Proceedings of the 2007 IEEE Symposium on
Artificial Life (CI-ALife 2007)

Robotic Etiquette: Guidelines for Human-Robot Embodied Encounters Involving a Mechanical-Looking Robot in a Fetch and Carry Task

M. L. Walters, K. Dautenhahn, S. N. Woods, K. L. Koay

Abstract—**This paper presents results, outcomes and conclusions from a series of Human Robot Interaction (HRI) trials which investigated how a robot should approach a human in a fetch and carry task. Two pilot trials were carried out, aiding the development of a main HRI trial with four different approach contexts under controlled experimental conditions. The findings from the pilot trials were confirmed and expanded upon. Most subjects disliked a frontal approach when seated. In general, seated humans do not like to be approached by a robot directly from the front even when seated behind a table. A frontal approach is more acceptable when a human is standing in an open area. Most subjects preferred to be approached from either the left or right side, with a small overall preference for a right approach by the robot. However, this is not a strong preference and it may be disregarded if it is more physically convenient to approach from a left front direction. Handedness and occupation were not related to these preferences. Subjects do not usually like the robot to move or approach from directly behind them, preferring the robot to be in view even if this means the robot taking a physically non-optimum path. The subjects for the main HRI trials had no previous experience of interacting with robots. Future research aims are outlined and include the necessity of carrying out longitudinal trials to see if these findings hold over a longer period of exposure to robots.**

I. INTRODUCTION

As robots are being developed to do useful tasks in domestic and office environments, it is important that they are able to interact with humans in ways which humans find comfortable. An excellent overview of socially interactive robots (robots designed to interact with humans in a social way) is provided in Fong et al. [1]. One of the areas where little is known about how robot should behave to wards humans is concerned with respecting user's social space requirements and preferences. The field of research into 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). The main emphasis of this research is on the physical, spatial, visual and audible non-verbal social aspects of robots interacting socially with humans. In order to study human-robot social spatial relationships, HRI trials using carefully devised test scenarios are conducted [2], where human responses and opinions can be collected using a variety of methods. A number of previous live HRI trials with human scaled PeopleBotTM robots have been carried out by our research group [3, 4, 5, 6, 7, 8]. Other researchers have also carried out HRI trials involving human sized robots interacting with people, including Dario et al. [9], Severinson-Eklundh et al. [10], Kanda et al. [11] and Hinds et al. [12]. There are two main important reasons why human-robot interaction trials need to be carried out with scenarios that seem 'natural' in a human-human setting:

1) Often, the behavior which is under investigation is seen as so trivial, or obvious, that there is little or no previous or published work available for the human-human interaction case. In which case carrying out user HRI trials are the only way to understand how robots should behave under these little researched conditions

2) As the study of socially interactive robots is relatively new, experimenters in the field often use existing research into human-human social interactions as a starting point. However, even where there is information about an interaction for the human-human context or scenario, it is important not to assume that robots should simply behave in the same way that a human should in a comparable situation.

We have found that this is often not the case [13, 14] and that any assumptions of how robots should behave which are based on similar human-human interactions should always be tested to verify how applicable they may be to human-robot interactions.

As domestic and office robots carry out useful tasks, they will have to move physically around in the same workspace as humans. However, it is important that robots will not just simply move around and avoid people in the same way as they would an inanimate object but they will have to respect people's social spaces and shared workspace preferences. Note, our work is using a mechanical-looking robot without any intention to make it look or behave like humans.

Hall [16, 17] provided 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

Manuscript received November 10th 2006. 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..

M. L. Walters, K. Dautenhahn, R. te Boekhorst, K. L. Koay, S. N. Woods. All authors from: Adaptive Systems Research Group, University of Hertfordshire College Lane, Hatfield, Herts. UK. Email: {M.L.Walters, K.Dautenhahn, R.teBoekhorst, K.L.Koay, S.N.Woods}@herts.ac.uk.

approach, touch, and avoidance behaviors, are fundamental to regulating human-human social interactions [18], and this has provided a guide for more recent research into human reactions to robots [19]. Michalowski et al. [20] have used a model of social engagement, which includes human-to-robot approach distance and direction to assess human intent to interact with a robot.

Other previous work has also generally 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. There is evidence to support this view that humans respond to certain social characteristics, features or behaviors exhibited by robots (Breazeal [21], Kanda et al. [22], and Okuno et al. [23]). Reeves and Nass [24] provided evidence that even in interaction with computers people exhibit aspects of social behavior. A study by Friedman et al. [25] 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). Walters et al. [26] has found that humans can appear to observe approach distances towards robots which are comparable in some ways to those found for human-human social distances [16, 17]. However, many humans do not seem to mind very close approaches to the robot which in a similar human-human context would be perceived as over-familiar or threatening. Thus, 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 [27, 28, 29, 30].

This paper summarizes and reviews the results from a series of Human Robot Interaction (HRI) trials carried out at the University of Hertfordshire (UH) which examined how robots must behave when fetching and carrying objects to and from human subjects in a domestic ‘living room’ scenario. The studies are part of our long-term goal to investigate requirements and ‘social rules’ (a ‘robotic etiquette’) for a robot companion which is able to a) perform useful tasks in a home environment and b) behaves in a manner that is acceptable and comfortable to humans [15??]. As fetching and carrying objects is an important fundamental component of a wide range of useful tasks for a robot companion in the home, the eventual aim of these studies is to provide a set of rules and parameters that can be used to provide guidance to the designers and builders of domestic (servant) robots in the future. (Note; in our studies, we study the human centered view of HRIs and our definition of a fundamental component of robot behavior is more broadly defined, compared to that which may be identified from a purely technical viewpoint). The main research question addressed in these studies documented here was:

How should a robot approach a human when fetching an object to the human?

To address this question a series of HRI trials were carried out; two sets of pilot trials and a set of more exhaustive main trials. The relevant results from the pilot trials are summarized briefly in section 2 below. Other aspects and outcomes from these pilot trials have been covered previously in [7, 8]. The main HRI trial was then carried out in order to verify and expand upon these limited outcomes and the results from these trials are covered more extensively in section III.

II. The Pilot HRI Trials

This section summarizes relevant results from two exploratory live HRI trials. First results were from a human-robot interaction demonstration trial event, which was run as part of an informal evening event at the AISB’05 Convention held at University of Hertfordshire in April 2005. Follow-up trials were then carried out in a controlled laboratory set-up, to re-test the provisional results gained from the demonstration trial.

The pilot trials were both carried out in converted seminar rooms where the scenario involved a robot using three different approach directions (front, left and right) to bring a seated subject an object (a TV remote control). The main aim of both trials was to establish subjects’ preferences for the different robot approach directions. The demonstration event was conducted as part of an evening of entertainment for convention delegates, and involved different robot demonstrations. Spectators were present during the trials which were performed under non-laboratory conditions using 38 volunteers from the convention. The follow up study was carried out under controlled conditions with 15 subjects, and one of the main aims of this trial was to re-test the results obtained from the informal study.

A. Experimental Setup

The trial set-up was identical for both trials and resembled a simulated living room with a chair and two tables. The subject was seated in the chair, which was positioned halfway along the rear wall (point (9), Fig.1), throughout the trial. To the left front, and right front of the chair, two tables were arranged (with room for the robot to pass by) in front of the chair. One of the tables had a television placed upon it; the other had a CD Radio unit. The robot was driven under direct remote control to the appropriate start position by an operator, but the robot’s approaches to the subject were fully autonomous. The operator was seated at a table in the far corner of the room. Subjects were told that the robot would be controlled by the operator while it was driven to the three start positions, but would be approaching them autonomously to bring them the TV remote control. This was reinforced as the operator made notes and did not press any of the robot control keys (on the robot control laptop) while it approached the subject (Figure 1). The robot carried the remote control in a small basket suspended between the fingers of the lifting gripper. The remote control was placed in the basket prior to each experimental run. For each approach trial, the subject took the remote from the basket then replaced it ready for the next approach.

B. Trial Scenario

The same scenario was used for both HRI trials, introduced by the experiment supervisor. The context explained to the subjects was as follows: the subject had arrived home, tired after a long day at work and rested in an armchair (point (9), Fig.1). After looking around for the TV remote control, the subject then asked the robot to fetch it for them as they were too tired to get up. The robot then brought the remote control to the subject. It was explained to the subject that the robot was new to the household and it was necessary to find out which approach direction the subject preferred; either from the front (2), the left (1) or the right (3). The three possible paths taken by the robot are shown in Fig. 1. In order to justify the scenario of the robot fetching the remote control, one of the tables had a (switched off) TV set upon it. The other table had a CD-Radio unit.

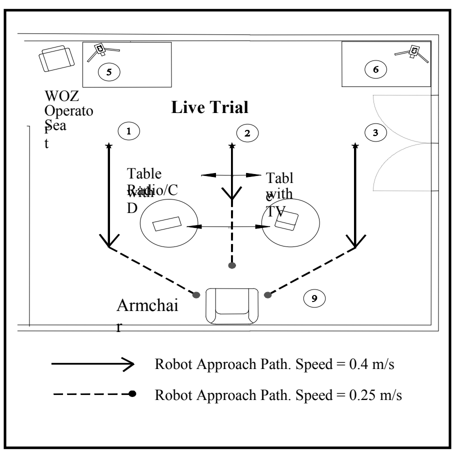


Fig. 1. Live Trial Area.

Fig. 2. Examples of the demonstration HRI trial.

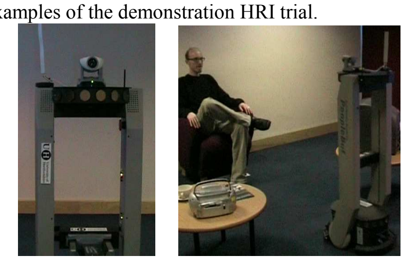


Fig. 3. Example of the follow-up HRI trial.

C. Experimental Conditions

The TV might have been a natural focus of subjects' attention and influenced the choice of preferred robot approach direction. Therefore, for the controlled lab conditions half the trials were carried out with the TV on the left hand table, and the other half with the TV on the right hand table. Each subject experienced the robot approaching from three directions: front, left and right. The order in this sequence was counterbalanced.

D. Subject Sample Sets

For the demonstration trial, 21 males (54%) and 18 females (46%) participated. The mean age of subjects was 36 years (range: 22-58). Thirty five subjects (95%) were right handed, and 2 subjects (5%) were left handed. All were delegates at the AISB'05 Convention. These trials were conducted in a demonstration context and only approach preference ratings (Likert scale; 1=Disliked a lot, to 5=Liked) a lot and basic demographic details (age, gender, handedness and job function) were collected by a simple questionnaire and consent form.

Fifteen subjects (9 (60%) males; 6 (40%) females) participated in the follow-up study. The mean age of this sample was 33 years (range 21-56 yrs). Only one subject was left handed. Four subjects were secretarial staff, 5 subjects were MSc students studying 'Artificial Intelligence', and the remaining 6 were research staff in the Computer Science Department at University of Hertfordshire. No subjects had previous exposure to the robots used in the trial. In light of the comparable HRI trial methodologies and the high degree of agreement between these approach preference results, they were combined to form one dataset from the 55 subjects who participated in both trials [6]. Thirty males (56%) and 24 females (44%) in total participated in the robot approach direction trials. The mean age of subjects was 36 years (range: 21-58, SD: 11.54). Forty nine subjects (94%) were right handed, and 3 subjects (6%) were left handed.

E. Procedure

For both trials, subjects completed introductory questionnaires to gain the necessary consent and basic demographic details. At the end of the trials, a questionnaire was used to assess subject attitudes and preferences for the different robot approach directions, and approach speed. The questionnaires also included questions about the robot stopping distances, comfort levels and practicality for the different approach directions, all rated according to 5-point Likert scales. Subjects also participated in a semi-structured interview after the follow-up trial, the main purpose of which was to assess subjects' views about the reasons for their approach preferences, the trial procedures and methodology, and also find out how the trial could be improved from the participants' point of view.

F. Combined Results of Pilot Trials

1) Approach Direction Preferences

Figure 4 illustrates that 59% (N: 31) of subjects stated preferring the right robot approach direction, followed by 28% (N: 15) who preferred the left approach, and just 13% (N: 7) preferred the front approach. An overriding majority of subjects stated least preferring the front robot approach direction (N: 43, 80%). Few subjects least preferred the left and right approach directions.

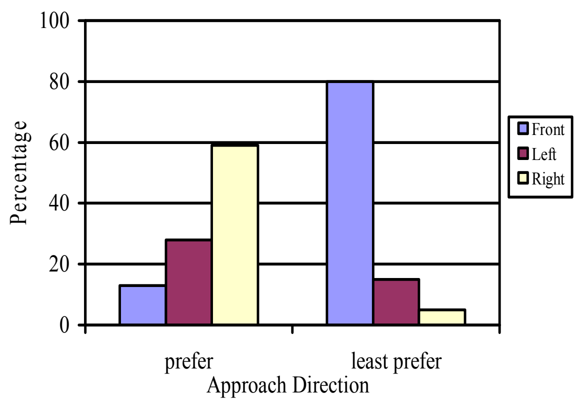


Fig. 4. Combined trial results: Overall robot to human approach direction preferences

2) Practicality of Approach Directions

A Friedman test for ordinal data illustrated that the rankings for approach direction practicality were significantly different from each other (χ^2 (54, 2) = 21.87, $p < 0.001$). The mean rankings indicate that the front approach direction (mean ranking = 1.55) was rated as the least practical, and that the right approach was the most practical (mean ranking = 2.34), followed by the left (mean ranking = 2.11) approach direction.

3) Comfort Ratings of the Approach Directions

Results from a Friedman test showed that the comfort level rankings for approach directions were significantly different from each other (χ^2 (54, 2) = 47.78, $p < 0.001$). The mean rankings highlight that subjects were the least comfortable with the front (mean ranking = 2.43) robot approach direction, and the most comfortable with the right approach direction (mean ranking = 4.15), followed by the left (mean ranking = 3.76).

4) Gender Differences

Chi-square cross-tabulations revealed a significant association between gender and the robot approach direction preferred (χ^2 (2, 53) = 5.83, p = 0.05). More females stated preferring the robot front approach direction compared to males, and more males preferred the right robot approach direction compared to females (See Figure 8). A small significant relationship was found between gender and least preferred robot approach direction (χ^2 (2, 54) = 5.72, p = 0.06). More males stated least preferring the front robot approach direction compared to females (males: 90%, females: 67%). More females stated least preferring the left (males: 10%, females: 21%) and right robot approach direction compared to males (males: 0%, females: 13%). Independent measures t-tests revealed a trend for males (M = 4.37) to rate the right robot approach direction as more comfortable compared to females (M = 3.88) (t (52) = 1.74, p = 0.08). No further significant gender differences were revealed for comfort ratings of the front and left robot approach directions.

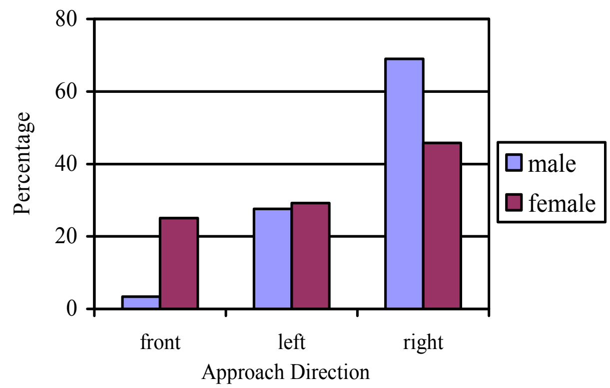


Fig. 5. Combined results: Male and female preferences

Independent measures t-tests were calculated to examine gender differences and ratings of the practicality of the robot approach directions. Significant differences were found for the practicality of the front approach direction (t (52)= -2.46, p=0.02). Females rated the front approach direction as significantly more practical compared to males (males M=2.60, females M=3.38). No further significant differences were found between gender and practicality ratings for the left and right approach directions.

TABLE 1. REASONS WHY SUBJECTS PREFERRED A PARTICULAR APPROACH DIRECTION.

Preferred Front Approach Direction
Front approach direction was easy to reach for the TV remote control The effort needed to reach for the remote control was the least, but this was still not close enough
Preferred Left Approach Direction
I felt the most relaxed and comfortable during this approach This approach felt the most natural This approach was the quickest and most direct It was the most convenient for the robot to approach this way.
Preferred this approach as I am left handed
Preferred Right Approach Direction
I felt the most comfortable with this approach This approach seemed the most natural This approach seemed to be the quickest
I am right handed, so it was the easiest way to take the remote control
This approach, because it was always in my field of vision

TABLE 2. REASONS WHY SUBJECTS LEAST PREFERRED A PARTICULAR APPROACH DIRECTION.

Least Preferred Front Approach Direction
I had to move forward to reach for the remote control, the robot was too far away from me
This approach was slightly threatening This approach was intimidating Seemed too aggressive This approach was just a little bit too close for comfort
The robot was always looking a me
I was concerned about the robot running into me during this approach
Least Preferred Left Approach Direction
Didn't like left approach as I am right handed It was difficult for me to reach for the remote control I felt awkward reaching across with my left hand It felt like I had to reach further for the left approach
The robot was not in my line of vision during the left approach
Least Preferred Right Approach Direction
Least preferred this approach because I am left handed
The robot felt like it was behind my back during this approach

5) Comments made by Subjects about the Three Robot Approach Directions

Subjects for the second trial were asked to provide details about the reasons for preferring and least preferring particular robot approach directions. The most frequently cited comments are provided in tables 1 and 2.

III. 3. MAIN APPROACH TRIAL

In the light of the encouraging results from these small scale pilot studies a main study was designed which under controlled experimental conditions investigated further aspects of how robots should approach and serve human subjects in a socially acceptable way. The specific aspect that the pilot studies considered was how a robot should approach a seated human. Therefore, the main aims of the main studies and trials were:

1) To confirm and consolidate the results previously obtained from small scale pilot studies, using more diverse live and video based HRI trials.

2) To extend the range of human-robot interaction situations and scenarios studied.

Other aspects of this study included investigating the relationship between subjects' personality traits and their approach preferences [15] and the comparability of live and video based HRI trials [16]. The trial was performed at non-University premises as comments from the participants of the pilot study indicated that the use of a converted conference room was not perceived by subjects as homely, neutral and characteristic of a domestic environment. Instead subjects occasionally felt tense and as if their behavior was being judged, although they were specifically informed that this would not be the case. In order to provide a more ecologically valid experimental environment, an apartment near to the University was rented, referred to here as the "Robot House", and the main living room furnished and used as the venue for the main trials. Feedback from the participants indicated that they thought the Robot House was not like a laboratory, they felt less as if they were being tested and the perception of the experimental area was more 'neutral' than a laboratory.

In total, four different scenarios were studied in the trials where a robot approached the subject who was located in the living room:

1) Seated on a chair in the middle of an open space.
2) Standing in the middle of an open space.
3) Seated at a table in the middle of an open space.
4) Standing with their back against a wall.

These particular interactions were chosen as they were typical approach situations which would be encountered in a wide range of fetching and carrying tasks that a domestic robot might be expected to carry out. It is hoped that once the appropriate approach behavior expected of robots is known, these actions could then be used as 'primitive' robot action components which could be sequenced appropriately into more complex task scenarios involving a robot approaching a human. The trials were performed in the living room of the Robot House. Of a total of 42 subjects, the first 20 subjects and the final subject experienced scenarios 1) and 2), the remaining 21 subjects were exposed to scenarios 3) and 4).

A. 3.1 Experimental Setup

The Robot House was a standard British or Northern European style, two bedroom, ground floor apartment with a small kitchen and a relatively large living room area. The living room area was used for all the live HRI trials, the larger bedroom for the video projection room, and the smaller bedroom used to contain video capture and data logging computers and equipment. The robot used for the trials was a commercially available PeopleBot™ with standard equipment fitted, including a pan and tilt camera unit and a standard short reach lifting gripper which was adapted to form a simple tray in order to fetch and carry objects as required. The furnishing for the room consisted of pictures on the walls, a three seater sofa, a table, three upright dining chairs and a low coffee table. During the trials, most of the furniture was arranged at one end of the room, to provide a large clear space for carrying out the HRI trials. A chair and/or table were moved to the central position as required for the trial scenarios where the subject was to be seated in the middle of the room or at the table.

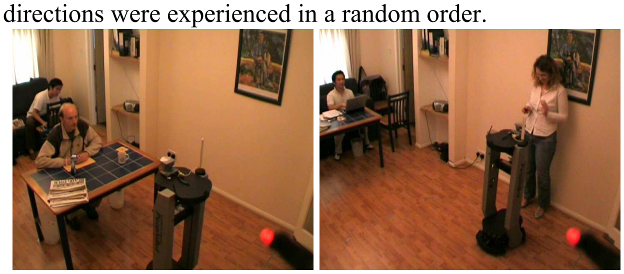
The experimental trials were carried out by three researchers: An experiment supervisor, a robot operator and a video and data equipment monitoring operator. The experiment supervisor introduced and explained the trial procedure to each subject. First, a short introduction video was shown to the subject, which provided some background details of our work with robots and HRI. The experiment supervisor then administered consent forms and introductory questionnaires.

The individual trial scenarios are considered separately in more detail in the following sections. It was not possible to allow subjects to be on their own with the robot during the live HRI trials for ethical and safety reasons. Therefore, in order to minimize the presence of experimenters in the room, the experiment supervisor handed control of the experiment to the robot operator for the duration of each live trial. The robot operator sat on the sofa at the far end of the room, away from the subjects' direct line of sight, but still visible to the subject. From post trial interviews of participants of the previous pilot studies subjects felt re-assured by the presence of the robot operator. It was explained that the robot operator would only be setting up the robot to a given start position and that the robot would approach them autonomously. Two video cameras recorded each trial; one fixed overhead wide angle camera with an overview of most of the experimental area, and a tripod mounted video camera which recorded a closer view of the subject.

After each HRI approach trial a questionnaire was administered to gain the subjects' categorical views of the most preferred and least preferred approach directions, the approach directions judged as most and least efficient and also other information regarding speed of approach and stopping distance. Other questions allowed the subjects to rate efficiency and comfort on five-point Likert scales (using 1 to signify highly negative, 2 fairly negative, 3 as neutral 4 as fairly positive and 5 as highly positive). For example, for rating task efficiency this translated to 1 = not efficient at all to 5 very efficient, and for comfort this translated to 1 = very uncomfortable to 5 very comfortable.

B. *Procedure*

Forty two subjects were involved in the study, including students and staff members from various disciplines at the University of Hertfordshire (age: 18 to 56 years, 36% female, 64% male, 9% (4 subjects) left handed or ambidextrous). All trials were based on the same general situation where the robot brought a snack to the human subject. Each time the robot approached from a different relative direction, the subject instigated the approach by speaking to the robot. The actual words were not important, but this was done to allow the subject to be prepared for the robot to actually move towards them. The robot operator also used this as a cue to set the appropriate robot approach program into operation. The robot then approached the subject under autonomous control with the operator ready to take over direct manual control only in case of error or emergency stop conditions. For each trial, the approach directions were experienced in a random order.



a) b)

c) d)

Fig. 6. Views from the Robot Approach Direction Trials. a) Seated at table, b) Standing against wall, c) Standing in middle of room, d) Seated in middle of room.

C. *Results*

1) *Seated at a table condition.*

A non-parametric Friedman analysis of variance by mean ranks was carried out to determine whether there were significant differences between subject comfort rating preferences for the different approach directions. Significant differences were found between the mean rankings for the approach directions (χ^2 (4) = 26.05, p < .001), with subjects rating the front left (X = 4.40) and front right (X = 4.35) approaches as the most comfortable. Subjects found the rear approaches the least comfortable.

The Friedman analysis of variance test for subject ratings of robot task efficiency was non-significant (χ^2 (4) = 3.23, p = .520), indicating that subjects had no preference for the level of task efficiency and the approach direction used by the robot.

2) *Standing against a wall condition.*

A Friedman analysis of variance by ranks revealed significant differences concerning subject comfort ratings for the different approach directions in the live HRI situation (χ^2 (2) = 9.33, p = .009). Subjects rated the front direct approach (x = 3.33) as less comfortable compared to the front left (x = 4.05) and front right (x = 4.19) approaches.

No significant differences were revealed between subject robot task efficiency ratings for the live robot approaches (χ^2 (2) = .689, p < .709). Task efficiency ratings ranged from 3.48 – 4.00 indicating moderate to high overall task efficiency.

3) *Seated in middle of room condition.*

Significant differences were revealed from the Friedman test of variance by mean rankings concerning subject comfort ratings for the approach directions (χ^2 (4) = 19.39, p = .001). Subjects rated the front left (x = 4.24) and front right (x = 4.24) approach directions as more comfortable than the rear approaches (rear left x = 3.38; rear right x = 3.62) and the frontal direct (x = 3.43) approach. Results of the Friedman test were non-significant for subject ratings of task efficiency, indicating that subjects did not display overall preferences for a more or less efficient robot approach direction.

4) *Standing in middle of a room condition.*

The non-parametric Friedman analysis of variance by mean ranks uncovered significant differences between subject comfort ratings for the different approach directions, for the live condition (χ^2 (5) = 72.36, p < .001). Subjects clearly felt the least comfortable with the rear central approach direction (x = 1.86), and were the most comfortable with the front left (x = 4.24) and front right (x = 4.38) approaches. The Friedman test was significant for subject ratings of robot task efficiency for the different approach directions (χ^2 (5) = 32.46, p < .001). The rear central (x = 2.57) approach was rated by subjects as being the least efficient, and the frontal approach (x = 4.10), front right (x= 3.95), and front left (x = 3.76) approaches were rated as the most efficient.

IV. Discussion and Conclusions

Overall, the front left and right approaches were rated by subjects as the most comfortable for all the different scenario scenarios. The rear approaches and front direct approaches were rated as being the least comfortable across different scenario scenarios.

With regards to robot task efficiency, subjects mostly did not distinguish a particular approach direction preference. However, there were a few exceptions, in particular for the 'standing in the middle of the room' scenario, where subjects did distinguish between robot task efficiency, with the rear central approach being rated as the least efficient and the frontal approaches as the most efficient. In particular, subjects preferred the direct frontal approach for task efficiency. This is in contrast to the other scenarios, but could be due to the fact that the subject was standing and would have been taller than the robot, therefore not finding the robot intimidating. This is in contrast to the seated conditions, where the subjects were shorter than the robot. Also, in a sitting condition it is 'harder to escape the situation' (compared to standing in the middle of the room) which may have led some subjects to rate the direct frontal approach as aggressive and invasive into their personal space. A distinction was also evident for the 'standing in the middle of the room' and the 'standing against the wall' scenarios for the frontal approach. When standing against a wall, subjects rated a frontal approach as somewhat uncomfortable, but did not when standing in the middle of the room. This could again relate to the feeling of safety with the robot, as it would be harder for a subject to escape the standing against the wall compared to standing in the middle of a room.

Based on our findings, the following design implications for robot behavior are suggested regarding a robotic etiquette for a robot carrying out a fetch and carry task in a living-room scenario as studied in our trials: A distinction should be made between standing and sitting scenarios. For seated scenarios, the robot should avoid using a direct frontal approach. However, this could be used for situations where the subject is standing, but not backed into a wall. Taking account of typical humans' preferences, a direct frontal approach should be avoided when the human is seated, even at a table. A robot should approach a person from the front left or right when delivering an item such as a snack.

With regards to robot physical task efficiency for delivering an item such as a snack, the robot should use the frontal approach directions where physically feasible. The robot should generally avoid using rear approaches, as subjects often found these approaches uncomfortable. However, frequently an approach direction preference was not strongly expressed, indicating that in cases where task efficiency is paramount, rear approaches could be used by the robot.

The main trial provided further statistical evidence reinforcing and extending the findings obtained from the single scenario studied in the pilot studies to four fundamental HRI scenarios. These situations will occur often in a typical robot 'serving' or 'object fetching' task typically with either standing or seated humans. Results indicated some general social and physical robot behavior rules that should be incorporated into robot approach behavior when interacting with humans. Different social approach rules apply depending whether the interacting human is sitting, standing in the open or against a wall or obstacle. The analyses have identified weaker social approach rules for robot handing over behavior, which may be overridden in case of physical task convenience. Some social approach behavior is also identified which should be strongly followed even at the expense of physical task efficiency. The social rules resulting from the HRI studies described in this paper have been implemented as default parameter settings in a robot companion motion planner developed at LAAS [14] within the Cogniron project, the background of this joint work is described in more detail in [31].

Much data obtained from this study awaits further analysis and work will continue to gain insights from the data records. It would also be desirable to extend the range of HRI scenarios studied in order to provide more generally applicable social behavior rules, devise more 'primitive' robot action components and the appropriate contexts where the rules apply. Current work extends the robot approach direction work to a 'handling over an object' scenario involving a subject and a robot equipped with a manipulator. Future work in this area will have to investigate how initial default setting of social rules can be adapted during long-term human-robot interaction as a requirement for a personalized robot companion [30]. Developing a robotic etiquette for a robot companion poses many challenges: due to the embodied nature of human and robot encounters interacting with human-sized robots in a living room scenario is very different from interactions with screen-based or other artificial life agents. Also, results from human-human interaction studies cannot directly be applied, robot companions are not people, but they are not conventional machines such as toasters, either. Thus, investigating the range of possible interaction scenarios and modalities, as well as the possible mappings between the design space of robot behaviour and appearance and the niche space of possible application areas, are important goals of research into robot companions [30].

ACKNOWLEDGMENTS

Thanks go to the University of Hertfordshire COGNIRON team members; Christina Kaouri, Chrystopher L. Nehaniv Rene té Boekhorst and Iain Werry. We would also like to thank Mike Blow, Aris Alissandrakis and Akin Sisbot for their help in carrying out the trials.

REFERENCES

[1] Fong T., Nourbakhsh I. and Dautenhahn K., "A survey of socially interactive robots", *Robotics and Autonomous Systems*, 42, 2003, pp. 143-166.

[2] Walters M. L., Woods S. N., Koay K. L. and Dautenhahn K., "Practical and methodological challenges in designing and conducting interaction studies with human subjects", in *Proceedings of the AISB'05 Symposium on Robot Companions Hard Problems and Open Challenges in Human-Robot Interaction*, 14-15 April 2005, University of Hertfordshire, UK, pp. 110-119.

[3] Koay K. L., Dautenhahn K., Woods S. N. and Walters M. L., "Empirical results from using a comfort level device in human-robot interaction studies", in *Proceedings of International Conference on Human Robot Interaction (HRI '06)*, Salt Lake City, Utah, USA, 2006, pp. 194-201

[4] te Boekhorst R., Walters M. L., Koay K. L., Dautenhahn K., Nehaniv C. L. , "A study of a single robot interacting with groups of children in a rotation game scenario". *Proceedings 2005 IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA 2005)*, June 27-30, 2005, Espoo, Finland, pp. 35-40.

[5] Woods S., Dautenhahn K., Kaouri C. "Is Someone Watching Me? Consideration of Social Facilitation Effects in Human-Robot Interaction Experiments." *Proceedings 2005 IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA 2005)*, June 27-30, 2005, Espoo, Finland, pp. 53-60

[6] Walters M. L., Dautenhahn K., te Boekhorst R., Koay K.L., Kaouri C., Woods S., Nehaniv C. L., Lee D. and Werry I. "The influence of subjects' personality traits on personal spatial zones in a human-robot interaction experiment." *Proceedings of 14th IEEE Int. Workshop on Robot & Human Communication (RO-MAN 05)*, Nashville, USA, 2005, pp. 347-352.

[7] Woods S. N., Walters M. L., Koay K.L., Dautenhahn K., "Comparing human robot interaction scenarios using live and video based methods: Towards a novel methodological approach", *Proceedings of the Ninth International Workshop on Advanced Motion Control (ACM 2006)*, Istanbul, March 27-29, pp. 750-755, 2006.

[8] Woods S. N., Walters M. L, Koay K. L., Dautenhahn K., "Methodological Issues in HRI: A Comparison of Live and Video-Based Methods in Robot to Human Approach Direction Trials", *Proceedings of 15th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 06)*, Hatfield, UK, 6-8 September 2006, University of Hertfordshire, pp 51-58.

[9] Dario P., Guglieimelli E., Laschi C., "Humanoids and personal robots: Design and experiments". *Journal of Robotic Systems,* 2001, 18 (12). 673-690.

[10] Severinson-Eklundh K., Green A., Hüttenrauch H., "Social and collaborative aspects of interaction with a service robot". *Robotics and Autonomous System,s* 2004, 42. pp. 223-234.

[11] Kanda T., Hirano T., Eaton D., Ishiguro H., "Interactive robots as social partners and peer tutors for children: A field trial". *Human Computer Interaction,* 2004, 19 (1-2). pp. 61-24.

[12] Hinds P., Roberts T., Jones L., "Whose job is it anyway? A study of human-robot interaction in a collaborative task". *Human Computer Interaction,* 2004, 19. pp. 151-181.

[13] Walters M. L., Dautenhahn K., Koay K. L., Kaouri C., te Boekhorst R., Nehaniv C. L.,Werry I. and Lee D., "Close encounters: Spatial distances between people and a robot of mechanistic appearance", in *Proceedings of the IEEE-RAS International Conference on Humanoid Robots (Humanoid 05),* Dec 2005, Tsukuba, Japan, pp. 450-455.

[14] Dautenhahn K.,Walters M., Woods S.,Koay K. L., Nehaniv C. L., Sisbot E. A., Alami R. and Simeon T., "How may I serve you? A robot companion approaching a seated person in a helping context", *Proceedings of Human Robot Interaction (HRI '06)*, 2-4 March 2006, Salt Lake City, Utah, USA, pp. 172-179.

[15] Syrdal D. S., Dautenhahn K., Woods S. N., Walters M. L., Koay K. L., "Doing the Right Thing Wrong - Personality and Tolerance to Uncomfortable Robot Approaches". *Proceedings of the 15th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN06)*, Hatfield, UK, 6-8 September 2006, University of Hertfordshire. pp 183-188

[16] E.T. Hall, (1966). *The Hidden Dimension: Man's Use of Space in Public and Private*. The Bodley Head Ltd, London, UK. 1966

[17] E. T. Hall, (1968). Proxemics. *Current Anthropology* 9(2-3): 83-108. 1968

[18] S. N. Woods, M. L. Walters, K. L. Koay, K. Dautenhahn, "Methodological Issues in HRI: A Comparison of Live and Video-Based Methods in Robot to Human Approach Direction Trials", *Proceedings of 15th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 06)*, Hatfield, UK, 6-8 September 2006, University of Hertfordshire. pp 51-58.

[19] Dautenhahn K., Woods S., Kaouri C., Walters M., Koay K. L., Werry I., "What is a robot companion - Friend, assistant or butler?". Proceedings of IEEE IROS 2005, Edmonton, Canada 2005, pp. 1488-1493.

[20] M. P. Michaelowski, C. DiSalvio, S. Sabanivic, "Socially Distributed Perception", in *Proceedings of the ACM Conference on Human-Robot Interaction (HRI 06)*, 2-4th March 2006, Salt lake City, USA. pp. 349-350.

[21] C. L. Breazeal, *Designing Sociable Robots*. Cambridge, Mass. The MIT Press, 2002.

[22] T. Kanda, T. Hirano and D. Eaton, "Interactive robots as social partners and peer tutors for children: A field trial", *Human-Computer Interaction*, 19, pp. 61-84, 2004.

[23] H. G. Okuno, K. Nakadai and H. Kitano, "Realizing Audio-Visually Triggered ELIZA-Like Non-verbal Behaviors", PRICAI2002, LNAI 2417, *Lecture Notes in Artificial Intelligence*, Springer-Verlag, pp. 52-562, 2002.

[24] B. Reeves and C. Nass. The Media Equation: How People Treat Computers, Television and New Media like Real People and Places, New York: Cambridge University Press, 1998.

[25] B. Friedman, .P. H. Kahn Jr. and J. Hagman, "Hardware companions? What online AIBO discussion forums reveal about the human-robotic relationship", *Digital Sociability*, 5, pp. 273-280, 2003.

[26] M. L. Walters, K. Dautenhahn, S. N. Woods, K. L. Koay, R. te Boekhorst, D. Lee, "Exploratory Studies on Social Spaces between Humans and a Mechanical-looking Robot", *Connection Science*, in press, 2006.

[27] D. A. Norman, "How might people interact with agents", *Communications of the ACM*, 37, pp. 68-71, 1994.

[28] D. C. Dryer, "Getting personal with computers: How to design personalities for agents", *Applied Artificial Intelligence*, 13, pp. 273-295, 1999.

[29] Z. Khan, "Attitude towards intelligent service robots", NADA KTH Technical Report, Stockholm, 1998.

[30] K. Dautenhahn, "Design spaces and niche spaces of believable social robots", in *Proceedings of the 11th Annual International Workshop on Robot and Human Interactive Communication (RO-MAN 02)*, 25-27 September, Berlin, Germany, pp. 192-197, 2002.

[31] COGNIRON website. www.cogniron.org. Last accessed Nov 2006.