006), it is likely that these two effects counteracted the impact of anthropomorphic attribution on proxemic expectations. This analysis found a slightly larger effect which approached significance, (F(1,21)=2.53, p=.13) supporting this view. The effect is described in Figure 5, which shows that the impact of anthropomorphic attribution is much larger for introverts than extraverts.

Figure 5 Approach Distances according to anthropomorphic attribution and extraversion.



These results suggest that expectations as to robot proxemic behaviour within a given interaction behaviour is influenced by anthropomorphic attributions based on appearance.

Research Question 3:

Having established the link between anthropomorphic attribution and the formation of proxemic expectations, the next question pertains to how potential users may rate the proxemic behaviour of the robot in a post-experimental evaluation. To assess this, an ANOVA was run in the post-experimental evaluation of the *Robot in Control* condition as in this condition, the robot would ignore the participants' proxemic preferences, thus consistently violate their expectations. The ANOVA did not find a significant or salient effect for anthropomorphic attribution ($F(1,21)=.129$, $p=.73$), nor did a model controlling for extraversion find a salient or significant interaction effect ($F=(1,21)=.128$, $p=.74$).

Discussion

This paper presented trends and significant results suggesting that anthropomorphic attributions play an important role in determining proxemic expectations when participants interact with a robot. Robots with a more humanoid appearance are attributed to be more humanlike, and this attribution leads to higher expectations of conformity to social norms regarding proxemics.

However, previous studies have suggested that anthropomorphic attributions are also related to general liking of that particular robot. Thus a higher degree of anthropomorphism increases the reward value of interactions and seems to mediate the evaluation of the violations of the proxemic expectations in this particular experiment.

From a human-robot interaction research point of view, these results highlight the importance of paying attention to a wide range of data capture, and to the fact that in-situ behaviour may not always translate directly into how participants evaluate interactions and technology after an interaction. As such, these results support the assertion by Sabanovic et al. (Sabanovic et al., 2007) that these discrepancies need to be addressed within HRI research.

In this particular experiment, the reward-value correlated with anthropomorphic attributions to a large extent mediated the impact of increased expectations of conformity to social proxemic norms. This may not always be the case. This particular study was short-term and reflects an initial interaction with a robot. It very well possible that continued violations of such expectations as well as other inconsistencies between appearance and behaviour may (in long-term repeated interactions) lead to rejection of a robot by its user as suggested by Walters et al. (2008). If this is the case, the use of anthropomorphism in form may not be a good strategy to encourage interactions, as the social expectations to a robot with this form will be more difficult to adhere to for such a system. The role of expectations based on appearance and other cues of varying anthropomorphism, especially in long-term interactions, remains a salient field of study.

While the above interpretation of the study's results necessarily need to be tentative, we believe that a report of these findings is worthwhile to the research community studying human-robot interaction in assistive and eldercare scenarios. In particular, it is also important to note that the results regarding the impact of extroversion are consistent with our previous studies, both in regards to anthropomorphic attributions (Walters et al., 2008), as well as proxemic preferences (Syrdal et al., 2006), suggesting that these results may be robust across a wider range of interactions and robot types. Future work will further investigate these issues, including users from an elderly population in long-term studies, as part of our work in the new European project LIREC that develops and studies long term companionship with robots and other computational artifacts.

Acknowledgements

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