Group Comfortability When a Robot Approaches

Adrian Ball[1], David Silvera-Tawil[2], David Rye[1], and Mari Velonaki[2]

[1] Australian Center for Field Robotics, The University of Sydney, Australia
{a.ball,d.rye}@acfr.usyd.edu.au
www.acfr.usyd.edu.au

[2] Creative Robotics Lab, The University of New South Wales, Australia
{d.silverat,mari.velonaki}@unsw.edu.au
www.crl.niea.unsw.edu.au

Abstract. This paper investigates the level of comfort in people with different robot approach paths. While engaged in a shared task, 45 pairs of participants were approached by a robot from eight different directions and asked to rate their level of comfort. Results show that comfortability patterns of individuals in pairs is different to lone individuals when they are approached by a robot. This in turn influences how comfortable a group is with different robot approach paths.

Keywords: Human-robot interaction, comfort, group.

1 Introduction

When robots interact with people in social environments it is important to consider how they can initiate interactions without making people feel uncomfortable. How a robot approaches a person will play a strong part in achieving a 'successful' interaction.

When a robot approaches a single person, it is known [1, 2, 3] that people are most comfortable with approaches from the front—where they can see the robot—and are least comfortable when the robot approaches from behind the person. Approaches from a person's front-right and front-left directions are considered more comfortable than a direct frontal approach [3]. These results hold when the person is sitting or standing in the center of the room or with their back against a wall [4].

Algorithms have been developed to allow a robot to approach individuals at home [5, 6], to maintain social awareness while navigating public places [7, 8] and to approach a pedestrian in a public place [9]. Although these algorithms improve how robots navigate in, and use, social spaces they do not consider how a robot should approach a group of interacting people. By knowing what people in groups find comfortable, social awareness can be incorporated into a robot's path planning algorithms so that the robot will approach a person from a direction that is not likely to cause them discomfort.

Preliminarily research into the comfort levels of groups of people when approached by a robot has been conducted by Karreman et al. [10], who investigated the comfort of a group of two people approached by a robot. The current

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paper builds on the findings of [10] by also investigating the comfort levels of individuals in the pair, and extending the experiment to 45 pairs of participants.

When interacting with each other, people form a shared interaction region and face this region [11]. The relative positions of people in the group will often lead to multiple 'front' regions that define frontal approaches to individuals and multiple 'rear' regions that are usually avoided when approaching. When a robot is to approach a group of interacting people it is not obvious which approach path would be most comfortable for the group as a whole.

Note that in all the cited works the notion of a person's 'comfort' is consistent with a natural language understanding of mental comfort as tranquil enjoyment and contentedness; as freedom from unease, anxiety and fear, and is typically assessed simply by asking a person "how comfortable" they are. The same approach is adopted here.

This paper presents the results of an experiment designed to investigate the levels of comfort in a group of two people seated in various configurations when approached from different directions by a robot. The experiment allowed the comfort level of the pair, and the influence of the presence of a second person on the comfort of an individual, to be measured. Two hypotheses were tested: (H1) A group of two people is more comfortable with robot approach directions from a common 'front' direction and less comfortable with approaches from a common 'rear' direction; and (H2) The presence of a second person does not influence the level of comfort of an individual approached by a robot. Hypothesis H2 is derived from the construction of (H1). If it is possible to estimate the comfort levels of groups interacting with robots from the comfort levels of lone individuals interacting with robots, then the presence of other people (H2) cannot influence an individual's comfort levels with different robot approach paths.

2 Experiment Design

For each experimental trial, two participants were seated in low armchairs adjacent to a small square table in the center of the room. The participants were asked to work on a cooperative task for the duration of the experiment. A robot periodically approached and interrupted the participants, asking each to rate their level of comfort with that particular approach direction. Once the robot had approached the group from eight different directions, the experiment concluded with a post-experiment questionnaire. Further details are given below.

2.1 Seating Configuration

Kendon describes [11] how groups of people use physical space while interacting. Three spatial regions are defined in Kendon's formulation: 'o-space', 'p-space' and 'r-space'. The o-space is a transactional space shared between interactants and maintained for the duration of the interaction. The central o-space is surrounded by the p-space; an agent must occupy the p-space to be considered part of the interaction. The nearby area outside the p-space is the r-space. The r-space encapsulates both the p-space and o-space and is the portion of the rest of the world that is monitored by the interactants.

The experiment used the three maximally different ways that two people working on a common task can be seated. These configurations are: opposite each other; in an ‘L-shape’ and side-by-side, referred to here as Configuration A, B and C respectively (Figure 1).

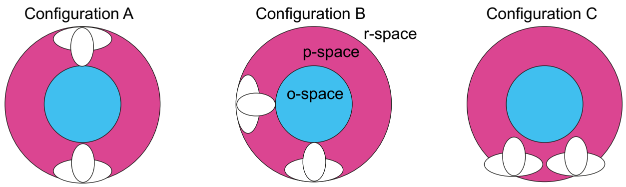

Fig. 1. Seating configurations of two people

2.2 Group Activity

Participants were asked to complete a task to provide a cognitive load that would distract them from the presence and movement of the robot, minimizing participant anticipation of the robot approaches. A jigsaw puzzle was chosen as the task as it is easy to understand, time consuming to finish and doesn’t involve taking turns. Tasks that are performed in turns have an increased chance of participants being less focused on the task when awaiting their turn. A three-dimensional puzzle was chosen to increase task novelty.

2.3 Experimental Space

It is desirable that the experimental space is symmetrical to remove spatial bias due to asymmetric placement of participants in the room. It should also have multiple exits so there is always an exit available to a participant avoiding confrontation with the robot. The room used in this work was square, with six-metre sides and with exits on three of the four walls. Although the exit locations were not completely symmetrical there were exits readily available to participants. Figure 2 shows the arrangement of the experimental space.

2.4 Robot Approach Directions

During each experimental trial the robot continuously circled the seated pair of participants and then approached once from each of the eight directions shown in Figure 2. The approaches were made in random order. Participant familiarity with the robot was expected to increase as they observed it moving around the room, potentially influencing their comfort level during the experiment. Randomizing the order of approach direction across all participants will remove any bias due to increasing familiarity with the robot during each experimental trial.

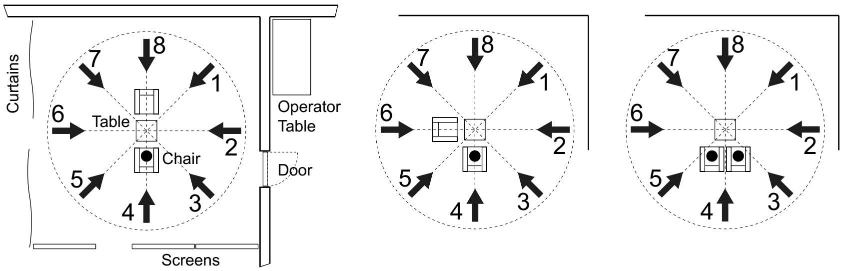

Fig. 2. Experimental space with chairs arranged in Configurations A, B and C. The dots represent reference locations referred to in Section 3.5.

The robot directly approached the center of the table which—as the focus of the group task—was assumed to be the center of the o-space. In every seating configuration there were approach directions where the robot could not reach the p-space surrounding the table by approaching in a straight line; for example, when the robot approached from behind a participant. In such situations the robot approached the p-space as closely as possible without a collision. The robot departed from each encounter along the approach path.

2.5 Robot Design

An Adept Pioneer 3 DX robot was used as the motion platform in this work. The motion platform was augmented with an aluminium frame that supported an Asus Xtion Pro Live RGB-D sensor and a speaker. A laptop computer was placed on the base of the aluminium frame. The robot can be seen in Figure 3. It was intended that the robot be mechanical in appearance to facilitate comparison of results with other research using similar robots.

The robot was controlled using the Wizard of Oz methodology. This decision allows for the robot to be operated in an ordinary room with only an overhead camera to assist the operator with robot movement. Should an unexpected situation arise, a Wizard of Oz methodology allows for safe control of the robot.

2.6 Conduct of the Experiment

Each pair of participants was brought into the room and seated in one of the three configurations. The robot was then wheeled into the room and placed in a corner of the space. The experiment was described to the participants; they were not told that the robot was being controlled remotely. Once the participants understood the experiment and the task, the experimenter left the room and the experiment began. On each approach, when the robot reached the p-space surrounding the table it stopped and prompted the participants via an audio message to answer the next question on the questionnaire. All questions were identical, and asked “Please rate your comfort level regarding the robot’s most recent approach path”, to be answered on a five point Likert scale. Following a

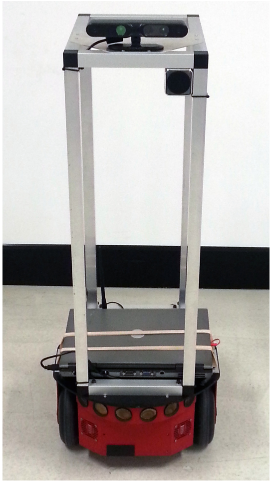

Fig. 3. Robot used for the experiment

short pause, the robot departed along its approach path. In the time between encounters, the robot travelled counter-clockwise around the periphery of the room. This movement was intended to reduce the predictability of when and from where the robot would next approach the participants. Once the group had been approached from all directions, the robot was steered to its initial location in the corner and the experimenter returned to the room with a post-experiment questionnaire. This questionnaire incorporated two commonly used tools: the NASA-TLX [12] and the Godspeed [13] questionnaires, together with questions on participant demographics and comfortability.

The NASA-TLX questionnaire measures a user's perceptions of the mental, physical and temporal demands required to perform a task. This questionnaire was included to determine whether participants were focused on the jigsaw puzzle task rather than the presence and movement of the robot. The Godspeed questionnaire was included to determine how participants perceived the robot. There are five sub-categories that form this questionnaire: anthropomorphism, animacy, likeability, perceived intelligence and perceived safety of the robot.

3 Results

3.1 Participants

Fifteen trials were conducted with participants seated in each of the three configurations. Thirty two of the 90 participants were male and 58 were female. The mean age of the group was 24.4 years old, with a standard deviation of 10.2 years, a minimum age of 18 and a maximum age of 73 years old. Most participants were university students; all were naive to the experiment. Although the variance was raised by the participation of four persons older that 60, no age-dependent effects were observed in the data. Although the variance was raised by the participation of four persons older that 60, no age-dependent effects were observed in the data.

3.2 Perceptions of the Robot

Responses to the three relevant questions in the Godspeed questionnaire, Table 1, show that the robot was perceived as being of mechanical appearance. For example, 74 of 90 (82%) participants gave a score ≤ 2 on a Likert scale of machine-like (1) to human-like (5).

Table 1. Results from the Godspeed questionnaire showing number of participants against scores rounded to the nearest integer

Score	1	2	3	4	5	
Machine-like	27	47	15	1	0	Human-like
Artificial	28	36	21	5	0	Lifelike
Mechanical	30	43	16	1	0	Organic

3.3 Perceptions of the Task

Table 2 shows how the mental demand and effort required to complete the 3-D jigsaw puzzle were rated. The majority of participants scored the mental demand and effort required for the task as 2 or 3, suggesting that moderate mental demand and effort were required to progress towards completing the puzzle.

Table 2. Results from the NASA-TLX questionnaire showing number of participants against scores rounded to the nearest integer

Score	1	2	3	4	5	
Low Mental Demand	16	29	21	17	7	High Mental Demand
Low Effort	12	27	24	25	2	High Effort

3.4 Group Comfort with Direction of Robot Approach

In each experimental trial the pair of participants was approached by the robot from all eight directions in a random order. Each approach direction was assigned a pair comfort score calculated as the sum of the pair's individual comfort scores for that direction. The eight pair scores were then ranked in descending order. Ranks were used in place of scores to remove individual participant bias by effectively using a measure of *relative* comfort rather than an absolute comfort level. Table 3 shows the mean rank of all pair comfort scores for each approach direction for the three seating configurations.

Table 3. Means and standard deviations (in parentheses) of *group* rankings for each robot approach direction and for the three seating configurations, across all pairs of participants

Direction	Config. A	Config. B	Config. C
1	4.4 (2.3)	2.7 (2.1)	3.2 (2.3)
2	4.6 (2.5)	3.9 (2.6)	4.9 (2.3)
3	3.1 (2.4)	3.5 (2.0)	4.3 (2.1)
4	4.9 (2.5)	4.3 (2.9)	6.2 (2.6)
5	3.6 (1.3)	4.9 (2.2)	4.4 (2.3)
6	4.2 (2.6)	5.2 (2.7)	3.6 (1.9)
7	4.5 (2.5)	3.4 (2.1)	2.7 (2.4)
8	5.3 (2.6)	4.5 (2.3)	3.5 (1.7)

A Kruskal-Wallis non-parametric one-way analysis of variance (KW-ANOVA) test was used to determine if there were statistically significant differences in group comfort levels with different robot approach directions. Where significant differences were found, multiple comparisons were made using the Mann-Whitney U test to determine which pairs of directions were significantly different. The p values from this set of comparisons were ranked, and compared with Q values calculated using the False Discovery Rate (FDR) control method with $q = 0.05$ [14]. The FDR method was preferred over the use of the—more conservative—Bonferroni correction factor as it leads to fewer Type I errors.

In Configuration A there was no significant difference in group comfort levels between any of the approach directions ($\chi^2(7{,}112) = 8.64$, p $= 0.28$, $\eta^2 = 0.07$). In Configuration B, there was also no significant difference in group comfort levels ($\chi^2(7{,}112) = 11.94$, p $= 0.10$, $\eta^2 = 0.10$). In Configuration C there was a highly significant difference in group comfort levels ($\chi^2(7{,}112) = 22.16$, p $<$ 0.01, $\eta^2 = 0.19$). Multiple comparison testing showed that the group comfort ranking for direction 4 was different to directions 6, 7, 8 and 1. The preferred directions can be seen in Table 3; approach directions with ranks nearest to one are most comfortable.

Analysis under the assumption of normally-distributed sample populations showed that at a significance level $\alpha = 0.05$, a statistical power $(1 - \beta) = 0.80$ and a sample size of 15 the smallest difference in rank that was statistically detectable was approximately 1.8. All results reported here and in the following section have mean differences greater than this value.

These results reject the first hypothesis. When the seating configuration had no common 'front' or 'rear' direction (Configuration A), there was no statistically significant difference in comfort level with different robot approach directions. In Configuration B, the common 'front' direction was not statistically more comfortable than the common 'rear' direction. In Configuration C, the participants shared a common immediate 'rear' direction that the robot could approach from. Approaches from all 'front' directions were found to be more comfortable than from this shared rear direction.

3.5 Individual Comfort with Direction of Robot Approach

The previous table summarizes the comfort level of the pair, making no distinction between the two individuals. By analyzing individual preferences it is possible to see how the presence of a second person influences the comfort level of an individual when the pair are approached by a robot. Table 4 shows the mean rank of each approach direction for each of the five different relative seating positions of an individual. The robot approach directions are numbered relative to the positions marked with dots in Figure 2.

Table 4. Means and standard deviations (in parentheses) of *individual* rankings for each robot approach direction for the three seating configurations, across all pairs of participants. The labels 'Left' and 'Right' identify where the person of interest was sitting in the pair.

Dir	Config. A	Config. B (Left)	Config. B (Right)	Config. C (Left)	Config. C (Right)
1	3.1 (1.9)	2.5 (1.9)	2.3 (1.7)	2.9 (2.1)	3.7 (2.1)
2	4.1 (2.5)	3.1 (2.4)	3.7 (2.6)	4.4 (2.3)	5.1 (2.3)
3	4.2 (2.5)	4.9 (1.9)	4.1 (2.5)	3.3 (2.7)	4.3 (2.5)
4	5.9 (2.8)	5.5 (2.7)	4.5 (3.1)	4.8 (3.1)	6.1 (2.4)
5	4.4 (2.4)	4.5 (2.6)	4.4 (2.7)	4.7 (2.5)	3.3 (2.5)
6	4.0 (2.7)	3.3 (2.2)	3.8 (2.6)	3.5 (1.7)	2.9 (2.0)
7	3.0 (2.3)	2.7 (2.1)	2.9 (1.7)	3.1 (2.7)	2.6 (2.4)
8	2.7 (1.9)	3.6 (2.6)	4.2 (2.8)	2.7 (2.3)	3.3 (2.0)

Since the relative position of the second person in Configuration A is identical for each participant, twice as much data is available for this configuration. Performing a KW-ANOVA test showed that there was a highly significant difference between individual participant comfort levels with different robot approach directions ($\chi^2(7{,}232) = 30.20$, $p < 0.01$, $\eta = 0.13$). Multiple comparison testing using the previously described procedure showed that direction 4 was ranked differently from all other directions. In addition, approach direction 8 was found to be more comfortable than direction 5.

For the person sitting on the left in Configuration B, a KW-ANOVA test showed a highly significant difference in individual comfort levels ($\chi^2(7{,}112) = 20.80$, $p < 0.01$, $\eta = 0.18$). The multiple comparison test showed that the distribution of rankings for direction 4 was different to that of directions 7, 1 and 2. Direction 3 was also different to both directions 1 and 7. The KW-ANOVA test for people sitting on the right in Configuration B found no significant difference in comfort levels ($\chi^2(7{,}112) = 8.33$, $p = 0.30$, $\eta = 0.07$).

For Configuration C with the person sitting on the left, the KW-ANOVA test showed that there was no significant difference in individual comfort levels ($\chi^2(7{,}112) = 11.28$, $p = 0.13$, $\eta = 0.10$). The test for the person sitting on the right in Configuration C showed that there were highly significant differences in comfort levels ($\chi^2(7{,}112) = 23.88$, $p < 0.01$, $\eta = 0.20$). The multiple comparison tests found that direction 4 was different to directions 1, 5, 6, 7 and 8. Direction 2 was also different to direction 6.

These results collectively show that hypothesis H2 is false; the presence and location of a second person does influence the comfort level of an individual approached by a robot. The patterns of participant comfortability also differ from prior results [1, 2, 3] where a lone individual was approached by a robot. It is interesting to note that there is a left-right asymmetry in the results between Configurations B and C.

4 Discussion

When the different robot approach directions are compared to each other, pairs of people are least comfortable when they are approached from directions where the robot cannot be seen by either individual. This agrees with previous results for lone individuals approached by a robot. The comfort levels of individuals within the group are influenced by the presence and location of another person. Most notably, if the second person can see the robot approach directions to the 'rear' of the first person, then the levels of comfort felt by the first person are increased for these directions.

There is a curious asymmetry present in the findings. When seated in Configuration B (L-shaped), individuals seated on the left of the pair showed highly significant comfort preferences for robot approach directions while individuals seated on the right had no preference. These results were reversed when participants were seated side-by-side in Configuration C. We are not able to explain this asymmetry. A deeper investigation of the psychology of group interactions may shed some light on these results.

5 Conclusion

This paper describes an experiment that measured the comfort levels of seated pairs of people engaged in a shared task when approached by a robot. It was found that the presence and location of a second person influenced how comfortable someone was with different robot approach paths. The comfort patterns of individuals within the pairs were also shown to differ from prior results for those of lone individuals approached by a robot.

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