COGNITIVE SCIENCE SOCIETY July 25-26, 2005, Stresa, Italy, pp. 29-37
TOWARD SOCIAL MECHANISMS OF ANDROID SCIENCE
A COGSCI 2005 WORKSHOP

The Influence of Subjects' Personality Traits on Predicting Comfortable Human-Robot Approach Distances

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Abstract

This study began with the hypothesis that the approach distances people prefer when interacting with a robot are similar to those that strangers prefer when interacting with each other. Our experiments involving humans interacting with a mobile robot confirm this hypothesis: the results show that a majority (60%) of the human subjects tested take up initial approach distances that are compatible with normal human-human social interaction distances. However, surprisingly, a large minority of subjects in the experiments (40%) took up positions which were significantly closer, suggesting that they were not treating the robot as a 'social entity'. We then tested the hypothesis that this large minority of subjects' had common personality factors that predicted their likely approach distance preferences. The subjects' personalities were assessed using several traits from the three-factor Eysenck personality model. Further analysis of the data identified four new factors, different from Eysenck's model, tentatively labeled "Proactiveness", "Social Reluctance", "Timidity" and "Nervousness". When testing for correlations between approach distances and personality data, "Proactiveness" correlates with social distance, i.e. subjects that score higher on this factor come less close to the robot.

Introduction

Studying social and personal spaces with regard to robots, designed for use in the home, is a particular area of research within the wider field of Human - Robot Interaction (HRI). In the near future, it is anticipated that robots will increasingly be used for applications in office and domestic environments. Therefore they will be required to work alongside and interact closely with the human residents.

An excellent overview of socially interactive robots (robots designed to interact with humans in a social way) is provided in Fong et al. (2003). As the study of socially interactive robots is relatively new, there is not a large body of established theories, methods and research experience to draw upon, so experimenters in the field usually use existing research into human-human social interactions as a starting point. These methods and results, along with later research, have provided a guide for more recent research, studies and investigations into human reactions to robots (Thrun, 1998), (Goetz & Kiesler, 2002), (Scopelliti et al, 2004), (Severinson-Eklundh et al, 2003), (Nakauchi & Simmons, 2002).

Previous work has often assumed that robots are perceived as 'social beings' and that humans will respond to a robot in a similar way, for example, as to a pet, another human, or even as to a child or infant. Evidence exists that humans do respond to certain social characteristics, features or behaviours exhibited by robots (Breazeal, 2002), (Friedman et al, 2003), (Sony, 2004), (Kanda et al, 2003) (Okuno et al, 2002). Reeves and Nass (1996) provided evidence that in interaction with computer technology people exhibit aspects of social behaviour towards computers. Indeed, if future android robots will be *indistinguishable* from human beings then humans can be expected to interact with and view them like people (Dautenhahn, 2004). The study by Friedman et al. (2003) has shown that while people in many ways view an Aibo robot like a real dog, they do not treat it and view it in precisely the same way as a living dog (e.g. with regard to moral standing). Thus, as long as robots can still be distinguished from biological organisms, which will still be the case for a long time to come, it is unlikely that people will react socially to robots in *exactly* the same ways that they might react to other humans or other living creatures in comparable contexts (Norman 1994), (Dryer, 1999), (Khan, 1998), (Dautenhahn, 2002), (Dautenhahn et al, 2002).

Research towards androids that are indistinguishable from humans is a very challenging area of research not only from a technological, but also from a psychological and social sciences point of view. For example, Minato et al. (2004) have built an android robot with a view to studying how humans interact with robots which have a very human-like appearance. Studying human behaviour towards increasingly human-like androids can be expected to shed light not only on human-robot interaction, but also on some fundamental principles of human-human interaction.

Human-Robot Social Spaces

The main emphasis of our research is on the physical, spatial, visual and audible *non-verbal* social aspects of robots interacting socially with humans. In particular, we are interested in studying human-robot social spaces and distances. Hall (1966) describes a basis for research into social and personal spaces between humans, and later work in psychology has demonstrated that social spaces substantially reflect and influence social relationships and attitudes of people. Embodied non-verbal interactions, such as approach, touch, and avoidance behaviours, are fundamental to regulating human-human social interactions (Hall, 1968). Spatial zones among people are strongly influenced by cultural factors.[1] The generally recognized *personal spatial zones* between humans are well known and are summarized (for northern Europeans) in Table 1 from Lambert (2004).

Table 1: Human-Human Personal Spatial Zones

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

This paper presents our exploratory research into human-robot social spaces, investigating whether human-human personal spatial zones transfer to human-robot interaction. As a starting point we have compared human-robot approach distances to those that would be expected for the case of a human approaching another human. A working hypothesis was assumed that human-robot interpersonal distances would be comparable to those found for human-human interpersonal distances, cf. (Christensen and Pacchierotti, 2005). We therefore expected that in scenarios designed for direct human-robot interaction, people would assume distances that on average correspond to the 'Social' or 'Personal' zone, (similar to the distances people use when having face-to-face conversations with each other) thus treating the robot as a 'social being' with respect to social distances.

Human-Robot Social Distance Experiments

The human-robot social space experiments were performed before a separate series of experimental sessions studying human-robot interactions in a range of task based scenarios. The subject sample set consisted of 28 adult volunteers as shown in Table 2. All subjects completed consent forms and were not paid for participation.

The Robot: The robot used for this study was a commercially available PeopleBot™ robot which is mechanistic in appearance (see Figure 1). This is a human scaled robot, 1.1m tall, fitted with a camera with pan and tilt capabilities. The robot was fitted with three banks of eight sonar range finders which allow the robot to sense objects at low level (approximately 0.25m from the ground) all around, and at high level (at a height of approximately 1m) in front. The sonar sensors are particularly good at sensing soft targets, such as humans and semi hard materials such as walls, furniture and so on. They are primarily used for object avoidance and safe movement in environments containing humans. The robot uses two differential driving wheels and a caster wheel at the back to aid stability. The only anthropomorphic feature of the robot was a lifting arm, with a hook type end-effector, to allow the robot to fetch and carry small objects in specially adapted pallets (see Figure 4).

Table 2: Subject Demographic Data

Subject Sample Set		
Number		N = 28
Male/Female Ratio		M=14, F=14 (50/50%)
Ages:	< 25	7%
	26-35	43%
	36-45	28%
	46-55	11%
	> 56	11%
Backgrounds:		
	Students:	39%
	Academic or faculty staff	43%
	Researchers	18%
Home Department:		
	Technology or robotics related (computer science, electronics and engineering)	50%
	Non-technology related dept (psychology, law or business).	50%

Figure 1: The PeopleBot™ robot used in the experiments.

The robot was operated under remote control by two hidden operators. This is commonly called Wizard of Oz (WoZ) and is a technique that is widely used in HRI studies. It provides a very flexible way to implement complex robot behaviour within a quick time-scale (Robins et al. 2004), (Green et al. 2004). The main advantage is that it saves considerable time over programming a robot to carry out complex interactions fully autonomously.

At the start of each experiment the robot was driven to the same fixed position in the room for each approach distance test. This was achieved by using the table in the corner of the room (position 5 in Figure 3) as a stop position reference for the robot's sonar range sensors. The robot could then therefore be driven towards the corner, until it stopped at a

This implies that robots and other agents interacting with people should be culturally adaptive [Patricia O'Neill-Brown. Setting the stage for a culturally adaptive agent. In Socially Intelligent Agents, pages 93-97. AAAI Press, Technical report FS-97-02, 1997].

fixed distance from the corner.

Experimental Method: The experimental sessions took place in a conference room at the University premises, which was converted and furnished to resemble a domestic sitting room as far as was possible. One end of the room was partitioned off using shelf units, cupboards and high screens to form a control area for the robot operators. Marks were made on the floor using masking tape along the diagonal of the experiment room, and scale marks made at 0.5m intervals between them (Figs. 2 and 3).

Figure 2: View of the simulated living room showing the robot and the 0.5m scale marked diagonally on the floor

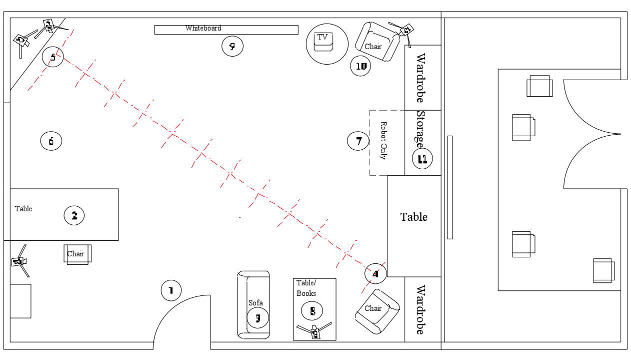

Figure 3: Plan view of simulated living room layout. Comfort distance tests carried were out along the marked diagonal line.

The human-robot comfort and approach distances were estimated from video records of the sessions, rather than having the experimenter making intrusive measurements or notes during the experimental sessions. Each experimental session followed the same format:

1) Entry to room and introduction of robot

2) Co-habituation and initial questionnaires; While the subject was filling in the first questionnaires, the robot wandered randomly around the test area to acclimatise the subject to the robot, for a period of five to ten minutes prior to the distance tests.

3) Comfort and social distance tests

4) Various other HRI task scenarios and questionnaires. [1]

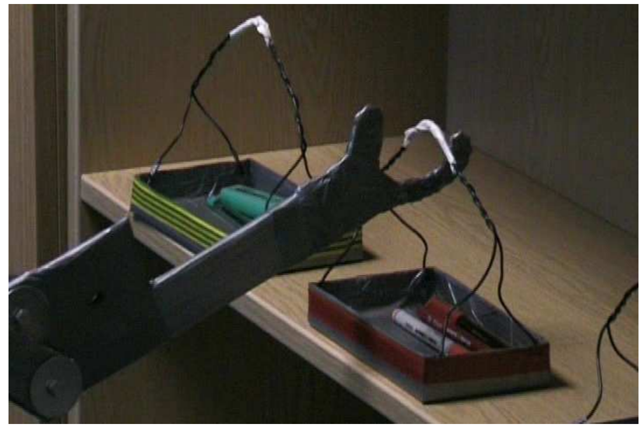

Fig 4: Detail showing the robot's arm and hand as used in the human-robot social distance study.

An experimenter explained to the subject the tests to be carried out and supervised the experiments. Otherwise, she interfered as little as possible with the actual experiment. For measuring the human subject's comfort threshold distance *when approaching the robot*, the robot was driven to point 5 (Figure 3), next to the corner table and turned to face along the distance scale towards point 4 (Figure 3). The subject was told to start at point 5 and to move towards the robot until he or she felt that they were at a comfortable distance away from the robot (Figure 5). The instruction used was "Move towards the robot as far as you feel comfortable to do so". Next, they were told to move as close to the robot as they physically could (if not already in that position); "Move as close to the robot as you physically can". Then they were told to move away again to a comfortable distance; "move back to your most comfortable distance". As we were interested in the non-verbal social behaviour of humans towards robots, by this form of words we avoided mentioning any possible reason for approaching the robot which may predispose the subjects to a particular approach scenario (i.e. talk to, touch or observe). They were then told to repeat these steps once again as a consistency check. The comfortable approach, closest physical and comfortable withdrawal distances were measured for each of the two tests by later close observation of the video records. The distances were estimated to the nearest 0.25m (accuracy ± 0.125m).

For the human-robot approach distance experiments two measurements for the comfortable approach distance and two for the comfortable withdrawal distance were obtained. In practically all cases subject's withdrawal distances were within 0.25m of their comfortable approach distances. The four approach and withdrawal distances were then aggregated to produce a single mean comfortable approach

[1] These latter parts were carried out for separate HRI investigations and are therefore not considered in this paper.

distance value for each subject.

A second set of comfortable approach distance measurements were then made for the situation where the *robot approached a stationary human subject*. The subject was asked to stand at position 4), and the robot was driven to position 5) (the diagonally opposite corner of the room). The subject was then asked to say "Stop" when the robot came as close as they felt was comfortable. The robot was then driven directly towards the subject at a speed of approximately 1 metre per second. When the subject said "Stop" the robot was stopped as quickly as the WoZ operators could react. This usually involved an overshoot so the distance of the robot from the subject at the instant when the subject actually said "Stop" was estimated from the video records of the experiment. By using the video system stop frame facility and the 0.5m scale marks on the floor it was possible to estimate the distance to the nearest 0.25m (accuracy ±0.125m). The robot-human approach distance experiment was also repeated twice as a consistency check. Two robot-human comfortable approach distance measurements were obtained, which were then aggregated to obtain a single mean distance value for each subject.

Figure 5: Human-robot approach distance experiment; a human subject approaching the robot

Results

The means of the four human-to-robot comfortable approach distance results obtained were calculated for each subject and a frequency histogram was plotted, with the ranges set at 0.25m intervals (consistent with the accuracy of the measurements). The results are shown in Figures 6 and 7.

For the case of the robot approaching the human the means of the two distances for each subject are shown in Figure 8. There was no robot-to-human approach distance less than 0.5m as the robot's anti-collision safety system prevented it moving closer than 0.5m to a human (or any other object).

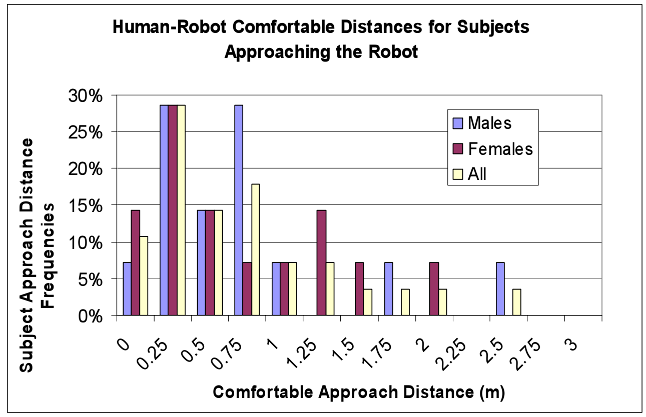

Figure 6: Comfortable distance frequencies for subjects approaching the robot. (Shown as percentages of the subject sample set: N = 28, M = 14, F = 14)

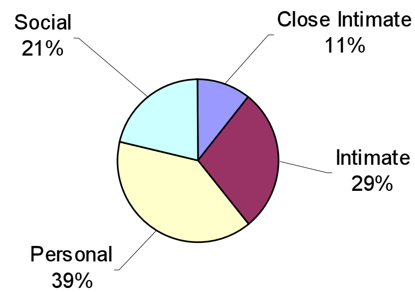

Figure 7: Human to robot comfortable approach distances categorised into Hall's personal spatial zones. (Shown as percentages of the subject sample set: N = 28)

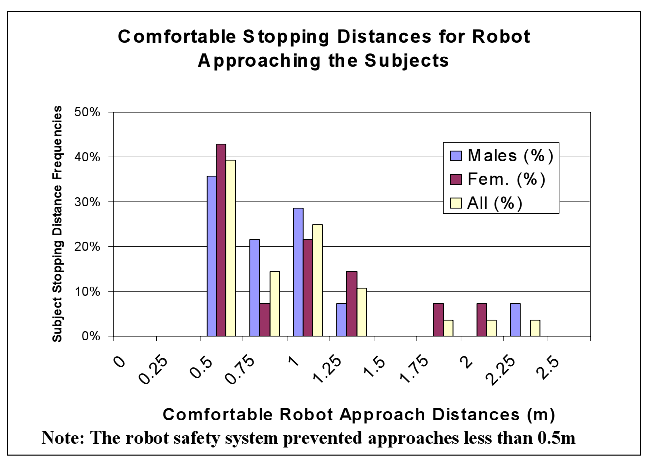

Figure 8: Social (stopping) distance frequencies when the robot approaches the human subjects. (Shown as percentages of the subject sample set: N=28, M=14, F=14).

The approach distance to the robot for the majority of subjects (60% total) was within the expected ranges for comparable human-human social distances, corresponding to either the personal or social spatial zones. However, approximately 40% of subjects approached the robot to a distance of less than 0.45m. Also, 38% of the subjects allowed the robot to approach right up to the 0.5m limit set by the robot's safety system. The fact that they did not stop the robot from physically approaching so closely indicates that the robot did not make these subjects feel threatened or uncomfortable. Indeed, if another, unfamiliar human (a stranger) was to approach to the same close distance; most humans would start to feel distinctly uncomfortable and threatened. Practically all the subjects stated (in post trial questionnaires) that they did not feel threatened by the robot and none wished to become intimate with the robot. It is probable therefore, that this large minority of subjects did not relate to the PeopleBot^{TM} in terms of the normal social distances between humans. (for example; a conversation between friends or acquaintances).

Social Distance and Subjects' Personalities

In order to explore these results further, we hypothesized that there could be common factors in subject's personalities which had an effect on their human-robot social distance preferences. As part of the subjects' preparation for the tests we administered a series of questionnaires. As one of the outcomes of these questionnaires was to obtain a measure of the subject's personalities, we were able to compare the social distance results with the subjects' personality profiles and thus determine if there were any factors which would consistently have had an effect on the human-robot social distance preferred by an individual.

Eysenck's Three-Factor Model of Personality.

In order to address the issue of personality, we chose Eysenck's Three-Factor Psychoticism, Extroversion and Neuroticism (PEN) model (Eysenck, 1991) as a starting point. This provided a relatively simple model which allowed us to categorise and quantify subjects' personalities in a systematic way. In Eysenck's (Eysenck & Eysenck, 1985) view, personality types are not categories that a few people fit; rather, types are dimensions that span a space in which persons can be pinpointed at all possible positions. Types tend to be normally distributed, meaning that they can take continuous values and most people fall around the average mark. From his studies with human subjects Eysenck concluded that personality can be understood in terms of three basic personality factors, which in turn are composed of a number of traits. Due to the time constraints for the HRI experiments not all 27 Eysenck traits were used. Also, since the subjects were rating themselves, certain traits were not considered suitable for self-assessment (e.g. antisocial). The traits chosen were those that seemed most relevant to the present study:

Psychoticism: The loss or distortion of reality and the inability to distinguish between reality and fantasy. This is not a dimension like the other two (it does not consist of polar opposites) - it is present in all individuals to some degree. The traits associated are: aggressive, cold, egocentric, impersonal, impulsive, antisocial, un-empathetic, creative and tough-minded. The traits selected to be used for our study were: aggressiveness, impulsiveness and creativity.

Extroversion: Degree to which a person is outgoing and participative in relating to others. Traits associated comprise: sociable, lively, active, assertive, sensation seeking, carefree, dominant, surgent and venturesome. The traits selected to be used for our study were: sociability, general activity level, assertiveness, excitement-seeking and dominance.

Neuroticism: An individual's adjustment to environment and stability of behaviour over time. The traits associated are: anxious, depressed, guilt feelings, low self esteem, tense, irrational, shy, moody and emotional. The traits selected to be used for our study were: anxiety, tension, shyness and emotional vulnerability. The subjects' personality questionnaires required the participants to rate themselves in terms of the 12 different personality characteristics using a 5-point likert scale. Subjects were all informed that this information would be treated confidentially and would not be linked to their real name during any stage of the evaluation.

The score for each personality factor (F) for every individual subject, is determined by adding up the score for each of the selected (Eysenck) traits (T) for that particular factor, and dividing by the number of selected traits (N) involved (Formula 1):

$$F = \frac{1}{N}\sum_{n=1}^{N} T_n \qquad (1)$$

The three factors thus produced are then combined to create an individual personality vector for each subject (Eysenck & Eysenck, 1985, p. 192).

Results of Personality Questionnaires

Instead of the 27 traits used by Eysenck, only 12 of these were measured in the present study. This means that the combined traits used by us may not fully reflect the original Eysenck factors. To check this, we performed a confirmatory factor analysis in which it was assessed in how far the correlation structure of the measured variables fitted with the original factor model of Eysenck.

As suspected, none of the chosen goodness-of-fit indices ((Adjusted) population Gamma = (0.664), 0.768, Joreskog GFI = 0.611, Joreskog AGFI = 0.438, Bentler-Bonnet Normed Fit Index = 0.224, BB Non-NFI = 0.083, BB Comparative FI = 0.252, RMSEA = 0.123) lend support for the model and both the ML- and independence model Chi square were highly significant (resp. 127.27 and 163.91, with degrees of freedom of 54 and 66). We therefore decided not to base our interpretations on Eysenck's model, but to analyse the correlations among the 12 selected variables on their own right.

An exploratory factor analysis on the 12 traits shows that 70 % of the variance in the data can be explained by four factors (Table 2). The main traits building up the first factor are Creativity and Impulsiveness. At first sight, this seems to correspond with the "Psychoticism" factor. However, instead of Aggressiveness, General Activity Level and Excitement Seeking also contribute strongly to this factor. We tentatively suggest characterizing this combination as

"Proactive" attitudes. This is backed up by the fact that "Shyness" correlates negatively with this factor.

Table 2: Subject Demographic Data: Loadings of factors abstracted from the 12 measured traits.

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Sociability	0.366230	**-0.728960**	-0.175871	-0.026398
Shyness	**-0.658963**	0.542248	0.016767	0.176433
Vulnerability	-0.424035	-0.559047	-0.052254	-0.472986
General Activity Level	**0.677153**	0.223206	0.251580	0.118710
Assertiveness	0.444187	0.060199	**-0.604208**	0.405537
Anxiety	-0.249595	-0.575984	-0.086875	**0.629583**
Tension	-0.596330	0.023251	-0.137943	0.501070
Creativity	**0.723497**	-0.104735	0.348556	0.060268
Excitement- Seeking	**0.652433**	0.271774	0.196174	0.044795
Dominance	0.514370	-0.064347	**-0.699076**	-0.211223
Aggressiveness	0.143104	0.485739	-0.590123	-0.175436
Impulsiveness	**0.887287**	-0.065932	0.125375	0.204800
Expl.Var	3.843357	1.852954	1.501525	1.204514
Prp.Totl	0.320280	0.154413	0.125127	0.100376

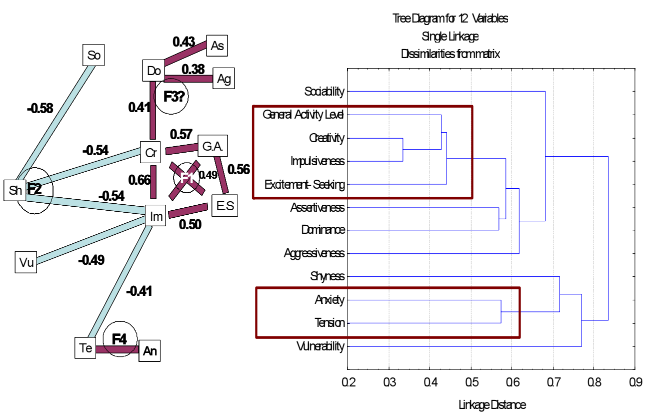

Figure 9: Left: Significant ($p < 0.05$) Spearman Rank Correlations (r_s) among the 12 attributes. Dark bars = positive correlations, light bars = negative correlations. Length of the bars is proportional to the correlation coefficients for $r_s > 0$ and proportional to 1-rs for $r_x < 0$. So = Sociality; Sh = Shyness; Vu = Vulnerability; G.A. = General Activity Level; As = Assertiveness; An = Anxiety; Te = Tension; Cr = Creativity; E.S. = Excitement Seeking; Do = Dominance; Ag = Aggressiveness; Im = Impulsiveness. Note the correspondence with the factors F1 – F4 from the factor analysis (Table II). Right: Cluster analysis based on 1-r_s as distance metric and Ward's Average as cluster criterion. A cluster analysis on the raw data instead of the correlation coefficients gave largely similar results.

Factor 2 appears to reflect the degree of what might be called "Social reluctance": Shyness contributes relatively strongly to it and there is a strong negative correlation with Sociability. Factor 3 seems to characterize "Timidity", as Assertiveness, Dominance and Aggressiveness are all associated negatively with it. "Nervousness" typifies factor 4: both Anxiety and Tension load rather high on it.

The factor analysis is backed up by a Principle Component Analysis (PCA; the principle components are almost identical to the factors), which is based on less assumptions and a non-parametric approach (clustering on Spearman Rank correlations; Fig. 8).

When testing for correlations between approach distances and personality data, "Proactive" is the only factor that correlates with social distance, in the sense that subjects that score higher on this factor come less close to the robot ($r_s = 0.647$, $p < 0.05$). Also the effects of gender, age and technical or robotics experience were investigated. Although males appear to score higher on the second ("Social reluctance") factor (Mann Whitney U Test, $U = 48$, $z = 2.389$, $p < 0.002$), none of these other demographic factors associated significantly with social distance.

Conclusions

We have found that a majority of human subjects (60%) when approaching a robot, or when being approached by a robot, prefer approach distances that are compatible with those expected for normal social interactions between humans (the *social* and *personal* zones as proposed by Hall). This partially confirms our original hypothesis in that it seems that humans respect human-robot approach distances in a way which is comparable to human-human social distances. However, in our experiments a large minority of subjects (40%) took up an initial approach distance to the robot, which was so close that it would be perceived as either threatening (if involving strangers) or intimate (in the case of close friends), if observed between two humans. That these subjects did not perceive the robot in a way that was comparable with normal human-human social distances implies that they did not perceive the robot as a 'social entity' with respect to distances in the same way as with another human being.

We studied subjects' personalities to see if there were common factors which could be used to predict the likely approach distance preferred by the subjects. Factor analysis resulted in four factors that we tentatively label "Proactiveness", "Social Reluctance", "Timidity" and "Nervousness". Correlations with the social distance experiments show a positive correlation for "Proactive". That is, the more proactive a person was, the greater the human-to-robot approach distance tended to be.

At this stage our characterization of these four factors, as an alternative to Eysenck's factors, is preliminary. For this particular study, we do not suggest to use them as a universal scale for human robot interactions. Potentially, factors might be identified as being most suitable for human-robot interaction studies; possibly specific to particular contexts, task environments, particular robots, and/or experimental settings. Future research needs to confirm the findings presented in this paper. Also, the sample of subjects we used was self-selected (all University staff or students). A subject sample which is more representative of potential users of a robot companion might yield different results. Also, in future work we need to consider that the markings on the floor could have influenced subjects' judgements.

Forty percent of our subjects approached the robot closer than would be expected from the *social* distances found in human-human interaction. It seems likely that the mechanistic appearance of the robot used in the experiments was not sufficiently anthropomorphic, or the behaviour not socially acceptable or interactive enough, for all of the subjects to perceive it as a 'social entity' with respect to distances. Previous work has established that robot appearance can be measured against a scale ranging from mechanistic looking, to more anthropomorphic (Woods et al. 2004). It is also known that humans treat robots differently according to their appearance. Mechanistic looking robots are treated less politely than robots with a more human-like appearance. Human expectations of robots which exhibit human-like appearance are higher than those for more mechanistic looking robots (Hinds et al. 2004). It seems possible that (socially) interactive robot behaviour could be rated in a similar way. At present, not enough is known about how to produce appropriate socially interactive behaviour for robots to exhibit. The work presented here is a first attempt to examine human-robot social (distance) relationships with respect to subjects' personality profiles, and to develop methods to estimate users' preferences for android robot appearance and behaviour.

Further work is required to investigate how robots and androids with a range of anthropomorphic features and behaviours are perceived by humans. In this way we hope to find more general principles of human-robot social interaction which can be applied to develop methods to adjust robots' social behaviour and interactions to specific social and task contexts, and also take account of users' preferences.

Acknowledgments

The work described in this paper was conducted within the EU Integrated Project COGNIRON ("The Cognitive Robot Companion") and was funded by the European Commission Division FP6-IST Future and Emerging Technologies under Contract FP6-002020.

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