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Human Approach Distances to a Mechanical-Looking Robot with Different Robot Voice Styles

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Abstract—**Findings are presented from a Human Robot Interaction (HRI) Demonstration Trial where attendees approached a stationary mechanical looking robot to a comfortable distance. Instructions were given to participants by the robot using either a high quality male, a high quality female, a neutral synthesized voice, or by the experimenter (no robot voice). Approaches to the robot with synthesized voice were found to induce significantly further approach distances. Those who had experienced a previous encounter with the robot tended to approach closer to the robot. Possible reasons for this are discussed.**

I. Introduction

Robots are now used in domestic environments to perform useful functions such as simple cleaning tasks (eg. the ROOMBA vacuum cleaning robot), lawn mowing and basic (remote) security monitoring. Currently, humans are treated as just another object to be avoided. However, the avoiding distance may well be closer than a human would prefer or find comfortable. Future domestic robots will carry out a wider variety of useful tasks which require them to interact with humans as they perform their duties. Therefore a domestic robot must satisfy two main criteria (cf. Dautenhahn et al. [1] & Syrdal et al. [2]):

It must be able to perform a range of useful tasks or functions.

It must carry out these tasks or functions in a manner that is socially acceptable, comfortable and effective for people it shares the environment with and interacts with.

Fong et al. [3] provides a taxonomy of attributes of socially interactive robots (robots designed to interact with humans in a social way). Our research emphasis here is on the physical, spatial, visual and audible non-verbal social aspects of Human-Robot Interaction (HRI). Human psychological research findings and methods have often provided a guide for research into human reactions to robots (e.g. [4][5][6][7][8]) and there is evidence that humans respond socially to robots. However, it is it is probable that they will not react exactly as they would to other humans (cf. [9][10][11][12]). Previous work (e.g. [13][14]) has indicated that humans may respond to a robot in some ways similarly as to a pet, another human, or even as to a child or infant.

Hall [15][16] provided a systemic basis for research into social and personal spaces between humans (Proxemics), and his and others work in psychology (cf. Hall [17] and Sommer [18]) have demonstrated that social spaces substantially reflect and influence social relationships and the attitudes of people to each other. Embodied non-verbal interactions, such as approach, touch, and avoidance behaviors, are fundamental to regulating human-human social interactions (cf. Gillespie & Leffler [19]). Hall's defined social spatial zones in terms of body, arm contact or reaching distances. Other studies found that humans tended to approach other humans at comfortable distances that were larger than those for inanimate objects of similar size (eg. Horowitz et al. [20], McBride et al. [21] and Sommer [18]). The generally recognized personal space zones between humans are given (for northern Europeans) in Table I, which quantifies and summarizes Hall's original qualitative distances. We hypothesized (H1):

Human-robot interpersonal distances would be comparable to those found for human-human interpersonal distances [17] [22].

Breazeal [23] has found that people respect the interpersonal space of robots, and we have performed two previous studies investigating this hypothesis. For both these studies, on an initial encounter with a mechanical-looking (PeopleBot™) robot, approach distance observations and

Fig. 1.The PeopleBot™ robot

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Table I: Hall's Personal Spatial Zones

Spacial Zone	Range (m)	Situation
Close Intimate	0 to 0.15	Lover/close friend touching
Intimate Zone	0.15 to 0.45	Lover or close friend only
Personal Zone	0.45 to 1.2	Conversation to friends
Social Zone	1.2 to 3.6	Conversation to non-friends
Public Zone	3.6 +	Public speech making

measurements were carried out. The main conclusions from these investigations were that most participants (both children and adults) took up initial approach distances to the robot which were broadly compatible with Halls personal or social spatial zones. However, it was also found that there were sizable minorities who approached the robot to distances that were much closer than would be expected from Hall's social zone distances. Details of these Human-Robot social-spatial trials can be found in [24][25], and other aspects and outcomes from these HRI trials in [26][27][28] [29].

The present trial included the additional conditions of different robot voice styles on people's initial comfortable approach distances. From human proxemics (cf. [19]) it is known that the gender of interactants has a significant effect on proximity, so it was also hypothesised (H2):

The perceived gender of the robot's voice would affect people's comfortable approach distances.

To explore the effects of robot voice gender, three voices were chosen for the robot: a male voice, a female voice and a (synthesized) neutral voice. A no voice condition was used as a control. This study was performed as one of two demonstration HRI trial events at the AISB Symposium at the University of Hertfordshire during April 2005.

II. Experimental Method

The PeopleBot™ was stationary in the far corner of the experimental area, which was screened on three sides and open at one end for audience viewing. The robot incorporated a simple lifting arm with a fixed hook style finger. This was used for simple gestures and manipulations in previous trials, and was left in place for consistency (see Fig. 1.). The participants were symposium attendees, and the trial session was run over two hours as one of several concurrent demonstrations of HRI trials and robotics research as part of an evenings entertainment for the symposium reception event. There were 21 (36%) female and 37 (64%) male participants (58 total) and ages ranged from 22 to 58. Most (approximately 83%) described themselves as being familiar with robots and computer technology and were academics or scientists. Thirty six (62%) had also previously participated in another separate experiment with a PeopleBot™ robot [30]. All were right handed, apart from 4 males who judged themselves as either left handed (2) or ambidextrous (2). They signed consent forms and provided basic demographic details by means of a short questionnaire, then entered the experimental area. The robot was switched on and made noises from servos, sonar and cooling fans in order to reinforce the 'live' nature of the trial. In the trial conditions where the robot had a voice (male, female and synthesized), the robot itself gave instructions to participants. The four robot voices styles were:

1. Male Voice - a high quality male voice, recorded by a male speaker with a neutral English accent.
2. Female Voice - a high quality female voice, recorded by a female speaker with a neutral English accent.
3. Synthesized Voice - a low quality voice created by a speech synthesizer (Festival Lite - flite). The voice was obviously synthesized, and ostensibly an American English male voice, but was pitched deliberately high in order to provide an androgynous neutral voice style.
4. No Voice - The male experimenter read scripted instructions in a neutral English accent.

The voice styles were chosen as we expected different responses towards different gendered voices (male/female, cf. hypothesis H2). We also expected that people might respond differently to a robot with a human-like voice, in contrast to a more 'robotic' (synthesized) voice. The no voice condition was chosen as a baseline. In all cases the script for instructions to participants was identical, apart from the part indicated in bold, where the experimenter gave instructions for the no robot voice condition:

1. "Welcome to the second part of our demonstration. We are investigating how robots should behave in the presence of people and we would be grateful if you would participate in a short experiment."
2. "If you are uncomfortable with this, or do not wish to participate for any reason, you may leave through the exit to the side of the test area."

Note: If the participant exited the test area at this point (or does not want to continue at any point) this would have terminated the trial).

3. "Thank you. We are very pleased that you have agreed to help by participating in this experiment. We want to find out the distance that humans prefer to take relative to robots."
4. "When I say 'Approach now', would you approach ***me*** (*or* ***"the robot"*** *as appropriate*) to a distance which you feel is the most comfortable for you.

When you reach that distance, please raise your hand."

If the participant did not understand, the last instruction was repeated. Otherwise:

5. "Approach now"

Once the participant had approached the robot to their desired comfortable distance and raised their hand, the experiment supervisor then measured that approach distance.

6. "Thank you for participating in our experiment. Please continue on through the area exit".

In order to find out more about participants' perceptions of the robot (as linked to the male and female voices), at the end of each trial, participants were asked to provide a name for the robot. However, many (26 from 58) declined and the (demonstration and entertainment context) nature of the trial did not allow us an opportunity to ask their reasons for this. Distance measurements were made using a marked paper tape strip on the floor and a tape measure (cf. Stratton et al. [31]). To standardize the measurements for this study, they were made from the closest part of the participants feet (invariably the front of the leading foot, shoe or toe) to the nearest part of the lower bump ring on the robot, to the nearest whole cm (accuracy ± 0.5cm).

III. Results and Analysis

The overall distribution of participants' approach distances is shown in Fig. 2. Compared to Hall's social zones, approximately 33% of the participants approached to a distance comparable to the Intimate zone, 56% to the Personal zone and 12% to the Social zone. As with our previous trials addressing H1, a similar proportion of close (intimate zone) approaches were observed (cf. Walters et. al. [24]). Consistent with this study, there was also a small proportion of participants who took up approach distances that were close to the far limit for the social zone. Univariate ANOVAs were performed on the approach distances

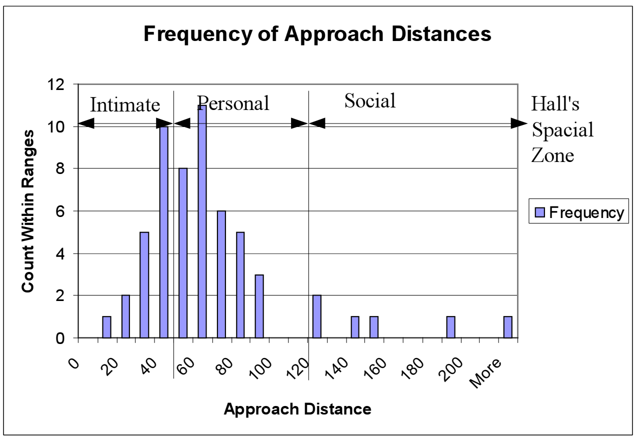

Fig. 2: Overall distribution of human to robot approach distances for robot voice style conditions.

grouped by various factors. Significant differences were found when participants were grouped by the robot voice conditions (H2, see Table II) and also depending on whether they had previously taken part in the other demonstration HRI trial (Table III). The findings are discussed below:

A. Robot Voice

The approach distance distributions are compared as box-plots in Fig. 3. There were significant differences in approach distance means between the groups approaching the robot with the synthesized voice (mean 80.3cm) and the other groups: the male voice (mean 51.5cm), the female voice (mean 60.3cm) and the no voice condition (mean 42.4cm). Significant differences in approach distances were found only for the robot with a neutral gender (synthesized) voice (partially supporting H2).

B. Previous Trial Experience

There were also significant differences in the human to robot approach distances for participants who had previously participated in a separate HRI demonstration trial as part of

Table II: LSD Post-hoc Tests for Robot Voice

Robot Voice (I)	(J)	Mean Diff. (I-J)	Std. Error	Sig.	95% Conf. Int. Lower	Upper
M	F	-9.08	11.02	.414	-31.21	13.05
	S	-28.83*	11.51	.016	-51.95	-5.71
	N	9.07	11.67	.441	-14.38	32.52
F	M	9.09	11.02	.414	-13.05	31.21
	S	-19.75*	9.74	.048	-39.32	-0.19
	N	18.15	9.93	.074	-1.80	38.10
S	M	28.83*	11.51	.016	5.71	51.95
	F	19.75*	9.74	.048	0.19	39.32
	N	37.90*	10.48	.001	16.86	58.95
N	M	-9.07	11.67	.441	-32.52	14.38
	F	-18.15	9.93	.074	-38.10	1.80
	N	-37.90*	10.48	.001	-58.95	-16.86

M = Male, F = Female, S = Synthesized, N = No Voice
* Mean difference significant at: $p < 0.05$.

Table III: Between subjects effects on proximity for robot voice style and previous trial experience.

Source	Type III Sum Sqr.	Df	Mean Sqr.	F	Sig.
Robot-voice	Source	3	5571.19	7.008	.001
Which-trial	4867.19	1	4867.1	6.122	.017
Robot-voice * Which-trial	6997.19	3	2332.52	2.934	.042
Error	39753.17	51	795.06		

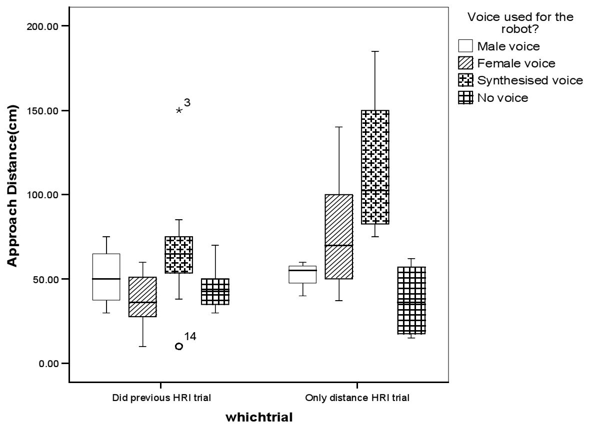

Fig. 3: Human to Robot Approach Distances for the Robot Voice Styles, Grouped by Previous Trial Exposure to the PeopleBot™ Robot.

the same event with another identical PeopleBot™ robot [30] [25] (see Table III). Participants who had experienced a previous interaction approached the robot significantly closer (mean 51.2cm) than those for whom this was their first encounter (mean 73.9cm).

C. Robot Names and Robot Gender

As a final item for the HRI approach distance trial, each participant was asked to provide a name for the robot. These names were sorted into three groups depending on the perceived gender of the names: Male, Female and Neutral. Of the 32 participants who supplied a name for the robot, 16 (50%) provided a Male name, 15 (48%) a Neutral name and only 1 (2%) a Female name. At a later demonstration event at the Science Museum in London in 2005 the same PeopleBot™ robot performed interactive games with children (ages estimated to range from 4 to 10 years) who were then asked to provide a name for the robot. The names obtained were grouped similarly: male names 50 (41%), neutral names 66 (58%) and only 2 (1%) gave a female name. It is interesting to note that these results were gained in a relatively uncontrolled public HRI environment, and indicates that most people (including children and academics) may perceive the PeopleBot™ robot as either male or of indeterminate gender.

IV. Discussion and Conclusion

The mean approach distances to the robot with a synthesized voice are greater then the other three robot voice conditions, and closest to that which would be expected from a strict interpretation of Hall's spatial zones. The approach distances to the robots with the other voices are generally closer than humans would position themselves to each other on first acquaintance. These results seem to provide mixed support for both H1 and H2, and are consistent with results obtained from our previous experiments (cf. [24] [32]) where 95% of the participants approached the same robot to distances ranging from 47cm to 96cm (Mean 71cm, St. Dev. 63.0). However, Nakauchi and Simmons [33] found that the experimentally derived distances between *humans* standing in a line ranged from 40cm to 80cm. These findings suggest that (non-interacting) humans in a line and humans approaching robots, take up approach distances that according to Hall, are reserved for communications between friends, or even very close friends and family! To account for these observed distances in terms of Hall's social spatial zones theory, one must assume either that the robots are being treated like close (even intimate!) friends (a very unlikely explanation, contradicting results from our previous study into people's perceptions of the PeopleBots™ robots (cf. [1]), or that humans perceive the robot (and other humans in a line) more as they would an inanimate object.

A different interpretation may be made. Stratton et al. [31] performed human-human approach trials with students and reported "comfortable" mean approach distances ranging from 13.9 to 27inches (35 to 69cm). However, this same study also found that human participants approached a clothed headless female tailors dummy to "comfortable" distances that were similar to (or possibly even slightly greater than) those for another human. In the light of these findings, it can be can be seen that the approach distances to all four robots is well within the range of distances which would be considered to be usual for human proximity. In our trials, the participants who had not encountered the PeopleBot™ in the previous trial, approached to distances that would be actually be considered normal in the human-human case. However, they approached the robot with the synthesized (neutral) voice to distances that were slightly greater than might be expected from a comparable human proxemic situation. This difference was not so apparent in those who had previously encountered the robot.

Stratton et al. [31] speculated that the slightly greater observed approach distances to the headless tailors dummy in their trials were due to the (in this case, slight) "fear of the strange" effect, comparable to that which Hebb [34] had found in non-human primates. This "fear of the strange effect" in primates may indicate the biological origin of Mori's "uncanny valley" repulsive effect [35][36]. The effect is well known and has been reliably reported as applying to very human-like robots and androids [37]. The main cause of the repulsive effect seems to be linked to a disjoint between appearance and behavior and is greatest for small perceived abnormal appearances or behavior. There is also evidence that the repulsive effect can apply even to robots with a mechanical appearance (cf. Bethal and Murphy [38], and Hanson [39]).

There are several possible explanations for these observations and it is likely that there may be more than one proxemic cause for the variations in the HR approach distances observed here. The robots synthesized voice was perhaps perceived as more consistent with the robots mechanical appearance. This may have reinforced the credibility of the robot, causing a slight uncertainty in the approaching participants who reacted with a slightly wary approach, proportional to the perceived "threat". Of course, the threat posed by these robots was not very great, so the "flight" response is noticeable as a slightly greater approach distance.

The participants seem to have judged the robots initially very quickly, perhaps based mainly on their appearance (cf. Lee and Kiesler [40]). Nass et al. [41] have shown that computers elicit a range of social responses from humans. However, humans do not respect the "personal space" of computers (otherwise they would be unusable!). The findings from our study have provided evidence to support H1, that humans do respect the personal spaces of even mechanical looking robots. This is almost certainly due to their physical form and embodiment (cf Breazeal [42], Walters et al. [24], Hüttenrauch et al. [43], & Nomura et al. [44]). However, the evidence with regard to H2 is more complex to interpret. It seems that issues related to consistency of robot appearance and voice style (non-verbal behavior) may have had more influence on participants' comfortable approach distances then their perceptions of the robots gender.

The participants in this HRI trial were mostly familiar with the technology and limitations of current robots and it could be argued that they would not be representative of the population as a whole. However, the findings from this trial that can be directly compared with the results from the previous similar studies, with robot naive participants, were very similar [24]. This indicates that experienced users may react in a broadly similar way to naive users for their initial perceptions of the robot. It is desirable for further experiments to compare the time taken by naive and experienced users to form and refine their initial perceptions of any particular robot. In the near future the first real users of domestic and companion robots will probably be those who are most enthusiastic about robots so experienced users may well be the norm for domestic robots.

The informal nature of the demonstration HRI trial event, where food and drink was provided, and the viewing audience may have affected the results. However, any effects due to this were broadly counterbalanced across the participant groups. Sabanovic et al. [45] have argued that it is essential that HRI study methods must be developed for normal situations and environments which cannot be replicated under controlled lab conditions. The findings from this study support the idea that valid results can be obtained from HRI studies in a (relatively uncontrolled) normal human environment.

What humans actually perceive and rate as consistency in robot appearance and behavior, and how these relate to the functionality and effectiveness of robots, are currently open questions in the field of HRI research. The appearance of the robot was mechanical-looking in this trial. Future work should investigate the effect of robot appearance on human perceptions, and also how this may change with longer term exposures and differing robot appearances. Some of these issues are addressed in our other recent studies (cf. Walters et al. [46], Syrdal et al. [47] & Koay et al. [48]) but this study has highlighted further areas where research is needed.

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