Investigating the Effects of Social Interactive Behaviours of a Robot on People's Trust During a Navigation Task

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Abstract. Identifying the roles and the specific social behaviours that evoke human trust towards robots is key for user acceptance. Specially, while performing tasks in the real world, such as navigation or guidance, the predictability of robot motion and predictions of user intentions facilitate interaction. We present a user study in which a humanoid-robot guided participants around a human populated environment, avoiding collisions while following a socially acceptable trajectory. We investigated which behaviours performed by a humanoid robot during a guidance task exhibited better social acceptance by people, and how robot behaviours influence their trust in a robot to safely complete a guiding task. We concluded that in general, people prefer and trust a robot that exhibits social behaviours such as talking and maintaining an appropriate safe distance from obstacles.

Keywords: Human-robot interaction · Social robotics · Robot companion · Trust in robots · Robot social navigation

1 Introduction

Service robots are now being used in human-oriented environments, such as airports, hospitals, schools, commercial centres and homes [5,32]. In particular, during the last few years, research communities have been aiming at building robot companions that will assist people in their daily activities [4,6,8]. This involves robots that are able to share the same physical space and to engage in social interactions with human users. Moreover, people need to accept robots' presence in these contexts [17] and to trust that robots will look after their

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safety [33]. When developing robots to work in human populated environments, an important aspect is to integrate strategies that allow robots to move around people in a safe and socially acceptable way. However, this raises new challenges in terms of defining safe robot navigation and natural and trusted Human-Robot interactions (HRI) [25]. Autonomous robots elicit certain expectations from the general public. One of the basic capabilities that they should possess is to be able to navigate safely in crowded environments, predicting the actions of others and acting accordingly. Several research studies have proposed different strategies for social acceptable movements for robots in complex environments where human users' presence and activities are unpredictable [29]. Classical robot navigation approaches to people tend to focus on efficiency during the path planning and execution; variables such as path length, clearance and smoothness are used to quantitatively evaluate performance [38], specially in cluttered environments. In contrast, more recent studies have also focused on robot socially-aware navigation, in which a robot can adapt its behaviour by estimating how its position affects the quality of interaction. This is by introducing social concepts, such as social distance or proxemics [21,26], in order to encode social conventions within robot navigation planners. Implementation and evaluation of the social component of these systems requires user studies in order to identify the most acceptable robot social behaviours in order to facilitate tasks such as guidance or human compliant navigation. Unfortunately, the scarce amount of detectable information under these circumstances increases the difficulty in evaluating human robot interactions. Resulting implementations are usually based on social conventions, essentially mimicking human-human interactions [14]. However, the study by Desai et al. [16] shows discrepancies between human-human and robot-human interactions. Therefore, evaluation of robot behaviours must be based on the acquisition of the desired response, natural acceptance and trust from humans.

This work investigated human users' responses to robot behaviours to enhance their acceptance and trust of a robot. In particular, we were interested in investigating people's trust in a robot which is able to complete safely a navigation task. Namely, the robot guiding them in both wide and narrow spaces, such as doors or corridors, in a human-populated environment. We were also interested in collecting people's preferences and perceptions of the social behaviours exhibited by the robot during the navigation task.

2 Research Questions

This research has been guided by the following Research Questions (R):

- **R1** Do human users trust a robot to be able to complete the task of guiding them from one point to another in a cluttered environment?
- **R2** Do people trust a robot to be able to guide them in narrow spaces, such as a door or corridor?
- **R3** What kind of robot behaviours do people prefer. A robot that behaves more like a tool or as a social entity?
- **R4** Which social behaviours should a robot exhibit during a navigation task according to human users' preferences?

3 Related Works

In this Section, we provide an overview of current research in the area of social robot navigation, with a particular focus on the development of trust in these particular human-robot interactions.

3.1 Robot Guide in Social Scenarios

Initial attempts to propose interactive guiding robots are presented by Burgard et al. [5] with a robot in the role of a museum guide. However, the focus of the work was the navigation performance with little consideration of the social aspects of the interaction. More recent experiments have studied associated social qualities such as people-aware navigation for goal oriented behaviour considering users [31]. Specifically, Pacchierotti et al. [28] used a multi-module path planner that focused on accompanying and manoeuvrering between groups and freezing when a safe trajectory is not feasible. Feil-Seifer and Matarić [11] proposed a Gaussian Mixture Model which is used to slow down or stop the robot when the human partner does not follow the robot's pace. However, such methodologies deviate from the expected behaviour of human beings, and exhibit a low degree of proactivity and social-awareness. More recent work [13], proposes a method that constantly monitors the user being guided, in order to proactively offer help. A Situation Assessment component of the system gathers spatial information in order to make decisions using a planning framework based on hierarchical MOMPDs (Mixed Observability Markov Decision Processes). Proactive change of speed is achieved by constantly monitoring the user where only the back of the robot is shown to the user. This necessarily limits any type of interaction during the navigation. However, in the study by Ferrer et al. [12], the guiding task is accomplished by the human and robot walking side by side. In this case, the platform is attracted to the user using the concept of a robot-person force implemented with an Extended-SFM (Social Force Model). Zhang et al. [40] went one step further by introducing a planner based on Artificial Potential Fields that includes the guided subjects and sub-goal location inside an office hallway. The guided person is represented as an attractive or repulsive potential field. In this manner, the authors not only achieve velocity adaptation to the guided person, but also a change of behaviour from guiding to following in the case that a person deviates from the original path.

3.2 Trust in Social Navigation

Several previous studies define the concept of trust in Human-Human, Human-Computer and Human-Robot Interactions. Although multiple definitions exist, we have adopted one of the first definitions of trust [10]. There is a convergent tendency [39] towards using this definition "Trust can be defined as the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability" [22, p. 51]. Enhancing people's appropriate level of trust of the robot in a successful Human-Robot Interaction can be a challenge [15]. In particular, human trust during robot guidance tasks has not been studied in depth.

Wang et al. [37] proposed a trust-based real-time framework to switch between autonomous and manual motion planning. This achieved a trade off between task safety and efficiency. Therefore, the goal satisfaction was guaranteed by using a human-in-the-loop, which provided a quantitative trust measurement. In [35] task guidance is provided in a collaborative part assembly scenario, while measuring participants' perceived robot competence, safety, trustworthiness and the impact of participants' personality traits in their perceptions. The presence of faults had a limited effect on the participants' perception of the robot which can be mitigated by applying robot transparency in the decision process [36]. Such results were corroborated in [24], where a robot platform was used as a navigational system to guide participants through a sign-posted maze. This indicated that users generally trust directions given by the robot more than their own judgment.

Hancock et al. [18] showed that robot performance had the greatest association with trust. Specifically, early decreases in reliability, negatively impacted on real-time trust differently than later reductions in reliability [9]. However, that does not necessary mean that there is necessarily an effect on participants' willingness to cooperate with an unreliable robot, as indicated by Salem et al. [34]. Other studies [32] show that participants' personality traits will also affect users' perceptions of the robot and their interactions.

4 Approach

This Section describes the approach used to identify people's preferences for a social robot navigation task. In this study we used the robot Pepper developed by SoftBank Robotics, which in particular, is designed for safe HRIs [30].

4.1 Experimental Design

The participants were each asked to follow the robot and adapt their behaviours to the robot's behaviours. We used a within-subject, counterbalanced, repeated measures experimental design. In order to test our research questions, each experiment was executed under 3 different conditions when the robot encountered people on its path towards the destination: a control condition **C1:** the robot stops and waits to have a clear path; condition **C2:** the robot performs simple obstacle avoidance while continuing moving; and **C3:** the robot uses social behaviours to communicate and interact with participants (see Sect. 4.2).

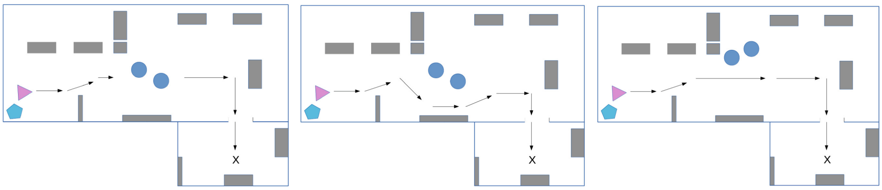
We asked two actors to block the robot that guided the participants in the experimental environment (see Fig. 1).

In order to analyse the interactions between the human participants and the robot, we asked the participants to complete questionnaires.

4.2 Experimental Procedure

Participants were asked to imagine that they were in a shopping mall which they were not familiar with. The robot called "Jax" would help them to find the Information Centre. We told participants that they were free to position themselves next to, or behind the robot, according to their preference for following the robot. Participants completed a pre-experimental questionnaire to collect their experiences with robots and their perceptions of generic robots. Participants were presented with the same navigation task three times. All participants started their interaction with a control condition (**C1**). Then, they were tested with the social (**C3**) and non social (**C2**) conditions in a randomised order. During **C1**, Jax stopped when it encountered two people talking to each other and blocking the robot's way (see Fig. 1a). When the two people cleared away from the robot's path, it then proceeded with its navigation. Once at the destination, the robot stopped. The experimenter informed the participants they had reached the Information Centre. At the end of the trial, participants completed a second questionnaire to collect their perceptions of Jax and their self-confidence.

During **C2**, the robot did not exhibit any social behaviours, but it avoided the actors by moving according to the social norm of passing a person by maintaining position on the right side [19] and performing a simple obstacle-avoidance technique (see Fig. 1b). Once at the destination, the robot just stopped. At the end of the trial, participants were asked to answer the same questions as in the second questionnaire. In conditions **C1** and **C2**, the robot moved at a constant velocity of 1 m/s.



(a) *Condition C1: baseline* **(b)** *Condition C2: non social* **(c)** *Condition C3: social*

Fig. 1. The robot's navigation behaviours. (a) The robot stops and wait for people to move away from its path; (b) the robot avoids the people on its path; and (c) the robot asks the people to let it pass, and when they clear the way, it continues its navigation. Participants are represented by the hexagon, and the robot by the triangle. The robot moves following the arrows until it reaches the destination, represented by an X. Obstacles are squares and rectangles. The two actors are represented by two circles.

In condition **C3**, the robot faced the participant and invited her to follow it to the Information Centre. It slowly increased and decreased the velocity, depending on whether the navigation was on a straight path, doing a turn or approaching an obstacle. Its velocity varied between 0 m/s to 1 m/s. It slowed down until it stopped when it detected people on its path (see Fig. 1c), while changing the colour of its shoulder LEDS to catch the participant's attention. It gently asked the two actors to let them pass saying "Excuse me, I would like to pass", and it thanked them once it had passed by. The robot continued its guidance task after gesturing with its arm for the participant to proceed. When it arrived at the destination, the robot verbally informed the participant while turning towards her. At the end of the trial, participants were asked to answer the same questions as in the second questionnaire and another small questionnaire about their preferred social cues.

At the end of the three conditions, participants were asked to complete a final questionnaire about their perception of the robot, their emotional state and preferences for Jax's behaviours.

5 Results

We collected data from 12 participants. However, since it was important to test participants' trust of the robot and not of the human operator, at the end of the final questionnaire we asked participants if they believed the robot was behaving autonomously. We decided to exclude two participants who did not believe this. We analysed responses from the remaining participants (5 men and 5 women), aged between 22 to 40 years old [mean age 27.7, std. dev. 5.59]. All participants were PhD students, researchers and administration staff members at SoftBank Robotics Europe in Paris, France.

5.1 Trust in Jax

As part of the pre-study questionnaire we asked the participants to rate levels of trust and acceptance of the robot as a guide in different environments, as shown below. We recorded their ratings on a 7-point Likert Scale [1 = not at all and 7 = very much]. At the end of each condition, participants were also given the same questionnaire. However, in these latter questionnaires we referred specifically to **Jax** instead of **a robot**. We asked participants to answer the following questions which were repeated specifically referring to Jax after each trial:

- Would you feel comfortable having **a robot** as a guide in a public environment, for example a museum, an airport or a shopping mall?
- Would you trust **a robot** to guide you safely in a public environment?
- Would you trust **a robot** to be able to navigate safely in narrow environments, such as a door or corridor?

We used Friedman tests to analyse the significant differences between three dimensions, which were the three different conditions participants' were tested with. We found that their perceptions of being comfortable in having the robot guiding participants was rated differently ($\chi^2(3) = 11.20, p = 0.011$) for the different conditions. Similarly, a Friedman test indicated that there is a statistically significant difference in participants' trust in the robot to guide them both in public ($\chi^2(3) = 7.405, p < 0.05$) and narrow ($\chi^2(3) = 17.28, p < 0.01$) spaces for these conditions.

In particular, a Wilcoxon Signed-Ranks test indicated that participants felt more comfortable ($z = -2.4, p < 0.01$) after condition **C3** (mean rank = 4) then after condition **C2** (mean rank = 0). Similarly, they felt more comfortable ($z = -2.81, p < 0.01$) after condition **C3** (mean rank = 5) than after condition **C1** (mean rank = 0).

Participants trusted the robot to be able to guide them more ($z = -1.86, p = 0.03$) when tested with condition **C3** (mean rank = 5) than their initial belief (mean rank = 4.43). While we did not find any statistically significant difference between the other conditions.

There are no other statistically significant differences between the conditions participants were tested with, but their initial trust towards a generic robot changed after their interactions with Jax. We found that they did not trust a generic robot to be able to guide them through narrow spaces more than the robot Jax respectively in **C1** ($z = -2.7, p = 0.004$), **C2** ($z = -2.539, p < 0.01$) and **C3** ($z = -2.682, p < 0.01$) conditions.

5.2 Participants' Self Confidence

After each trial, participants' self-confidence was rated with the following questions: (1) I believe I could have found the way on my own; (2) I believe I could have found a faster way on my own; (3) I believe I could have found a safer way on my own. We did not find any statistically significant differences in people's perception of self confidence in finding the destination on their own, in a faster or safer way or, depending the different conditions.

5.3 Previous Experiences with Robots

As part of the pre-experiment questionnaire, we were also interested in participants' previous experiences with robots. We used a 7-point Likert Scale where 1 corresponds to "not at all" and 7 corresponds to "very much". In particular, we asked participants about previous experience: (1) Do you have any experience interacting with robots? (2) Please, specify what kind of experience you have with robots (if any) [as a participant in an other experiment, observer, developer, researcher]. (3) Which robots? (if any).

Participants had previous experience with robots (min = 2, max = 7, mean 5, std. dev. 1.82). Participants with previous experiences with robots were (a) participant in previous studies = 30%, (b) developer = 40%, (c) observer = 50%, (d) researcher = 40%. In particular, 9 from 10 participants had previous experiences with a Pepper robot.

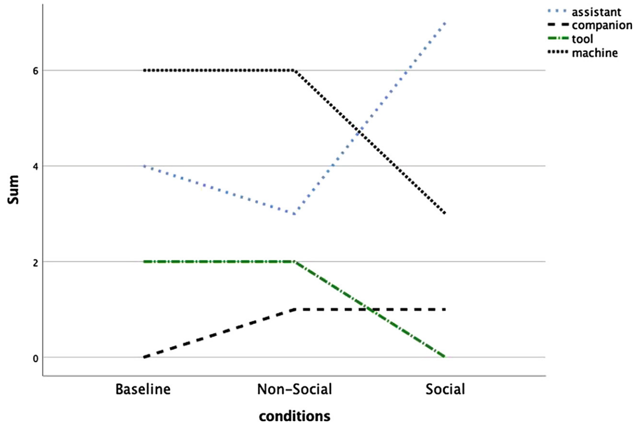


Fig. 2. Participants' perception of the robot's role after the conditions.

5.4 Role of the Robot

After each trial, we asked the participants to choose a role perceived as suitable for robots from the following: (1) friend; (2) butler; (3) companion; (4) pet; (5) assistant; (6) machine; (7) tool; or (8) other. These robot roles were chosen according to previous studies conducted by Dautenhahn et al. [6,7] and Ljungblad et al. [23].

Figure 2 shows that participants' ratings varied based on the different conditions. We observe that their perception of the robot as assistant and machine drastically changed. People perceived the robot more as an assistant and less as machine when it exhibited social behaviours. Figure 2 also highlights that there was a small variance in the perception of the robot as tool and companion when comparing these conditions. Participants considered a social robot less as a tool, while they considered a robot that is not social or does use simple obstacle avoidance techniques less as a companion.

5.5 Godspeed Questionnaire

At the end of all trials, we were also interested in evaluating the perceptions of the participants after their interactions with Jax. We used the Godspeed questionnaire [2] to evaluate the perception of the robot using a set of semantic differential scales. We tested the internal consistency of the subscales using Cronbach's alpha test. The high Cronbach's α is 0.930 which suggested that we could proceed by treating the data as interval scales [2].

The effects of the conditions on participants' ratings along the Goodspeed questionnaire's dimensions were assessed using an ANOVA test. We found a significant effect for stagnant ($p < 0.01, F = 20.00$), inert ($p < 0.01, F = 13.18$), dislike ($p = 0.03, F = 6.40$), unpleasant ($p < 0.01, F = 30.97$) and awful ($p = 0.01, F = 10.57$) dimensions. The results of the ANOVA test highlighted also that participants' mean ratings were higher when they were tested with conditions in the following order: **C1** (baseline), **C2** (non social robot) and **C3** (social robot). We also observed that participants tested with **C1**, **C2** and **C3** conditions' order felt more anxious ($p < 0.01, F = 13.91$) and agitated ($p = 0.02, F = 4.00$).

From these results, we tend to believe that people's perception of the robot is mostly formed at the beginning of the interaction with a non-social robot. Indeed these findings might be also in line with other studies [32,39]. Similarly, we also hypothesise that participants' emotional state was affected by their very first interaction. However, we do not have enough information to corroborate our beliefs. Further studies are planned which will involve a larger pool of participants, and hopefully they will help to clarify this effect when comparing people's emotional state before and after the interactions with the robot. This is of particular interest because people's negative emotional state might affect their trust [27]. For example, anxiety, which is characterised as a low certainty emotion, might have affected negatively their trust in Jax.

5.6 Preferred Behaviour by Participants

We asked the participants to choose the robot behaviour they preferred or considered most necessary during a guidance task from the following: (1) the robot waited to have a clear path (Baseline) and the robot exhibited social behaviours (e.g. talking, changing velocity, using lights, etc.); (2) the robot waited to have clear path (Baseline) and the robot avoided people without any social behaviour; (3) the robot exhibited social behaviours (e.g. talking, changing velocity, using lights, etc.) and the robot avoided the people without any social behaviour.

All participants considered it necessary to have a social robot as a guide compared to both non-social behaviours and the baseline. They did not have specific preferences when asked to choose between a robot without social behaviours (50%) and a robot that waits to have clear path before continuing its navigation (50%).

5.7 Social Behaviours Preferred by Participants

As part of the questionnaire completed by participants after the condition in which the robot showed social behaviours, we asked them to select the specific behaviours they preferred during the guiding task with the robot. These were: speech; coloured lights; maintaining an appropriate distance from obstacles, humans or objects; approaching obstacles at an appropriate velocity, humans or objects, and narrow places; gesture; head and body orientation; or write down any social cues not included in the previous ones. These social cues were chosen according to [3], suggesting that naturalistic social interaction in robots can be designed through five main methods of non-facial and non-verbal affective expression: body movement, posture, orientation, color, and sound. Others [1,20] have also studied participants' preferences based on the robot's type, size, proximity, and behaviour. One participant did not answer the question, the remaining participants unanimously preferred a robot that is able to talk. Other preferences were for a robot that is able: to maintain the appropriate distance from obstacles (55.5%), to use gestures to communicate (33.3%), and approach obstacles and narrow places at an appropriate velocity (22.2%).

5.8 General Observation

We told participants that they were free to follow the robot by positioning themselves as they preferred. During the **C3** condition, all participants chose to be behind the robot on its right side, while during the other conditions only 7 made the same choice. In **C1** and **C2** conditions, 2 participants were on the front-right side of the robot, which incidentally was perceived as too slow. One participant preferred to walk on the right side of the robot with his arm on the robot's shoulder. After the study, he did not give any specific justification for his behaviour besides feeling more comfortable that way.

6 Conclusions and Future Works

In this study we investigated people's trust in the capabilities of a robot to guide them in a cluttered environment, including passing through narrow spaces. We compared people's perception of trust in the robot after three different conditions in which the robot was behaving differently. We found that participants felt more comfortable to follow a social robot, and that the social robot gained participants' trust which they did not have before interacting with it. We also observed that people's expectations for a robot to be able to guide them in narrow spaces were significantly lower compared to their perceptions after their interactions with the real robot.

We were also interested in what kind of robot behaviours people preferred for a guidance task. For example, would they prefer a robot behaving more like a tool or a social entity? We observed that they perceived the robot more as an assistant and less as a machine when it behaved in a social manner. In particular, they preferred a social robot that communicates using speech and maintains an appropriate distance from obstacles.

The results of this study showed that in general people preferred and trusted an interactive sociable robot more. However, we are aware of limitations to this study. For example, further investigations will also investigate the development of trust in more complex navigation scenarios.

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