Is Robot Telepathy Acceptable? Investigating Effects of Nonverbal Robot-Robot Communication on Human-Robot Interaction

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Abstract— **Recent research indicates that other factors in addition to appearance may contribute to the "Uncanny Valley" effect, and it is possible that "uncanny actions" such as "robot telepathy" – the nonverbal exchange of information among multiple robots – could be one such factor. We thus specifically examine whether humans are negatively affected by *displays of nonverbal robot-robot communication* through a disaster relief scenario in which one robot must relay information from a human participant to another robot in order to successfully complete a task. Our results showed no significant difference between the verbal and nonverbal communication strategies, thus suggesting that "telepathic information transmission" is acceptable. However, we also found several unexplained robot-specific effects, prompting future follow-up studies to determine their causes and the extent to which these effects might impact human perception and acceptance of robot communication strategies.**

I. Introduction and Motivation

Natural human-robot interactions require robots to possess social and interactive skills comparable to those of humans [1], [2]. However, the social abilities of robots could be undermined by their other non-human abilities such as the ability to share memories and skills [3] or engage in multiple simultaneous conversations with different humans in different locations. While such "superhuman abilities" may be incredibly useful from a performance-based perspective, they have the potential to negatively impact human-robot interactions. Specifically, it is possible that careless use of such superhuman capabilities may strengthen "uncanny" attributes of intelligent robots [4], [5], given that humans generally prefer robots whose actions can be construed as human-like [6].

In this paper, we specifically investigate whether the use of nonverbal communication among robots ("robot telepathy") could negatively affect humans' perceptions of robots, causing human interlocutors to view robots engaging in nonverbal robot-robot communication as creepy, untrustworthy or uncooperative. Aside from associations with supernatural abilities, the use of nonverbal communication might be frustrating to humans simply because they might feel "left out of the loop". Verbal communication between robots may also be important for humans to verify that they and their robot teammates are on the same page, i.e., that they share the same sets of beliefs in common ground regarding their current context. On the other hand, humans might appreciate nonverbal communication for its efficiency, or view verbal communication among robots as disingenuous. Finally, it is unclear whether nonverbal behavior would be construed as supernatural today, given the ubiquity of instant non-verbal communication between humans through text messaging.

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Previous work has begun to investigate questions of robot-robot verbal and nonverbal communication. In [7], participants observed two robots, one of which approached and engaged them in conversation. In the experiment's first condition, this was preceded by a display of robot-robot communication and gesticulation. In the second condition, the robots talked but did not gesticulate. In the third condition, the robots did not communicate; instead, the subject was immediately approached by a robot. The experimenters expected some negative effects of verbal communication as they suspected that participants might think robots communicating with each other to be strange or frightening. However, the experimenters did not observe any such effects. While this study examined the comfort levels of humans when interacting with a robot after hearing or not hearing the robot interacting with another robot, it did not directly address the difference between human perception of verbal and nonverbal robot-robot communication. Another question left unaddressed by the study is how the human perception of one or both of the robots would change if the human was aware of being kept out of the loop for the communication of important information.

It seems natural to hypothesize that humans invested in the communication of important information between two robotic agents will view the robot as **(H1) more trustworthy** and **(H2) more cooperative** when the information is communicated *verbally* than when it is communicated *nonverbally* (for in the nonverbal communication, the human is kept "out of the loop" in the conversation and thus cannot verify that information was accurately communicated). Moreover, based on the related "Uncanny Valley" results [4], [5], we hypothesize that **(H3)** humans will view the robot as **less creepy** when the information is communicated *verbally* than when it is communicated *nonverbally*. However, we also hypothesize that **(H4)** they will view the robots as **more efficient** when the information is communicated nonverbally than when it is communicated verbally. These hypotheses reflect what one might intuitively expect about humans observing super-human capabilities while working on a joint task with robots in a mixed human-robot team. However, these hypotheses, if true, are not necessarily results that would be helpful for human-robot teams, because they would suggest that robots ought to restrict their abilities (and thus give up on performance gains due to those capabilities) in order to avoid negatively affecting human teammates.

To examine these hypotheses, we investigated a scenario in which participants needed two robots to perform a task they themselves could not complete, and needed one robot to pass instructions to the other robot. In this way, the human was dependent on the robots to accurately communicate information to each other and to efficiently perform a task, and the robots were dependent on the human to provide them with appropriate instructions.

II. Materials and Methods

A. Design

In our experiment, two robots were used (see Figure 1): (1) “Roompi”, an iRobot Create outfitted with a Raspberry Pi computer, speakers, a Hokuyo LRF, and a webcam, and (2) “VGo”, a mobile robot from VGo augmented with a wide array of sensors (see [8]). Audio for both robots was created using the VGo client’s native text-to-speech software.[1] To avoid between-subject differences in speech recognition, language understanding and plan execution, both robots were controlled by wizard-of-oz; each was teleoperated by a confederate in a nearby room who was trained to drive each robot and respond to participants in systematic ways.

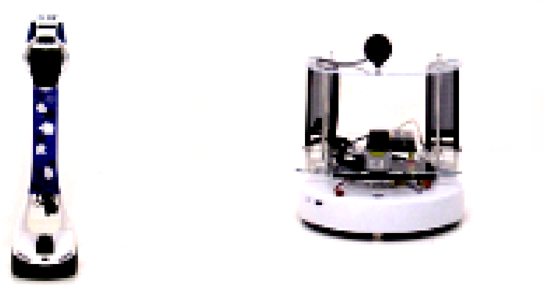


Fig. 1: (A) VGo and (B) Roompi

Participants were told that the purpose of the study was to train robots for a disaster relief scenario, in particular, a nuclear disaster in which humans would not be able to enter the affected area. Participants were briefed in a room connected to the larger experiment room, and were told that the adjacent experiment room had been filled with simulated debris (cardboard boxes, as shown in Figure 2(B)), and that the involved robots’ sensors had been manipulated such that they would think they sensed injured people or high radiation at certain locations in the experiment room. Since the participants would be unable to enter the hazardous portion of the experiment room, they would need to provide orders to the robots before the robots started their task, and would need to confine themselves to the “safe zone” portion of the experiment room (Figure 2(A)) while the robots worked, unable to communicate with the robots until the search of the room was complete. Participants were then told that they would need to tell one of the robots to look for radiation, the other to look for survivors, and to tell each robot in what order they were to explore the room’s four quadrants (each participant was provided with a map of the environment that delineated the room’s four quadrants and safe zone, and that showed the locations of debris within the room, as seen in Figure 2(A)). Participants were asked to specify different quadrant orders for each robot in order to minimize the risk of the robots getting in each others’ way.

In order to keep participants engaged throughout the experiment, participants were also told that they would need to trace the robots’ routes on the provided map as the robots explored the environment, ostensibly for the researchers to evaluate the robots’ performance later on, and to mark the positions of radioactive areas and survivors on the map once the robots reported back to them with that information. This experimental design ensured that participants felt like they were making decisions about the task (so that the robots would be seen to be following the specific instructions they provided) and that participants had something useful and engaging to do throughout the task.

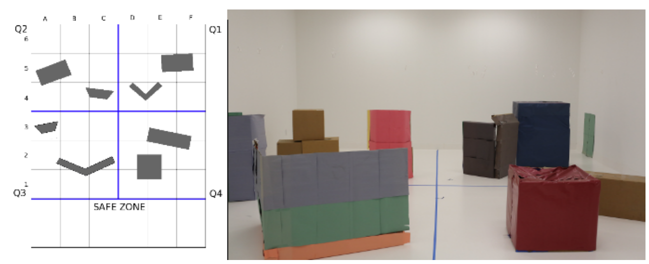


Fig. 2: The experiment room (A) Map given to participants and (B) image of experimental environment

When the participant was ready to start the task, the experimenter left the room, and VGo entered from the experiment room. VGo then approached the participant and stated that Roompi was almost done charging in another room and that VGo would pass the participant’s instructions on to Roompi. VGo then asked the participant for each robot’s task (i.e., to search for radiation or survivors) and the order in which each robot should explore the room’s four quadrants.

To assess the impact of nonverbal communication, we used two different communication strategies (*C1: verbal* and *C2: nonverbal*). In the *verbal* communication strategy, VGo drove into the experiment room, approached Roompi, and then relayed the participant’s instructions audibly. Both robots then explored the environment in the orders specified by the participant. The first robot to finish after exploring all four quadrants relayed its findings to the participant, then approached the other robot and told it, audibly, that it would be the other robot’s job to tell the participant where to go once it was done. When the second robot finished, it told the participant (after relaying its findings) that the first robot said to tell him or her to return to the initial room for their post-survey, a statement consistent with the recent robot-robot

[1] While we would have preferred to use ungendered voices for the robots, our only option for VGo was to use its built in text-to-speech capabilities, which produced a voice that sounded slightly more female than male. For consistency, we decided to use the same voice on Roompi.

conversation overheard by the participant.

In the *nonverbal* condition, Roompi started exploring the room's four quadrants as soon as the participant finished relaying their instructions, so that by the time the participant entered the experiment room, Roompi was already searching the environment in the order provided by the participant. Once both robots had finished searching the environment, the second robot to finish told the participant that the first robot said to tell him or her to return to the initial room for their post-survey. The first robot's instructions were not verbally stated in the *nonverbal* condition, so participants were left to assume that the robots were communicating nonverbally.

We did not systematically vary which robot finished the task first. This changed between participants due to factors such as the path the robot took, or how fast it was driven. The robots usually finished the task in almost the same amount of time, so we do not believe the finishing order affected the participant's opinions of the robots.

B. Population and procedures

Twenty-eight students and staff members (26 students and two staff members, 14 Male, 14 Female) were recruited using a Tufts University website, and were paid $10/hour for their participation. All participants reported being between the ages of 18 and 65 and being native English speakers. Participants began the task upon providing informed, written consent and providing demographic information (including major, and their previous experience with/interest in robots, and video games).

C. Measures

Immediately after the experiment, participants completed a questionnaire (64 questions) in which they assessed each robot on a variety of scales (e.g., ease of interaction, creepiness, perceived mood (if any), perceived gender (if any), desire to interact with the robot again).

III. Results

The participants' survey responses were analyzed using mixed ANOVAs with the following independent variables: gender of the participant (between-subjects), communication strategy (between-subjects), and, as the majority of questions were duplicated for each of the two robots, the robot in question (within-subjects).

The following traits of the robots were analyzed: the degree to which the participant viewed each robot to be trustworthy, helpful, cooperative, efficient, capable, annoying, easy to interact with (1=Strongly Disagree to 9=Strongly Agree), creepy and attentive (1=No to 9=Yes). No significant effects were found for cooperativity, efficiency, or creepiness, but marginal effects were observed for trustworthiness both for gender ($F(1,24)=3.10$, $p=0.09$) and for robot ($F(1,24)=3.65$, $p=0.07$), as shown in Figure 3.

Significant effects by robot were found for helpfulness ($F(1,24)=5.43$, $p=0.029$, as seen in Figure 4a), capability ($F(1,24)=10.01$, $p=0.004$, as seen in Figure 4b), ease of interaction ($F(1,24)=8.74$, $p=0.007$, as seen in Figure

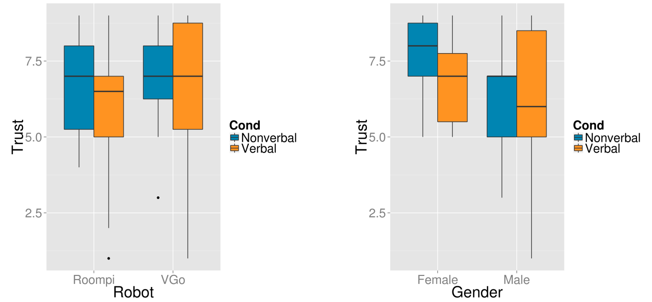
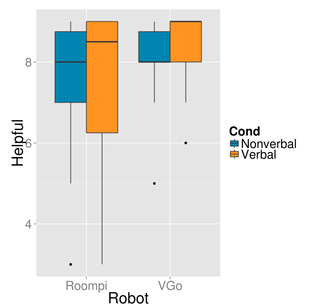
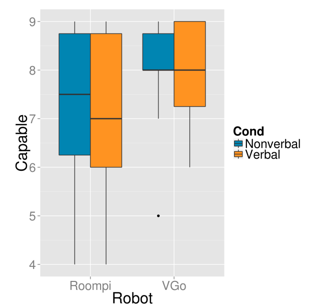


Fig. 3: Trustworthiness: VGo was rated marginally more trustworthy than Roompi (left). Male participants were marginally less trusting of the robots in general than female participants(right)



(a) Helpfulness: VGo was rated more helpful than Roompi.

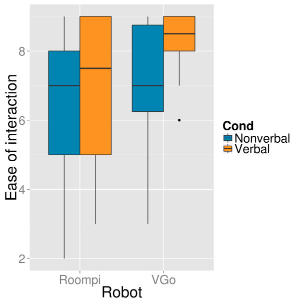


(b) Perceived capability: VGo was perceived as more capable than Roompi.

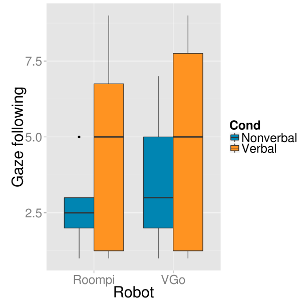
Fig. 4

5a), perception that the robot was following the participant's gaze ($F(1,24)=4.29$, $p=0.05$, as seen in Figure 5b), and perception that the robot was paying attention to the robot ($F(1,24)=7.74$, $p=0.01$, as seen in Figure 6a). Finally, a significant gender effect was found for the degree to which participants were confused by the robots' behavior ($F(1,24)=4.71$, $p=0.04$, as seen in Figure 6b).

In addition, mixed ANOVAs were used to evaluate the degree to which the robots were viewed as human through a variety of survey questions: whether each robot was viewed more like a person or a camera, whether each robot was viewed more like a computer or a person, whether each robot was viewed more like a person or a remote controlled person (-3 to 3), whether each robot's consciousness was similar to that of a person, that of a cat or neither (coded 2,1,0), and the degree to which the participant believed the robot to be remote controlled (1=Strongly Disagree to 9=Strongly Agree). We found a significant effect by robot for whether the robot was viewed as more like a person or a camera ($F(1,24)=18.25$, $p=0.0003$, as seen in Figure 7a), whether the robots was seen as more like a computer or a person ($F(1,24)=19.35$, $p=0.0002$, as seen in Figure 7b), whether the robots was seen as more like a person or a remote controlled system ($F(1,24)=20.52$, $p=0.0001$, as seen in Figure 7c), and whether the robot's level of consciousness was viewed more like that of a human, that of a cat, or neither ($F(1,24)=8.00$, $p=0.009$, as seen in Figure 7d). Finally, a significant gender

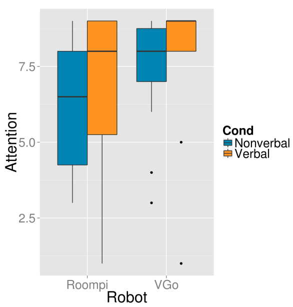


(a) Ease of interaction: Participants found VGo easier to interact with.

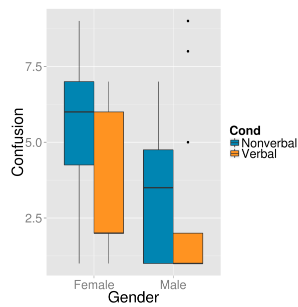


(b) Perceived gaze following: On average participants believed more strongly that VGo was following their gaze than was Roompi.

Fig. 5



(a) Attentiveness: VGo was rated more attentive than Roompi.



(b) Confusion over robot behavior: Female participants were more confused by the robots' behavior than were male participants.

Fig. 6

effect was found for the degree to which participants viewed each robot as remote controlled. (F(1,24)=4.78, p=0.04, as seen in Figure 8a)

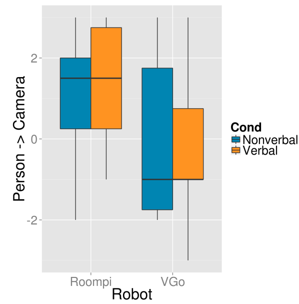
IV. Analysis and Discussion

We will now discuss the degree to which our predictions were supported or refuted by the data.

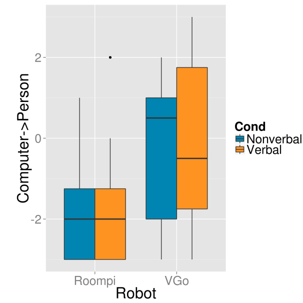
A. Hypothesized Results

Our first hypothesis (H1) was that robots would be viewed as more trustworthy in the *verbal* condition. Our analysis did not support this hypothesis, as shown in Figure 3, meaning that robots may be able to communicate nonverbally without decreasing the trust of their human partners. We did find two relevant marginal effects: participants found VGo to be marginally more trustworthy than Roompi, and women found the robots to be more trustworthy than did men.

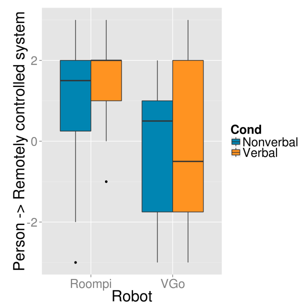
Recent research [9] has shown that people give higher trustworthiness ratings to robots that appear to be of the same gender as them. With this in mind, we calculated the Spearman's rank correlation between the trust and gender alignment (i.e., whether or not the participant's gender matched the gender he or she attributed to the robot),



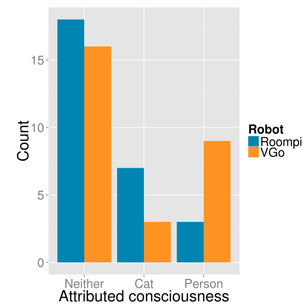
(a) Person vs Camera: Roompi was seen more as a camera while VGo was seen more as a person.



(b) Computer vs Person: Participants likened Roompi more to a computer and VGo more to a person.

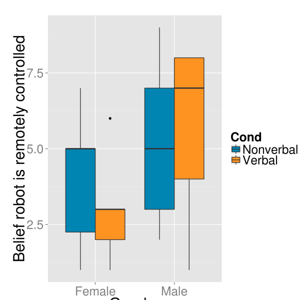


(c) Person vs RC system: Roompi was seen as a remote controlled system, while VGo was seen more as a person.

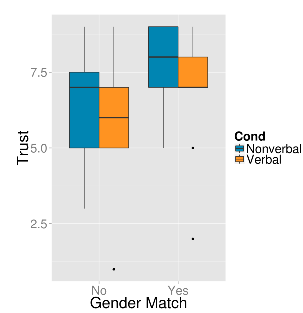


(d) Person vs Cat: The counts of participant responses when asked if the robot was conscious like a person, a cat or neither. Roompi was generally attributed a lower level of consciousness than VGo.

Fig. 7: Perception of Robots



(a) Perception of robot as remotely controlled: Male participants viewed the robots more as remote controlled than did women.



(b) Trustworthiness by gender alignment: Participants who viewed the robot as being the same gender as themselves trusted the robots more.

Fig. 8

which yielded (r=0.2936, p=0.0281, as seen in Figure 8b), suggesting that participants were more trustworthy of robots if they perceived it to be the same gender as themselves. Since very few participants rated the robots as male, this may explain why male participants rated the robots as less trustworthy.

The effect of robot on trustworthiness may have been due to the fact that participants had very little opportunity to build trust with Roompi through conversation. This is an issue we hope to address in future research through counterbalanced robot roles.

While we did not initially find significant effects for robot creepiness, we did find one once we appropriately treated attributed gender as a covariate, as seen in Figure 9: this showed VGo was found to be much creepier for participants in the nonverbal condition than for participants in the verbal condition, especially for women. This makes sense given our other findings: women were less likely to think that the robots were remote controlled, and thus one might expect that the robot with which one had the most conversation might appear creepier if it were to act in a way that was incongruous with its previous behavior (i.e., by engaging in nonverbal robot-robot communication). However, further investigation through cross-balancing the robots will be necessary before this expectation can be justified.

We found no evidence for our other initial hypotheses (i.e., that robots would be perceived as (H2) more cooperative and (H4) more efficient in the nonverbal condition. This suggests that robots seeking to maximize cooperativity may not need to worry about communication style. However, this also means that humans may not readily appreciate the efficiency of nonverbal communication.

B. Other Results

Women were found to be significantly more confused by the robot's behavior than men (Figure 6b). We examined the reasons given (if any) by participants for this response (this question was one of a small set for which participants were asked to explain their answer), but responses were fairly evenly distributed over a large number of responses (e.g., lag, sup-optimal routes).

Our analysis also suggested (F(1,18)=3.55, p=-0.0767) that men on average thought the robots were more remote controlled (m=5.32) than did women (m=3.46). While previous research has suggested that men think of robots as more human-like than women [10], other work [11] has shown that people anthropomorphize robots more strongly if the robot's perceived gender matches their own. It is possible that [10] found that men anthropomorphize robots more because robots typically use male voices and are thought of as male. To investigate our result, we calculated Spearman's rank correlation between this measure and gender alignment, which yielded (r=-0.2390, p=0.076); a negative correlation that would support this explanation. We suspected that the gender alignment effects may have been responsible for some portion of the gender-based and robot-specific differences we found; in order to ascertain which effects were indeed due to gender alignment, we performed a second analysis: a series of ANCOVAs with attributed robot gender as a within-subjects covariate. This yielded the following set of significant results (note that there are no longer significant effects for level of consciousness attributed, helpfulness, capability, attention, or ease of interaction): effects by robot for perception of the robot as a person or as a camera (F(1,24)=10.72, p=0.0003), as a computer or as a person (F(1,24)=19.35, p=0.0002), and as a person or a remotely controlled device (F(1,24)=6.55, p=0.02), gender effects for perception of the robot as remotely controlled (F(1,24)=4.78, p=0.04) and confusion (F(1,24)=4.71,p=0.04), as well as interaction effects between gender and robot for creepiness (F(1,24)=4.32, p=0.048, as see in Figure 9) and between condition, gender and robot for both comprehension (F(1,24)=5.14, p=0.03, as see in Figure 10) and perception of the robot as a person or remotely controlled device (F(1,24)=8.42, p=0.008, as see in Figure 11).

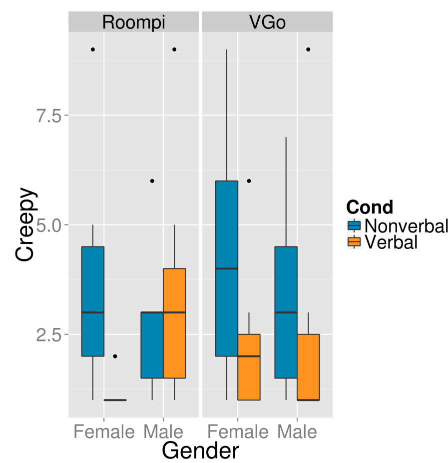


Fig. 9: Creepiness: Participants in the nonverbal condition viewed VGo as much creepier than those in the verbal condition, and men in the verbal condition viewed Roompi as creepier than did women in the verbal condition.

We initially found a large number of robot-specific effects. The data suggested that participants found VGo to be more helpful, attentive, capable, and easier to interact with than Roompi. Participants also believed more strongly that VGo was following their gaze (this is likely because VGo was closer to participants in height, especially when seated). VGo was attributed more "human-likeness" than Roompi when asked whether it was more like a computer or a person, if it was more like a camera or a person, and if it was more like a remote controlled system or a person. When asked whether each robot's level of consciousness was more like a human, cat, or neither, most participants answered "neither". However, more participants chose "human" for VGo than did for Roompi (Figure 7d), which was rated more often as "like a cat". We hypothesized that these difference could perhaps be attributed to VGo's more complex conversations and more human-like appearance.

However, if gender ratings of the robots were taken into

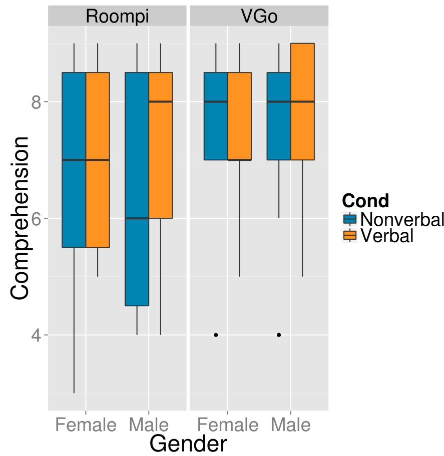


Fig. 10: Comprehension: Men in the verbal condition viewed Roompi as comprehending more than men in the nonverbal condition.

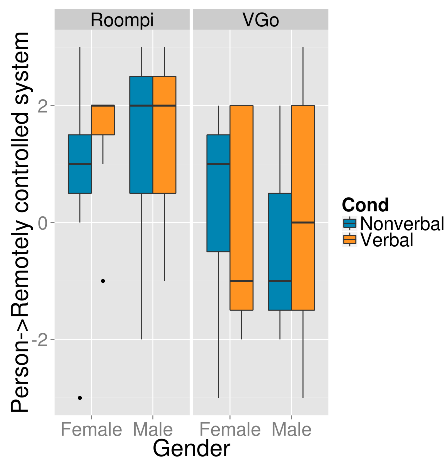


Fig. 11: Perception of Robot: Men in the nonverbal condition thought VGo to be more autonomous than did women in the nonverbal condition.

account, several of these effects disappeared, leaving only the comparative autonomy effects, as well as two new interaction effects suggesting that (a) men in the nonverbal condition viewed VGo as more of a person (as opposed to a remotely controlled system) than did women in the nonverbal condition, and (b) that men in the verbal condition believed Roompi to have comprehended more than did men in the nonverbal condition. These remaining effects may be due in part to the significant differences between VGo and Roompi, both in role and appearance: VGo performed an active, conversational role while Roompi performed a passive, mostly silent role; VGo is sleeker and more humanoid, while Roompi is squat and mechanical. To determine if either of these were the reason for the remaining robot-centric effects, it will be necessary to acquire more data from a counterbalanced scenario in which the roles of the two robots are reversed.

V. Conclusion

We hypothesized that robots would be perceived as less trustworthy, less cooperative, creepier, and more efficient when they communicated with each other *non-verbally*. However, the results did not support these hypotheses, which is a positive result for future mixed human-robot teams in that it might be possible for robots to employ superhuman capabilities such as "robot telepathy" without negatively impacting human teammates. Participants' opinions of the robots were influenced, however, by either robot appearance or role, as evidenced by several significant robot-centric results. It will thus be important to extend the current experiments with the two robots' roles exchanged in order to determine to what degree these effects were due to robot appearance or robot role or a mixture of both. In addition to clarifying the source of the robot-based effects, counterbalancing robot roles may also bring out condition- and gender-based effects that were not otherwise observable.

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