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Living with Robots: Investigating the Habituation Effect in Participants' Preferences During a Longitudinal Human-Robot Interaction Study

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Abstract—**This paper presents and discusses a longitudinal study which investigated habituation effects between humans and robots over a period of five weeks. Participants' preferences for the robot's *approach distance* with respect to its *approach direction* and *appearance* were investigated in a variety of domestic scenarios. These human-robot interaction (HRI) scenarios were also designed to explore the notions of autonomy and control.**

The results of this study show that participants' preferences *change* over time as the participants habituate to the robot. This trend was significant in terms of the robot's appearance and approach direction. Also, it seems to indicate that participants who are accustomed to the robot prefer to be more 'in control' of the situation - in that they appreciated reduced robot autonomy in case of unexpected events.

I. INTRODUCTION

Research in the field of Human-Robot Interaction (HRI) has recently received significant attention, especially in the areas of assisting people in their daily activities [1–7]. Many researchers believe such robots should behave in a *socially acceptable manner* in order to gain acceptability in human-inhabited social environments [8–12]. Therefore, it is essential to include humans in the loop when designing HRI trials.

Experimental results must also be analyzed from a *human centered perspective* in order to gain insight into how to build a socially acceptable robot that can engage in a socially acceptable manner [8] and bring harmony and comfort to its user instead of fear, annoyance or boredom. Fong et al. [9] stress the importance of such issues as relevant to robots.

Hall's Proxemics [13] and Kendon's F-Formation system observations [14] have demonstrated that human social distances and spatial formations play important roles in human-human relationships. Within HRI scenarios, various studies have been conducted, based on these guidelines, in order to help the design of *robot spatial conduct* [15]–[19]. A human-aware path/trajectory planner was designed [18], based on results from studies of HRI trials investigating social spaces and robot-to-human approach directions [1][19]. Pacchierotti et al. [17] also applied proxemics to implement an initial encounter robotics system for evaluating the passing distance (between robot and humans) in a hallway.

However, results from these (effectively short-term) studies are likely to be applicable only in 'first contact' scenarios. There are few previous investigations into longer term habituation of humans to robots. Examples include the CERO robot assistant trial reported in Severinson-Eklundh et al. [20], the robot peer tutor study by Kanda et al. [3][4] and the use of robots to interact with autistic children by Robins et al. [5]. The relationship between humans and agents is likely to change over time as for inter-human relationships, as Petersen et al. [21] pointed out in their studies. Also, the novelty effect can quickly wear off (measured as frequency of interaction), as shown e.g. in [3]. Hall [13], in his original work on proxemics, noted that the degree of acquaintance between individuals was the most important factor in determining intra-cultural interaction distances. Another important issue in HRI concerns robot autonomy and transparency of intention. Kim and Hinds [22] found that participants' perception of robot behaviour changes according to the degree of autonomy and independent intention displayed by the robot.

To address these issues, long-term studies were conducted to study changes of participant's preferences over time, and to identify significant parameters (based on their preferences) that could inform the design of HRI studies. The study involved 12 participants interacting with robots of different appearances repeatedly over 5 weeks. Results, while limited by the relatively small sample size and constrained by the specific design of 4 robot appearances, do point to important issues to consider in human-robot long term habituation.

II. METHODS

A. Experimental Setup

Longitudinal trials were conducted at the University of Hertfordshire's *Robot House* during the summer of 2006 to examine the impact of habituation effects on participants' preferences for robot approach direction and distance. The Robot House provides a more naturalistic and ecologically valid experimental environment compared to laboratory conditions. This study focused on participants' preferences with respect to *robot appearances*, a series of *Human-Robot Interaction (HRI) scenarios* and *Notions of Autonomy and Control*. The objectives were to investigate:

1. How participants' preferences change over time, and

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2. Help identify significant parameters (for participants' preferences) that may be influenced by a habituation effect.

Within the longitudinal study, two sets of experiments were conducted:

- *Pre-/Post -Trials Set* – these main trials aimed to measure participants' preferences concerning robot-to-human approach distances and directions.
- *Exploratory Trials Set* – various smaller, independent trials were designed to support the main trials by involving participants in a variety of *HRI scenarios* during their habituation period. The trials were exploratory in order to keep the participants' interest and motivation in the study.

The longitudinal trials were conducted over a period of five weeks. Participants had a total of eight interaction sessions with the robot, each lasting approximately one hour.

Four different robot appearances were used in the trials (see Fig. 1) in order to address robot appearance issues. *Tall mechanoid* and *tall humanoid* robot appearances were originally designed for previous video HRI studies reported in [23]. For this study, shorter versions of the mechanoid and humanoid robots were constructed. This height difference was designed to test the hypothesis in Woods et al. [24], namely that seated participants may feel less intimidated when being approached by a robot which is shorter, rather than one that is taller than them.

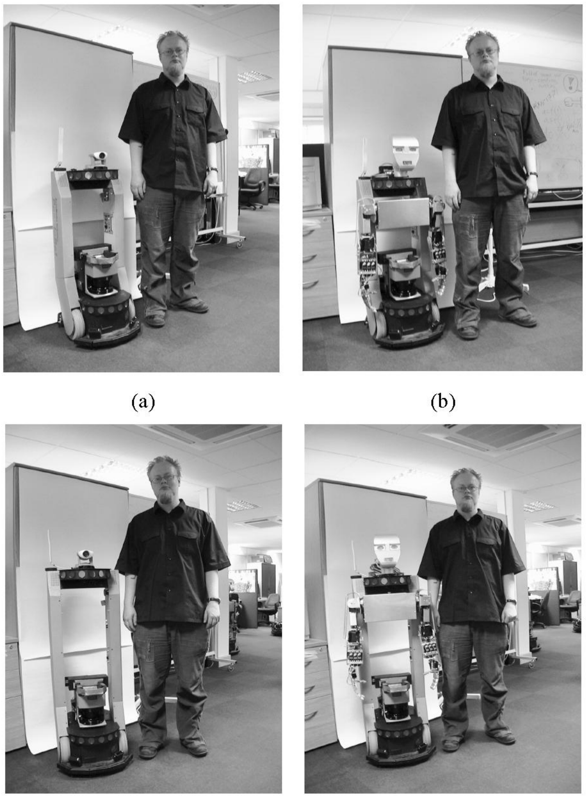
B. The Trials

The longitudinal trials were carried out by an experiment supervisor, a robot operator, and a video and data equipment monitoring operator. The experiment supervisor introduced and explained the trials to the participants and also played a role in some of the exploratory HRI scenarios. Before the first trial, all participants were asked to rate their own personality traits using the 'Big Five' domain scale from the International Personality Item Pool (IPIP) [25].

The whole sample ($sample_W$) for this study consisted of thirty-three participants (20 males, 13 females) recruited from the University of Hertfordshire. Ages ranged from 18 to 50, all were staff or students from various departments including Computer Science, Engineering, Psychology, Physics, Astronomy and Business Studies (the participants were not part of the HRI research team). The trials began with all participants taking part in the Pre-Trial 1 throughout week 1. However, due to limited resources, time constraints, and the difficulties of maintaining a large sample size of participants over a period of five weeks, only twelve participants ($sample_L$), 8 males and 4 females from $sample_W$, participated in the longitudinal trials. Their ages ranged from 21 to 40, and had representative backgrounds from the overall $sample_w$. $Sample_L$ experienced all their HRI sessions with one robot with the same appearance and was not exposed to any of the other robot appearances (Fig. 1).

1) Pre-/Post-Trials Set

Four groups (of 2 males and 1 female each) were assigned to the four different robot appearances. The schedule of the longitudinal trials is shown in Table 1. Three identical trials (*Pre-Trial 1*, *Pre-Trial 2* and *Post -Trial*) were conducted at different times during the five week trial period in order to track participants' preferred robot-to-human *approach distances* and *directions* over time. Participants' *Pre-Trial 1 preferences* ($preferences_{Pre1}$) and *Pre-Trial 2 preferences* ($preferences_{Pre2}$) were collected during their first and second encounters with the robot before the *Exploratory Trials* (i.e. before the habituation phase). Participants' *Post-Trial preferences* ($preferences_{Post}$) were collected after four weeks of habituating to the robot. *Pre-Trial 2* was intended to validate the results from *Pre-Trial 1* in order to check for consistency of participants' responses as well as control for a possible novelty effect.



(a) (b)

(c) (d)

Fig.1 The four different robot appearances used in the trials, a) short mechanoid, b) short humanoid, c) tall mechanoid, and d) tall humanoid. Note, the term 'mechanoid' refers to a mechanical-looking robot.

TABLE 1
SCHEDULE OF LONGITUDINAL TRIALS

Week	Trial Session	Participants
1	Session 1 – Pre Trial 1	$sample_W$
2	Session 2 – Pre Trial 2	$sample_L$
	Session 3 – Hot and Cold Game	
3	Session 4 – Robot in the Family	
	Session 5 – Confidential Information	
4	Session 6 – Watching TV with the Robot	
	Session 7 – Helping the Robot	
5	Session 8 – Post Trial	

To improve our understanding of participants' preferences with regard to robot-to-human approach distances and directions, three different interaction scenarios were used in the trial. These three interactions scenarios were:

Physical-Interaction – Robot approached the participant in order to allow the participants to examine three upturned cups on a tray to find a cube with the darkest color (prolonging the close physical interaction).

Verbal-Interaction – Robot approached the participant to initiate the participant practicing simple voice commands (e.g. "robot move forward").

No-Interaction – Robot approached and turned away from the participant, treating the participant as another obstacle in its path across the living room.

The trial focused on two different robot approach directions based on previous findings [1] that show that most participants preferred the robot to approach either from the front or the side, and disliked the robot moving behind them [12]. These results also revealed that a minority actually preferred the robot to approach from their front. An important part of the research here aimed to investigate if such divisions remain significant after a longer period of exposure to the robot.

The participants' approach distance preference data were collected during the trials with the aid of a *Comfort Level Device* (CLD) [12][16]. They used the CLD prior to the trial for familiarization. Then they were asked to press the button on the CLD when they thought the robot had approached closely enough for their preference. Every time a participant used the CLD, it automatically triggered the recording of the approach distance from the robot's laser range sensor.

Two different human/robot control conditions were used in this trial to explore how notions of perceived autonomy and control of the robot affected the participants' approach distances and comfort ratings. These two conditions were:

- *Human in Control* (*HiC*) – a press of the CLD button caused the robot to either stop approaching or turn away, depending on the interaction scenario. The participants' preferred approach distances were recorded at the instant they pressed the CLD button.
- *Robot in Control* (*RiC*) – pressing the CLD button caused the robot to record the participants' preferred approach distances. However, the robot only stopped or turned away (depending on the interaction scenario) when it reached the preset approach distance - for safety reasons (120mm).

The trial for each participant was carried out as two separate sub-sessions (for each of the *HiC* and *RiC* conditions) so as not to confuse the participants (so that they knew what they were expected to do). For both *HiC* and *RiC* conditions, each participant experienced a total of six approaches (two approach directions from front and side for each of the three interaction scenarios). After each of these human/robot control condition (*HiC* and *RiC*) sub-sessions, a questionnaire was used to obtain participants' comfort ratings regarding the approach distances, directions, and robot appearance using five-point Likert scales. The trial was counter-balanced with regard to human/robot in control order, approach direction, and interaction scenario.

2) Set of Exploratory Trials

The exploratory trials consisted of five different trials which aimed to habituate the participants with the robot. These trials were identified to represent situations that were likely to occur when a cognitive robot companion shares a home with a person. Each of the trials ended with a questionnaire and a semi-structured interview. These exploratory trials were:

- *'Hot and Cold' Game Trial* – The participant identified an object in the room and directed the robot toward the object, using the words "hotter" (if the robot was moving closer toward the object) or "colder" (if the robot was moving further away from the object).
- *'Robot in the Family' Trial* – Explored issues of space negotiation. The robot moved through the living room between the kitchen and the hallway, while the participant was talking to the experimenter (e.g. how the design of the living room could be improved), while walking around the living room.
- *'Confidential Information Disclosure' Trial* [26] – Explored issues regarding the robot recording and revealing confidential information. The participant and the experimenter had a casual conversation. The robot joined the conversation with (neutral) remarks revealing information the experimenter might want to hide (e.g. revealing an inconsistency in the experimenter's claims). Note, the robot was not trying to be malicious but provided truthful information to the best of its knowledge.
- *'Watching TV with the Robot' Trial* – Exploring participants' opinions about the robot interrupting them in order to serve them (e.g. drinks and food) while they are enjoying a TV program.
- *'Helping the Robot' Trial* – Exploring how participants feel about helping the robot. Which (if any) of several hard-coded robot attention seeking behaviors would cause the participant to interrupt watching TV in order to open a door for the robot?

Results from the exploratory trials will be presented in future publications. This paper focuses on the results from the pre- and post-trials.

III. RESULTS

A. Robot Interaction Scenario

The approach distance preferences of the participants under the different conditions were assessed using a repeated measures ANOVA. For $sample_W$, the approach distance $preferences_{Prel}$ means for the no-interaction, verbal-interaction and physical-interaction scenarios were 602mm, 612mm and 489mm, respectively. A significant main effect for these interaction scenarios was found, $F(2,31)=35.638$, $p<.001$. The partial η^2 effect size measure was .70, indicating a sizeable effect of the interaction scenarios. Fig. 2 suggests that there is no significant difference between the no-interaction and the verbal-interaction scenarios approach distance means, but in the physical-interaction scenario, participants allow the robot to come significantly closer than in the other two interaction scenarios.

For weeks 1, 2 and 5, the means of $sample_L$'s preferred

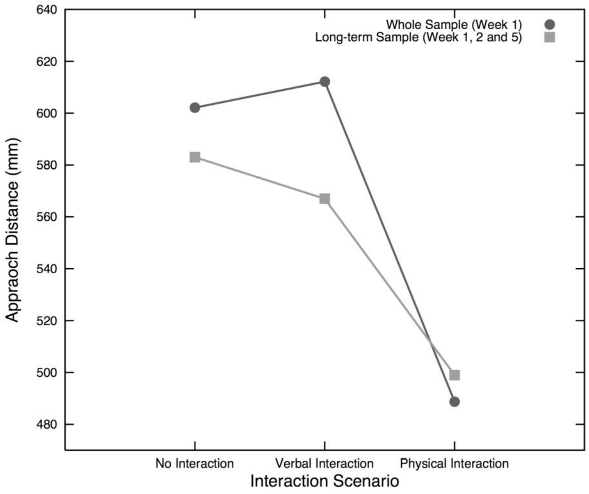


Fig. 2 Means of participants' preferred approach distance scores for three different interaction scenarios.

approach distances ($preferences_{Pre1}$, $preferences_{Pre2}$ and $preferences_{Post}$) for no-interaction, verbal-interaction and physical-interaction scenarios were 583mm, 567mm and 499mm, respectively. A significant main effect for these interaction scenarios was found, $F(2,10)=15.702$, $p<.005$. The partial η^2 effect size measure was .76, indicating a sizeable effect of the interaction scenarios in the long-term study as well. Fig. 2 suggests that there is no difference between the no-interaction scenario and the verbal-interaction scenario. However in the physical-interaction scenario participants allow the robot to come closer than in the other two interaction scenarios.

B. Robot Appearance

An independent groups ANOVA indicates that that there is a significant main effect for our robot appearance on $sample_W$ approach distance $preferences_{Pre1}$ ($F(1,29)=11.396$, $p=0.002$). The partial η^2 effect size measure was .28, indicating that the appearance of the robot had a clear effect on appearance preferences. Fig. 3 indicates that the robot's appearance (mechanoid or humanoid) has more effect on the participants' decisions as to how close they allow the robot to approach them than the robot's height. A subsequent ANOVA for $sample_L$ indicated that the relationship between approach distances preferences and robot appearance approaches significance ($F(1,8)=5.109$, $p=0.054$). The partial η^2 for $sample_L$ was .39 which indicates that this effect was similar to that in $sample_W$. This effect is shown in Fig. 4, which also indicates that participants' preferences for robot approach distances with respect to our mechanoid and humanoid appearances become less pronounced in weeks 2 and 5.

C. Human/Robot Control Conditions

No significant differences for approach distance preferences were found for the human/robot control conditions ($F(1,31)=.329$, $p=.570$). The partial η^2 effect size measure was .01, which indicated a very small effect.

D. Approach Direction

The repeated measures ANOVA found a significant main effect for robot approach direction on $sample_W$ approach

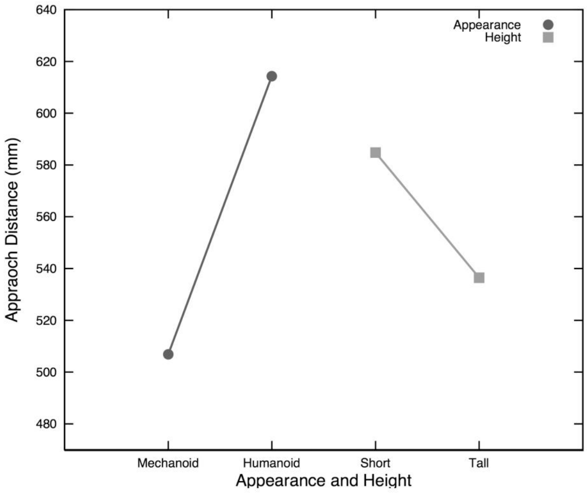


Fig.3 Means of $sample_W$' preferred approach distance scores vs. the robot's appearance and the robot's height.

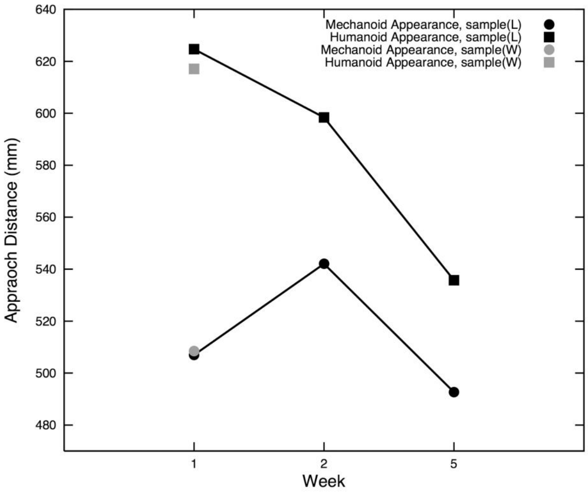


Fig.4 The habituation effect of robot appearance vs. participants' preferences for robot approach distance over a period of five weeks.

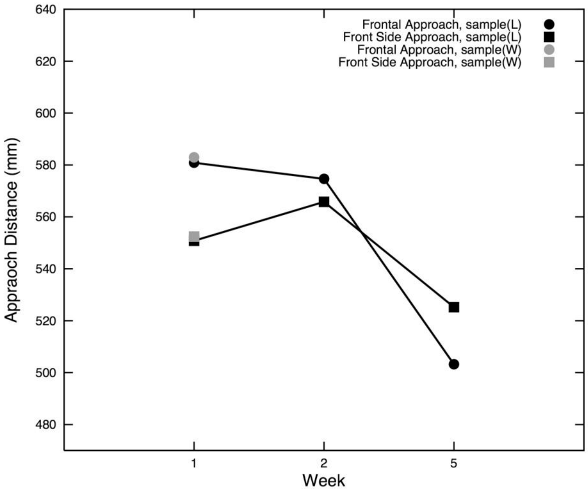


Fig.5 The habituation effect of robot approach directions vs. participants' preferences for robot approach distance over a period of five weeks.

distance $preferences_{Pre1}$ ($F(1,32)=4.756$, $p<.05$) with a partial η^2 of .13. The mean approach distance for the frontal and front side approaches were 583mm and 552mm, respectively (see Fig. 5). This suggests that participants allowed the robot to come closer from the front side rather than from the front. However, the $sample_L$ overall approach distance preference means ($preferences_{Pre1}$, $preferences_{Pre2}$ *and* $preferences_{Post}$) for the robot approach from the front and from the front side shows no significant differences between the two directions ($F(2,9)=2.25$, $p=.162$). This could be caused by the participants' habituation to the robot, hence their preferred approach distances for both approach directions become less pronounced as shown in Fig.5. Furthermore, Fig.5 also indicated that by week 5, the participants' preferred robot frontal approach was closer than their preferred front side approach, a pattern different from the previous two weeks (i.e. weeks 1 and 2) where the robot's frontal approach was halted further away than the robot's front side approach.

E. *Habituation Effects*

The overall approach distances means for $sample_L$ $preference_{Pre1}$, $preference_{Pre2}$ and $preference_{Post}$ were 565mm, 570mm and 514mm, respectively. An ANOVA revealed that this effect approached significance ($F(2,10)=3.621$, $p<.066$) with a partial η^2 of .42. This suggests that while there is no difference in approach distances between weeks 1 and 2, participants are more likely to allow the robot to come closer in week 5 compared to both weeks 1 and 2 for all the test conditions (interaction scenario, human/robot control condition, approach direction, and appearance).

F. *Questionnaire Results*

Post-experiment questionnaire results (see Table 2) for the most comfortable interaction type for the *HiC* condition reveal no differences between $sample_W$ and $sample_L$ for weeks 1, 2 and 5. Also, the results from the *RiC* condition show that in $sample_W$ as well as in week 1 for $sample_L$, there are no differences between physical and verbal interaction. In week 2 however, the differences between physical and verbal interaction approaches significance ($\chi^2(1)=2.778$, $p=.09$) and in week 5, this relationship reaches significance ($\chi^2(1)=4.5$, $p=.034$). From this, we can conclude that in weeks 2 and 5, participants preferred verbal interaction to a greater degree than physical interaction, a relationship that did not exist in week 1.

IV. DISCUSSION AND CONCLUSIONS

The results presented in this paper are mainly based on participants' preferred approach distances obtained through the used of the CLD (Comfort Level Device). One effect was that after five weeks of habituation, participants preferred the robot to approach more closely than before habituation.

The habituation effect seems to have an influence on the participants' evaluations of robot appearances and robot approach direction. During their first encounter, participants exhibit a strong tendency to allow the robot with mechanoid appearance to approach closer than the robot with humanoid appearance. However, this tendency faded away as the participants habituated to the robots (see Fig. 4). This is supported by the robot appearance results presented above (section III.B.) which demonstrate that the approach distances for both of our humanoid and mechanoid robot appearances were significantly different for the entire $sample_W$, but were not significantly different for weeks 2 and 5 for the long-term $sample_L$.

TABLE 2
QUESTIONNAIRE RESULTS FOR THE MOST COMFORTABLE INTERACTION SCENARIO

	Wk. 1 (*Sample*$_W$)		**Wk. 1** (*Sample*$_L$)		**Wk. 2** (*Sample*$_L$)		**Wk. 5** (*Sample*$_L$)	
	HiC	***RiC***	***HiC***	***RiC***	***HiC***	***RiC***	***HiC***	***RiC***
No Interaction	2	4	2	1	3	2	1	2
Verbal Interaction	16	14	5	6	5	7	4	7
Physical Interaction	15	13	5	4	3	2	5	1
No Response	0	2	0	1	1	1	2	2
Total	33	33	12	12	12	12	12	12

A similar trend was observed in the *approach direction* results, where $sample_W$ participants preferred the robot to come significantly closer when it was approaching from the front side, than from the front. However, the results from $sample_L$ (weeks 2 and 5) do not indicate such a preference. For the robot approaching from the front, participants who had habituated to the robot may feel less threatened, intimidated, or perceive the robot as less invasive than when it was first encountered. Therefore, they may allow it to approach closer.

Results from both $sample_W$ and $sample_L$ indicate that the preferred robot approach distances for the physical interaction scenario were significantly closer than the preferred approach distances for the other two interaction scenarios. This effect may be caused by participants feeling the need to be close to the robot in order to complete the physical interaction task, even though the majority of the participants did not find the physical interaction scenario to be the most comfortable (Table 2).

However, the results (Table 2), for the physical-interaction task in week 5, show that a larger number of participants (5 participants) indicated the *HiC* (human in control) condition was the most comfortable interaction compared to the *RiC* (robot in control) condition (1 participant). This indicates the participants' need and/or preference for control increased over time as they habituated to the robot. A similar trend was observed under the *RiC* condition for weeks 2 and 5, where participants preferred the verbal-interaction scenario to a much greater degree than the physical interaction. This relationship did not exist in week 1. The reason for this may be that the verbal-interaction task gave the participants some degree of (perceived) control over the interaction, and this may have proved to be more important to the participants in the *RiC* condition.

However, this effect does not necessarily indicate that the participants want to take full control over the robot, since the effect size for the non-significant differences in approach distance preferences found for the *RiC* and *HiC* conditions was too small, to have any practical bearing on robot behaviour. Rather, this effect indicates that participants may need to feel in control and be able to step in if required. Further studies with larger sample sizes need to confirm and extend these interpretations of the results. Also, these results, when considered with those of Kim and Hinds [22], suggest that while the evaluation of an interaction may change due to the robot's autonomy, it does not necessarily lead to a change in proxemic behaviour and preferences.

In this study, we have shown that participants' preferences do change over time. It is important for researchers and designers of social robots to focus not only on short-term studies, but also on long-term studies. Short-term studies may be insufficient to elicit key aspects of robot social behaviors that participants will identify as important. However, certain envisaged applications of robots only involve short-term encounters (e.g. robot receptionists etc.) and some of these social behavior parameters may *only* be applicable in first encounters. Participants may find these social behavior parameter settings to be annoying as they later become more familiar with the robot. Therefore in this paper, it is strongly argued that it is *essential* to conduct long-term studies, to identify the social behavior parameters that are influenced by habituation effects in order to create better social behavior models for robots that adapt their social rules over time [8].

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