Human-Robot Interaction: Proximity and Speed—Slowly Back Away from the Robot!

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Abstract This experiment was designed to evaluate the effects of proximity and speed of approach on trust in human-robot interaction (HRI). The experimental design used a 2 (Speed) × 2 (Proximity) mixed factorial design and trust levels were measured by self-report on the Human Robot Trust Scale and the Trust in Automation Scale. Data analyses indicate proximity [$F(2, 146) = 6.842$, $p < 0.01$, partial $\eta^2 = 0.086$] and speed of approach [$F(2, 146) = 2.885$, $p = 0.059$, partial $\eta^2 = 0.038$] are significant factors contributing to changes in trust levels.

Keywords Human factors · Human-robot interaction · HRI · Human-robot trust · Proximity · Proxemics · Speed · Psychological experiments · Human robot trust scale · Trust in automation scale

1 Introduction

Human-robot interaction, the branch of science that evaluates how people interact with autonomous robotic entities, is becoming increasingly relevant as robotic platforms are progressively being integrated into many social environments. For example, robots now play a critical role in healthcare, entertainment, and education. As such, we must examine the acceptance and integration of these robotic entities across domains. A critical part of this examination is the consideration and evaluation of key factors such as social norms, relationships, and trust [1].

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1.1 Trust in Robots

Trust can be defined in multiple ways. It is most easily defined as the willingness to be vulnerable to another, and has been defined as the belief that others (human or non-humans) will help in uncertain situations [2]. Trust is a critical factor in the acceptance of automated machines or robots among the general public, as it shapes the successful perpetuation and efficacy of collaborative relationships both in human-human relationships and in human-nonhuman relationships [3]. Furthermore, ongoing research indicates that human trust in automated machines may directly and indirectly affect human-machine interaction outcomes such as safety and performance [4]. However, trust is not the exclusive creator of successes or failures in such interactions. Instead, trust interacts with several additional factors as part of the larger human-machine system, making it necessary to examine the many factors that influence trust as a predictor of human-machine performance.

In Hancock et al. [5] identified such additional factors that influence trust in robots including: robot attributes such as proximity of the robot to the human, and human attributes such as degree of comfort with the robot. When considering an attribute such as comfort, it is also prudent to consider what factors affect such comfort. For example, do we feel more comfortable when we and those around us adhere to social norms?

Social norms are the rules of behavior considered acceptable by a group or society in a given context [6]. We argue that adherence to social norms is indeed a predictor of trust in human-robot relationships. Social norms are typically addressed in completely human relationships, but they may also provide useful guidance in human-robot relationships as well. While there are differences when comparing human-human and human-robot interaction, overtime these will diminish and become similarities as technological advances reduce the shortcomings in robotics [7]. Specifically, we aimed to address this gap by examining the influence of two factors deemed important in social norms: proximity and speed of movement. Research concerning the social norms and expectations of human-robot relationship informed our approach.

1.2 Proxemics

One important social norm is the use of interpersonal space, the scientific discipline that addresses this concept is proxemics, which evaluates the unconscious requirements of personal space and crowd density on behavior [8–10]. Hall's [8] seminal research on proxemics classified multiple nonverbal factors that contribute to acceptable interpersonal proximity (e.g., proximity, touching, and eye-contact). Proxemics can be applied to human-robot interaction; however, Hall's non-verbal factors will need to be evaluated based on the degree to which technology has advanced to provide for those factors (i.e., can your robot touch or have eyes?). The exploration of proxemics in human-robot interaction has only become systematic in the last decade [1, 11, 12].

Other areas of research have used proxemics experimentally to evaluate interpersonal space as it relates to their particular field. Virtual reality is one such area, evaluating the interpersonal distance of participants to human-avatars (human-controlled) and agent-avatars (computer-controlled) in a virtual environment [13, 14]. Although findings from the aforementioned research indicate that people respond differently to agents than humans, it creates a foundation for the use of proxemics to empirically evaluate interpersonal distance to a non-human agent.

1.3 Speed of Approach

A human walking down the road, when confronted with an obstacle, will alter their course and speed in avoidance [15]. This adjustment of speed and trajectory, two fundamental aspects of movement, originate as a safety precaution. The development of cities and metropolises have generated a cornucopia of walking spaces, leading to the inclusion of movement into human social norms.

If robotic entities are going to be successfully integrated into human environments they will be expected to conform to the social norms of movement. For example, robots are expected to modify their paths and speed to accommodate people as they approach [16]. High speeds of approach with low interpersonal distance may be tolerated by a human, if the robot signals the intention to pass [17]. However, research also indicates that humans prefer robots to move slower than 1 m per second or just under the average human walking speed [18].

1.4 Hypotheses

Proximity, interpersonal distance, rate of speed, and movement have an effect on human-human systems, and previous research has also evaluated these factors on human non-human systems. Our hypotheses were based on personal theories of human-robot interaction in regards to proximity and speed of approach.

- H_1: participants will report lower trust when the robotic entity moves quickly
- H_2: participants will report lower trust when the robotic entity's proximity is closer.

2 Method

We used a 'Wizard of Oz' paradigm in the present experiment [19]. Participants were under the belief that the robotic entity was fully autonomous and followed pre-programmed instructions whereas it was in fact controlled by a hidden operator.

2.1 Participants

One hundred and forty-eight students (55 males and 93 females), ranging in age from 18 to 31 years (*M* = 18.82, *SD* = 1.62), from the University of Central Florida's undergraduate population participated in the present study. Students were recruited via Sona, the university's anonymous recruitment service, which provides students the opportunity to participate in research. In an effort to mitigate any potential bias from the incentive to participate in research in exchange for course credit, Sona allows students to write an essay in substitution. The University of Central Florida's Institutional Review Board approved the use of human participants in this experiment.

All participants reported to have either normal or corrected-to-normal vision. No participants reported any hearing impairments. One participant reported having post-traumatic stress disorder, and was the only participant to report having military experience. Forty participants reported having interacted with a robot prior to the experiment, fifteen reported having built a robot before, and twenty reported having controlled a robot in the past. The majority of individuals who reported controlling a robot before reported using a videogame or remote control interface (Table 1).

2.2 Design

The present study utilized a 2 (speed) × 2 (proximity) mixed factorial design, and block randomization to control for primacy effects. To assess trust in the physical presence of the robotic entity, we manipulated the proximity of the robot to the participant as well as the rate of speed at which the robot moved. Dependent measures of trust included scores on the Human Robot Trust Scale [20], the Trust in Automation Scale [21, 22], and the Interpersonal Trust Questionnaire [23]. Additionally, the Negative Attitude Towards Robots Scale was included to evaluate participants' predispositions toward robots [24]. Baseline scores for both the Human-Robot Trust Scale and Trust in Automation Scale were collected utilizing a photograph of the robotic entity prior to any interaction or observation.

Table 1 Participant demographic information

Age	$\bar{x}$ = 18.82
Ethnicity	
Caucasian	n = 80
African-American	n = 23
Hispanic	n = 30
Asian	n = 8
Hawaiian/Pacific Isl.	n = 1
Other	n = 5

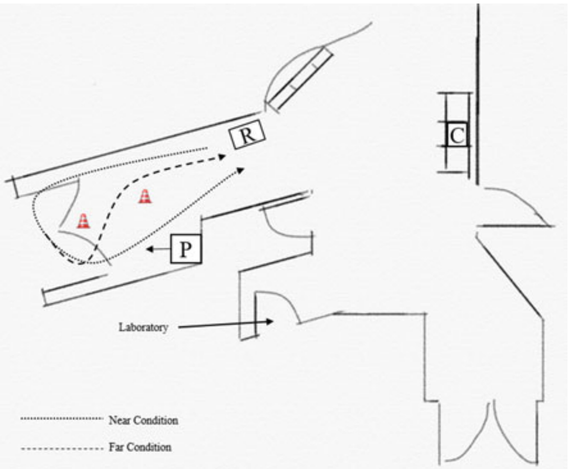
Fig. 1 Custom-designed and custom-built robot used in the present study

2.3 Apparatuses

A custom crafted robot-like entity was built using a Traxxas Stampede XL-5 series remote controlled truck and a foam-core constructed exterior, painted silver (see Fig. 1). A camera mount was affixed to the top of the base unit, and a dummy web camera attached to the top to give the illusion that the robot had the ability to "see" the environment.

A maintenance hallway, a public area on the second floor of the University of Central Florida's Orlando campus psychology building, was used as the experimental space (see Fig. 2); allowing for an area sufficient to maneuver the robotic entity and allow a confederate (i.e., robot operator) to blend into the student population.

Fig. 2 Map of the experimental space, delineating the starting position of the robot, the confederate's vantage point, and the proximal condition tracks



2.4 Procedure

Two researchers were needed to conduct this experiment. One researcher to guide and instruct the participant, and the other to surreptitiously control the robotic entity so as to afford it the necessary simulacrum of autonomy. When participants signed up for the experiment they were instructed to meet at the first floor entrance to the research laboratory. Participants were greeted by one of the researchers and subsequently escorted, via a stairwell within the laboratory, to the second floor. The second researcher, pretending to be a student studying, was pre-positioned on a bench in the hallway at location C in Fig. 2, prior to the participant's arrival. Participants were only in the hallway during the practice trial and experimental conditions; informed consent and administration of surveys were conducted within the laboratory. The informed consent document was given to the participant for their review, and both researcher and participant were required to sign it. Once consent was granted, the participant was instructed to complete the demographics portion of the survey which was comprised of the Interpersonal Trust Questionnaire [23], the Negative Attitude Towards Robot Scale [24], the Human-Robot Trust Scale [20], and the Trust in Automation Scale [21, 22]. Participants were then escorted into the experimental space, and seated in a classroom chair located at P in Fig. 2. Participants first observed a sample trial to acclimatize them to the robotic entity. Immediately after the sample trial, the participant observed the first experimental condition. After each of the experimental conditions participants were escorted back to the laboratory and completed the Human Robot Trust Scale and Trust in Automation Scale in reference to the trial they had just observed. Upon completing all of the experimental conditions, participants were thanked for their time and dismissed.

3 Results

Surveys were scored according to common practices and a mixed-design ANOVA using a within-subject factor of condition (quick-near, quick-far, slow-near, slow-far) was conducted. Analyses indicate proximity as a significant factor contributing to changes in trust scores [$F(2, 146) = 6.842$, $p < 0.01$, partial $\eta^2 = 0.086$]. These findings were observed in both the Human-Robot Trust Scale ($F = 13.212$, $p < 0.001$, partial $\eta^2 = 0.082$) and the Trust in Automation Scale ($F = 11.099$, $p = 0.001$, partial $\eta^2 = 0.07$). Our hypotheses were thus supported. A Bonferroni corrected pairwise comparison of proximity (near-far) presented a mean difference of -4.73 in the Human Robot Trust Scale, and a mean difference of -0.19 in the Trust in Automation Scale. This indicates participants rated higher trust scores in conditions where the robot was further from them, supporting our second hypothesis.

The speed of approach was also a significant factor contributing to changes in trust scores [$F(2, 146) = 2.885$, $p = 0.059$, partial $\eta^2 = 0.038$]. A Bonferroni corrected pairwise comparison of speed of approach (fast-slow) presented a mean difference of −0.702 in the Human Robot Trust Scale, and a mean difference of −0.12 in the Trust in Automation Scale. Support for the effects of speed on trust were found only in the Trust in Automation Scale ($F = 4.149$, $p = 0.043$, partial $\eta^2 = 0.027$) and not the Human Robot Trust Scale ($F = 0.572$, $p = 0.451$, partial $\eta^2 = 0.004$). This indicates participants rated higher trust scores on the Trust in Automation Scale in conditions where the robot moved slower, supporting our first hypothesis. There was no significant interaction between speed of approach and proximity [$F(2, 146) = 1.654$, $p = 0.195$, partial $\eta^2 = 0.022$].

The Negative Attitude Towards Robots Scale is comprised of three subscales measuring negative attitudes toward: situations of interaction with robots ($M = 15.32$, $SD = 3.98$), social influence of robots ($M = 15.18$, $SD = 3.6$), and emotions in interaction with robots ($M = 8.66$, $SD = 2.3$).

The Interpersonal Trust Questionnaire contains three subscales: Fear of disclosure ($M = 86.17$, $SD = 16.15$), Social coping ($M = 24.31$, $SD = 6.68$), and Social intimacy ($M = 13.76$, $SD = 3.58$).

4 Discussion

The present experiment was designed to evaluate the effects of a robotic entity's proximity and speed of approach on the levels of trust held by humans for robotic entities as measured by the Human Robot Trust Scale and the Trust in Automation Scale. Results support both hypotheses that proximity and speed of approach have a significant effect on trust levels. The difference in support of the two trust measures for the speed of approach factor may be related to the difference in the intended purposes of the two trust measures.

Our results add to the foundation of current literature in the area of proxemics and movement as they apply to field of non-human or human-robot interaction. Studies of this nature are critical for the further integration of robotic entities into the everyday lives of humans. Understanding how and why trust changes in response to a robotic entity's physical presence, will ultimately decide if and when robotic entities are widely accepted. Proximity and speed of approach are only two of many social norms that roboticists will have to consider while designing the physical structure of robotic entities and developing the software intelligence.

Limitations of our study and its experimental design include the following issues: (a) robot autonomy, (b) robot morphology and materials, and (c) participant pool. For the purpose of our research, we defined a robot as a machine that can perform the work of a human and work autonomously or controlled by pre-existing computer programming. Our use of the 'Wizard of Oz' paradigm precluded the robot-like entity in our experiment from meeting this definition of a robot which led to complications. During the protocol, students, staff, or faculty passing through the hallway would stop and ask the confederate researcher about the experiment thus potentially divulging their researcher role to the participant sabotaging the illusion of robotic autonomy. In these situations, the participant continued the experiment to completion and would be politely asked if they become aware of the confederate's control of the robotic entity. Those participants who answered in the affirmative were excluded from the data set, as they were aware that the robot was not autonomous.

As mentioned previously, the robot-like entity was built from a Traxxas (Traxxas, Plano, TX, United States) Stampede XL-5 remote controlled monster truck with a maximum speed of 25 miles per hour. The exterior was constructed from foam-core poster board, hot glue, and silver spray paint. A Logitech C525 (Logitech International S.A., Romanel-sur-Morges, Switzerland) web camera was affixed to the top of the vertical extension to simulate a sensor by which the robot could detect the environment. Subjective testimony from colleagues had mixed responses regarding the physical appearance of our robot-like entity. Some Opinions were split as to how realistic a portrayal of a robot the device was. Future research may want to consider the construction of their robot and its conformity to participant expectations, as the morphology and material composition may be a confounding factor.

The range of participants spans from 18 to 31 years of age, however, the mean age was only 18.82 years indicating that the majority of participants were quite young. The lack of middle aged and senior participants reduces the generalizability of the findings to the general population. Such difficulty in generalizing these findings may delay the acceptance and integration of robotic entities into the daily lives of humans.

Future research in the field of human-robot interaction should consider proximity as a factor that contributes to trust levels; and speed of motion, should the robot have mobility, as a possible contributing factor. Further research needs to be conducted on a robotic entity's speed of approach to determine, to what degree, it effects trust levels.

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