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Effects of Robot Gaze and Proxemic Behavior on Perceived Social Presence during a Hallway Navigation Scenario

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Robots are increasingly being introduced into task environments that require the ability to exhibit appropriate social functionality. The present study is an examination of how social cues conveyed by a robot, during a brief interaction, affect the perception of the robot as a socially present agent. Participants were exposed to one of three gaze conditions and two proxemic behavioral programs during a number of experimental trials involving path-crossing in a hallway setting. Results indicated that participants perceived the robot as more socially present when it exhibited a passive proxemic behavior and more socially present over time; though, findings varied at the sub-scale level. Design recommendations are presented for roboticists.

INTRODUCTION

As we begin to integrate robots into daily life, considering their social functionality has become increasingly important. Although modern robots are becoming efficient navigators and workers, most lack the capability to perform a vital aspect of day-to-day social life: natural non-verbal communication that conveys intentions. A long line of research in interpersonal communication suggests that approximately 60-65% of social meaning is derived from non-verbal cues and behaviors (see Burgoon, 1994). Thus, as robots transition from isolated environments that require little human interaction into complex social environments, they require the social skills to take on the roles of team members (e.g., Goodrich & Schultz, 2007; Phillips, Ososky, Grove, & Jentsch, 2011). We further suggest that, for humans and robots to collaborate, HRI research needs to not only explore how human-robot teams develop a shared understanding of their tasks and operational contexts, they must also understand how social cues and signals conveyed by robots are perceived by humans.

Social Cues and Signals

Social signal processing (SSP) is a theoretical framework that takes a multidisciplinary approach to understanding social cognition and the ways it can be instantiated in machines (Vinciarelli et al., 2012). In recent work, we have used this as a foundation for understanding the social dimensions of HRI (Streater, Bockelman Morrow, & Fiore, 2012). With this framework, social signals are comprised of two types of cues: physical cues and behavioral cues. Physical cues consist of physical appearance and environmental factors, such as the proximity between two social actors, while behavioral cues consist of vocalizations and movements or expressions using the body and face. A social actor utilizes these cues to convey a social signal encompassing qualities such as personality, emotion, and status to others. For example, the social signal of submission can be conveyed by the physical cue of wide proximity and the behavioral cues of slumped posture and downward pointed gaze. From this, the observer can interpret the intentions of the actor and respond accordingly. In this context, we set out to better understand the exchange of social cues and the resulting social signals in HRIs.

Social Presence and the Media Equation

The successful conveyance of social signals in HRI may come with the prerequisite that humans first recognize robots are social actors so as to perceive their cues as social. We see this as an issue of robots conveying a sense of *social presence*. For our purposes, social presence is defined as the perception of being in the company of another social agent capable of mental states (Harms & Biocca, 2004). Ascribing social presence to a robot during an interactive context is an essential, though not fully understood, precursor to understanding the intentions of a robot. Previous research has demonstrated that people have a tendency to implicitly treat computers as social actors when prompted with subtle cues (Nass & Moon, 2000). This tendency has been termed “the media equation” (Reeves & Nass, 1996) and has been examined by applying social categories and behaviors such as gender and helpfulness to computers (Nass & Moon, 2000). Although participants perceived these categories and judged the computers accordingly, they explicitly denied that they viewed the computers as social beings. It was argued that these behaviors are the result of a “mindless” overextension of social categories to machines.

More recently, this phenomenon has been applied to the study of HRI (see Fischer, 2011; Syrdal, Dautenhahn, Koay, Walters, & Otero, 2010). For example, the way humans physically respond to robots bears similarity to the way they respond to other people. Specifically, the proxemic distance participants kept between themselves and a non-humanoid robot appeared to be based on rules applied when interacting with other humans (Takayama & Pantofaru, 2009). Further, human-robot proxemics research has also shown that the basic physical cue of distancing is enough to alter the behavior of participants in ways that resemble human-human interactions (Mumm & Mutlu, 2011; Walters et al., 2005).

For research in HRI, we suggest that the broader question to consider with the media equation is the degree to which robots are able to convey a sense of social presence. But, to understand social presence, and how humans perceive presence in non-humans, HRI research must consider an additional facet of social cognition, that of understanding robot intention.

Understanding Robot Intention

Dual-process theories of cognition provide some insight regarding the “mindless” extension of social categories. Here, researchers posit that some behaviors, observable through social cues, allow humans to make mental state attributions, such as intentions, using more automatic cognitive processes referred to as Type 1 processes (e.g., Bohl & van den Bos, 2012). Other behaviors, though, require more controlled and deliberate Type 2 processes for the processing of social stimuli. These two types of processes play distinct yet interdependent roles in human social cognition. Similarly, Takayama (2012) posits two perspectives on agency: *in-the-moment* and *reflective* (cf. Bockelman Morrow & Fiore, 2012). In-the-moment perceptions of agency occur during a given interaction, whereas reflective perceptions of agency occur after the situation has resolved and the individual deliberately considers the situation. Most studies examining the media equation for computers and robots have found consistent in-the-moment perceptions of agency based on behavioral responses, while finding little, if any, reflective perceptions of agency regarding the machine. However, in some instances, research has shown that people explicitly will identify robots as social agents. For example, Saulnier, Sharlin, and Greenberg (2011) applied "minimal non-verbal behavioral cues" (i.e., gaze, motion, and proximity) to a box-like robot to study the behaviors necessary to display the social signal of interruption. In semi-structured interviews, participants described the robot's behavior in terms of emotion, personality, and intention. This suggests that even basic social cues conveyed by robots are powerful enough to communicate social signals that are explicitly understood by humans. Research with humanoid robots that can convey more complex cues has yielded similar findings (Kahn et al., 2012).

The ability for robots to non-verbally reveal their intentions has major implications for HRI. For example, during an HRI collaborative task, conveying social cues was found to significantly increase participant performance (Breazeal, Kidd, Thomaz, Hoffman, & Berlin, 2005; Mutlu, Yamaoka, Kanda, Ishiguro, & Hagita, 2009). Moreover, certain social cues appear to increase likability and perceived social intelligence of robots. In particular, Takayama, Dooley, and Ju (2011) took animation techniques used by Pixar Animation Studios and applied them to a virtual model of a robot performing tasks in different scenarios to convey the robot's intentions. The results showed that levels of perceived intelligence, competence, and confidence of the robot increased when compared to robots that did not communicate with non-verbal cues.

In light of the utility of non-verbal communication in supporting HRIs, we submit that studying the social signals that humans perceive as a result of social cues conveyed by robots, during a simple navigation scenario, would be a worthy contribution to HRI research. To the best of our knowledge, no research has examined the effects of multiple social cues on social presence over the course of multiple interactions. As such, we were also interested in how these perceptions of social presence might change over time. The present research is motivated by the question of whether or not humans engage in the controlled processing of robotic social signals, as mindfulness is generally required for the interpretation of intentionality (Apperly & Butterfill, 2009). We suggest that dual-process theories of social cognition may provide the means for understanding how people behave around, or respond to, non-human agents, such as robots or computers, as though they were social agents, while often times, explicitly denying they were doing so. We suggest the attribution of social presence is an important step in examining how humans interpret the intentions of robots.

Present Study

The data reported here are part of a larger study examining the role of mental state attribution of a robotic agent by a human in a shared physical space. In order to determine how humans perceive social signals when robots convey certain social cues, we conducted an experiment using a prototype iRobot® Ava™ robot, a non-humanoid robot. The context for the experiment was a hallway navigation scenario in which the robot's navigational path crosses the human's. iRobot programmed Ava to display different proxemic and gaze behaviors specifically for this experiment. To assess perceived social presence, we used Harms and Biocca's (2004) social presence inventory (SPI). Our hypotheses were as follows:

H1: *Variations in gaze will have an effect on the scores of participants on the SPI administered after their interactions with the robot such that the more the robot exhibited a gaze pattern that appeared human (i.e. variable), the more participants would perceive it as a socially present agent.*

H2: *The proxemic behavior of the robot will have an effect on the perceived social presence of the robot such that the more the robot behaved in a way that appeared to give consideration to the human's trajectory (i.e., passive), the more participants would perceive it as a socially present agent.*

H3: *Attributions of social presence will be different from when participants first interact with the robot behaving a certain way compared to after they interact with the robot behaving that way across multiple trials.*

METHOD

Participants. 74 participants from a southeastern university voluntarily participated in this study in exchange for course credit (37 women, $M_{\text{age}} = 19.2$ years, age range: 18 - 27 years). Two participants' data were excluded from the analyses due to technical difficulties.

Materials. The prototype iRobot® Ava™ robot was used for this experiment. Qualtrics, a web-based survey software, was used to collect data on subjective measures. A 5 ft. by 30 ft. hallway was constructed for this experiment with a 5 ft. by 5 ft. hallway alcove intersecting at the midpoint on participants' right side of the hallway.

Design. The design of the experiment was a 3 x 2 x 2 mixed model design with the between factor (gaze: congruent, person-oriented, variable) crossed with two within factors: proxemic behavior (passive or assertive) and measurement time (time 1 and time 2). Each participant was randomly assigned to one of the gaze conditions and run through a total of 12 trials, six for the passive condition and six for the assertive with administration of the SPI after the first and sixth trail for each of the proxemic behavioral conditions.

Independent variables (IV). In this experiment, the IV gaze had three levels and was operationalized as the direction that the robot's primary sensors were oriented in terms of pan and tilt. The primary sensors of the robot were in a location that could be perceived by a human as the robot's head or eyes. The three levels of the gaze variable were congruent, person-oriented, and variable. *Congruent gaze* was defined as the head consistently being oriented in the direction of the robot's movement throughout the interaction, and was considered the least natural gaze behavior. *Person-oriented gaze* was defined as the head consistently being oriented approximately towards the head of the participant, and was considered more natural than the congruent gaze behavior. *Variable gaze* was defined as an initial orientation of the robot's head towards the participant's head and then towards the navigation goal, which was considered the most natural gaze behavior as it provided both the cue of sensing the human and the signal of intended direction of travel. Proxemic behavior was an instantiation of how assertive or passive the robot was with regard to its navigation behavior. This is operationalized by having the robot modify its path and change speed. The *passive behavior* slowed the robot and modified the path to the side of the hall to provide more space for the participant to pass in front of the robot. The *assertive behavior* sped up the robot and modified the path to "cut the corner" so as to pass in front of the participant. Lastly, there were two measurement times to examine differences in participant responses after the first interaction with the robot behaving a certain way and after multiple interactions.

Dependent variables (DV). The DVs in the study were administered using Qualtrics. This included four subscales from the SPI (Harms & Biocca, 2004), which were used to assess social presence. They are as follows: *social co-presence* (CP): awareness between social actors; *attentional allocation* (AA): measure of focus on the other social actor; *perceived message understanding* (PMU): how well social actors understood each other; and *perceived behavioral interdependence* (PBI): how much one actor's behaviors were dependent on another. The survey was slightly modified given this is an HRI study (e.g. references to "my partner" were replaced with "Ava" and "thoughts" in questions 13 and 14 of the PMU subscale were changed to "intentions"). Participants responded using a 5-point Likert scale.

Procedure. Participants provided informed consent prior to participation. Participants then interacted with the Ava robot across 12 trials. In our study, a trial was considered one interaction event with the robot. Each interaction event occurred in a hallway setting during which participants were required to walk to the opposite end of the hall while the robot, initially navigating in the opposite direction from the other end of the hallway, crossed the participant's path perpendicular to the trajectory of the participant, at the midpoint of the hallway. Participants were block-randomly assigned to an experimental condition consisting of one gaze condition and a counterbalanced display of the two levels of proxemic behavior. That is, participants interacted with the robot programmed to behave in the passive condition for six consecutive trials and assertive condition for six consecutive trials or vice versa.

After the first, sixth, seventh, and twelfth trials, participants were asked to fill out measurements on a computer to assess their perceptions of the interactions. Thus, participants provided responses to questions about the social presence of the robot after their initial interaction with the robot, after a series of interactions where the robot exhibited the same gaze and behavior settings, after interacting with the robot behaving in a different proxemic manner, and after interacting with the robot behaving in this way for several additional trials. In the results section, responses after the first and seventh trials represent the first measure time for the given proxemic condition, and responses after the sixth and twelfth trials represent the second measure time for the given proxemic condition. Lastly, demographic information was collected.

RESULTS

Social presence. We next report a series of analyses to understand the effects of the IVs on social presence. A 3 (gaze) x 2 (proxemic behavior) x 2 (measurement time) mixed model ANOVA was conducted with the between-subject variable being gaze (congruent, person-oriented, and variable), the within-subjects variables being proxemic behavior (assertive or passive) and measurement time (first measurement and second measurement) with overall scores on the SPI as the DV.

Results indicated a significant main effect for proxemic behavior, $F(1, 69) = 8.08$, $p < .01$, $\eta_p^2 = .11$, in that, social presence was rated higher during the passive condition (M = 3.70) than in the assertive condition (M = 3.53). Further, results also indicated a significant main effect for measurement time, $F(1, 69) = 15.10$, $p < .001$, $\eta_p^2 = .18$, in that, social presence was rated higher during the second measurement time (M = 3.70) than the first (M = 3.53). No effect for gaze, $F(2, 69) = 0.17$, $p >. 05$, as well as no interaction between proxemic behavior and gaze was found, $F(2, 69) = 2.66$, $p > .05$. This shows that when the robot behaved passively it was perceived as more socially present than when the robot behaved assertively. Further, there was an increase in social presence over time, which shows that even over a relatively brief period, multiple interactions with the robot increased the amount of social presence perceived irrespective of the cues it expressed.

Social presence sub-scales. To analyze the findings at the sub-scale level, four mixed model ANOVAs, setup as described above, were conducted with the exception that a rating for one of the four sub-scales on the SPI (CP, AA, PMU and PBI) was the DV. For multiple comparisons, Bonferroni corrections were used to mitigate the chance of family-wise errors.

Co-presence. The results indicated a significant main effect for time on CP, $F(1, 69) = 5.14$, $p < .05$, $\eta_p^2 = .07$, in that, CP was rated higher during the second measurement time (M = 4.40) than the first (M = 4.25). This shows that, over time, there was an increase in perceived CP for both proxemic behavioral conditions.

Attentional allocation. Results indicated a significant main effect for time on AA, $F(1, 69) = 7.78$, $p < .01$, $\eta_p^2 = .10$, in that, AA was rated higher during the second measurement time (M = 3.63) than the first (M = 3.50). This shows that, over time, there was an increase in perceived AA for both proxemic behavioral conditions.

Perceived message understanding. Results indicated a significant main effect for proxemic behavior on PMU, $F(1, 69) = 17.05$, $p < .001$, $\eta_p^2 = .20$, in that, PMU was rated higher during the passive condition (M = 3.34) than the assertive (M = 2.97). In addition, there was a significant main effect for time, $F(1, 69) = 18.36$, $p < .05$, $\eta_p^2 = .21$, such that, PMU was rated higher during the second measurement time (M = 3.30) than the first (M = 3.01). These findings show that PMU was greater when the robot behaved passively although there was a general increase in PMU over time for both conditions.

In addition, results showed a significant two-way interaction between proxemic behavior and gaze, $F(2, 69) = 3.60$, $p < .05$, $\eta_p^2 = .09$. To examine this two-way interaction, tests for simple effects were computed. Results of pairwise comparisons showed that, within the variable gaze condition, PMU was higher in the passive condition ($M = 3.38$) than the assertive condition ($M = 3.04$), $p < .05$. Similarly, within the congruent gaze condition, PMU was higher in the passive condition ($M = 3.49$) than the assertive condition ($M = 2.81$), $p < .05$. No differences were found for person-oriented gaze between either proxemic behavioral condition.

Further, results indicated a significant three-way interaction between proxemic behavior, gaze, and measurement time, $F(2, 69) = 4.04$, $p < .05$, $\eta_p^2 = .11$. To examine this three-way interaction, tests for simple effects were computed. Pairwise comparisons showed that within the variable gaze condition, differences were found in the second measurement time between the proxemic behavior conditions, with PMU being higher in the passive condition ($M = 3.74$) than in the assertive condition ($M = 3.08$), $p < .05$. Within the congruent gaze condition, differences were found in both the initial and final SPI measures such that, for both times, PMU was significantly higher in the passive condition than the assertive condition, *p's* < .05. Within the passive condition, differences were found in the second measurement time, with scores being higher in the variable gaze condition ($M = 3.74$) than in the person-oriented gaze condition ($M = 3.24$), $p < .05$. Within the variable gaze condition, differences were found in the passive condition between the SPI measures, with scores being higher in the final measure ($M = 3.74$) than in the initial measure ($M = 3.01$), $p < .05$. Lastly, within the congruent gaze condition, differences were found in the assertive condition between the SPI measures, with the scores being higher in the final measure ($M = 3.04$) than in the initial measure ($M = 2.59$), $p < .05$.

Perceived behavioral interdependence. Results showed a significant main effect for time on PBI, $F(1, 69) = 4.93$, $p < .05$, $\eta_p^2 = .07$, in that, PBI was rated higher during the second measurement time ($M = 3.47$) than the first ($M = 3.35$). This shows that, over repeated interactions with the robot, PBI increased in both proxemic behavioral conditions.

DISCUSSION

In this study, we explored how the social cues of proxemic behavior and gaze, manipulated on a robotic platform, influence social-cognitive processes in humans during a hallway navigation scenario. Specifically, social presence was measured to understand the degree to which these cues affected whether participants were willing to make mental state attributions, such as intentions, to the robot, and, the degree to which these might change over multiple interactions.

Contrary to H1, gaze did not appear to have any significant effect on social presence, though there was an interaction with proxemic behavior for the PMU subscale, as described above. This lack of a significant main effect could be due to gaze having an effect more at the automatic or Type 1 level of mental state attribution. In line with dual-process theories (e.g., Bohl & van den Bos, 2012), the SPI is designed more for assessing controlled and reflective Type 2 cognitive processes. That is, given that this study used questionnaires administered after-the-fact, assessments of automatic, Type 1 processes may not be measured in this fashion. Behavioral data from this study, captured via motion tracking sensors and video, may result in differences at the automatic Type 1 behavioral level, but it is still being analyzed. Even though the SPI was able to capture some degree of *reflective* perspective of agency attributed to the robot based on its proxemic behavior, the effects of robot gaze may only be significant *in-the-moment*, keeping with Takayama's theory on agency (2012). As such, further research is warranted to explore the nature of dual-process of social stimuli in HRI.

In support of H2, overall results indicate that participants perceived the robot as more socially present when it followed the passive behavioral programming. This may be due to participants feeling acknowledged by the robot, and being treated deferentially, as the robot would give participants the "right of way" at the interaction point of the hallway. A mindless machine, that is programmed to simply carry out its task, would not be expected to act deferentially or follow any implicit politeness social rules. Therefore, when participants interacted with a robot that appears to follow such rules, they might have perceived the robot as a social actor as opposed to just a machine. However, as the participants in this study were young adult university students, it remains an open question as to whether this interpretation would generalize to the broader population.

In support of H3, the data revealed changes in attributions of social presence over time. Specifically, there were increases in social presence in both proxemic behavior conditions. These findings suggest that, as with human-human interactions, behavioral consistency is an important component of mental state attributions. Specifically, repeated exposures to a robot behaving in a consistent way may lead to people perceiving it as more socially present and better understanding what it is the robot is intending to do. Given that future deployment of robots in everyday setting will lead to frequent interactions distributed across time, further research is necessary to understand the potentially differing effects of a variety of behaviors beyond those studied in this experiment.

The findings at the sub-scale level paint a more nuanced picture of how varying the cues expressed by the robot influenced perceived social presence. For the Co-Presence, Attentional Allocation, and Perceived Behavioral Interdependence dimensions of social presence, there were no significant differences based on the cues displayed by the robot. Instead, it seemed that repeated interactions drove the changes in these dimensions of social presence. Conversely, for Perceived Message Understanding, there were differences based on the manipulated social cues. This dimension measures understanding another's intention as well as perception that the other entity understood one's own intentions. This was shown to be greater when the robot acted according to the passive behavior programming relative to the assertive behavior programming; particularly, when the robot's gaze was congruent with its trajectory or variable (first to the person and then the intended navigational goal), the latter of which we considered to be the most natural social gaze behavior in this context.

Given the relatively common features of the scenario used in this study—two social actors temporarily in a hallway environment—we can provide context appropriate design recommendations for programming social cues that can help a robot to convey intention and be perceived as socially present (see Table 1). However, we note that behavioral data from this study are still being analyzed and accordingly, further recommendations may be forthcoming.

Table 1. Preliminary Robot Design Recommendations

1.	From the results of the passive behavioral condition, we can recommend that robots that are to be perceived as socially autonomous agents should follow implicit social rules, such as those that indicate when to treat a human deferentially.
2.	From the results of the Perceived Message Understanding, we can recommend that passive programming be used to better convey the navigational intentions of robot.
3.	From results regarding measurement time, behavioral consistency over repeated interactions increases perceptions of a robot as a socially present agent. Robots that are designed to exhibit many different behaviors should maintain some degree of consistency when interacting with the same individuals, in order to foster this increased perception.

CONCLUSION

This research investigated the effects of multiple social cues conveyed by a robot on perceived social presence during a hallway navigation scenario that occurred across repeated interactions. One limitation of this study is that our results may not generalize to contexts that are more socially dynamic than the present scenario. This could include situations with more than two social actors, areas that are more spacious, or situations with other events occurring. However, while the results of the present study may not generalize to these other social contexts, the features of the scenario used in this study are not uncommon. As such, this study provides a first step for beginning to assess the mental states attributed to robots as a function of the cues they convey and the degree to which they are perceived as social present. In short, as robots becomes increasingly pervasive in daily settings, results from this study, as well as future efforts, serve as a basis from which researchers can understand the ways humans perceive robots and how they should be designed.

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