Differences in Interaction Patterns and Perception for Teleoperated and Autonomous Humanoid Robots

Maxwell Bennett, Tom Williams, Daria Thames and Matthias Scheutz

***Abstract*— As the linguistic capabilities of interactive robots advance, it becomes increasingly important to understand how humans will instruct robots through natural language. What is more, with the increased use of teleoperated humanoid robots, it is important to recognize whether any differences between instructions given to humans and robots are due to the physical embodiment or perceived autonomy of the instructee. In this paper, we present the results of a human-subject experiment in which participants interacted in a collaborative, task-based setting with both a human and a suit-based, teleoperated humanoid robot said to be either autonomous or teleoperated.**

Our results suggest that humans will use politeness strategies equally with human, autonomous robotic, and teleoperated robotic teammates, reinforcing recent findings that autonomous robots must comprehend and appropriately respond to human utterances that follow such strategies. Our results also suggest variations in how different teammates were perceived. Specifically, our results suggest that human-teleoperated robots were perceived as less intelligent than human teammates; a finding with serious implications for human-robot team dynamics.

I. Introduction

As the linguistic capabilities of interactive robots advance, it becomes increasingly important to understand how humans will instruct robots through natural language, and how this might differ from how they instruct fellow humans. Knowing how humans will instruct robots is especially important both for robot developers seeking to enable learning-from-demonstration capabilities as well as those seeking to enable more general natural language understanding capabilities.

What is more, with the increased use of teleoperated humanoid robots, it is important to recognize whether any such differences are due to the physical embodiment or perceived level of autonomy of the instructee. While some previous work [1], [2] has begun to look at linguistic differences in human-to-human and human-to-robot instructions, it has not considered such possible effects. Furthermore, in that work a specific instruction task was provided by the experimenters, which may have biased the utterances used in task instructions. In this work, we thus present an experiment investigating the linguistic differences between human-to-human and human-to-robot task instructions using a paradigm in which participants sequentially teach a human and a robot (believed by participants to be either autonomous or human-teleoperated) how to arrange a set of objects in a unique manner and determined by each participant.

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To better understand the causes of linguistic differences, we also evaluated the differences between participants' perceptions of autonomous versus teleoperated humanoid robots. Little empirical research in HRI has investigated perceptions of teleoperated humanoid robots, and to the best of our knowledge all previous research investigating human perceptions of autonomous versus teleoperated robots has been *observational*, and has used robots controlled through graphical interfaces. In contrast, we study actual *interactions*, and use a novel, immersive interface in which teleoperator motions are replicated by a robot in real time.

In Section II we discuss previous work informing our experiment. In Section III we then discuss the design of a human-subject experiment to investigate our questions of interest. In Section IV we present the results of that experiment, and discuss our findings in Section V. Finally, we conclude with design recommendations and directions for future work in Section VI.

II. Related Work

A. Linguistic Interaction with Robots vs. Humans

Recently, there has been much research investigating how social norms such as *politeness* will transfer from human-human interactions to human-robot interactions [3], [4], [5], [6]. One politeness strategy common to human-human interactions is the use of so-called *indirect speech acts (ISAs)* such as "Could you get me a coffee?" in which the literal meaning does not exactly match the intended meaning [7]. Recent work has shown that humans consistently use ISAs when interacting with robots, especially in contexts with conventionalized social norms [8]. Because enabling robots to understand ISAs is both crucial yet overlooked, we have chosen to examine them specifically, and leave other linguistic phenomena for future work.

For teleoperated and autonomous robots operating in novel task-based contexts (i.e., without conventionalized social norms), we would expect the linguistic interaction patterns to differ with respect to the extent that such politeness strategies are used. But, like recent work from Gross [1], [2] which investigated linguistic differences in human-to-human versus human-to-robot task instructions more generally, these interaction studies used highly constrained tasks, such as having participants instruct how to attach different parts of a tube. As a result, these constrained tasks may have biased participants' linguistic patterns. What is more, this research did not examine whether differences were due to perceptions of embodiment or autonomy. Because the presented experiment examines such differences through the use of robots purported to either be teleoperated or autonomous, we must also briefly describe previous research investigating differences in interaction with or perception of teleoperated versus autonomous robots.

B. Perceptions of Autonomous vs. Teleoperated Robots

Little previous work has investigated perceptions of Autonomous vs. Teleoperated Robots. Weiss et al. [9] found that participants who viewed videos of a teleoperated robot thought they would have felt the same about working with an autonomous robot, but that participants who viewed videos of an autonomous robot felt they would have *preferred* working with a teleoperated robot. However, research has suggested significant perceptual differences of robots in observation versus interaction [10], [11], [12], and as such it is unclear to what extent these observational findings would apply to actual interactions. In contrast, Choi et al. [13] present an interaction study in which robots purported to be autonomous are perceived as more intelligent than robots known to be teleoperated. However, that work examined only a brief greeting rather than an extended task-based interaction.

In addition, these two studies exhibit characteristics largely common to HRI studies of teleoperation which prevent direct application to modern teleoperated robots. With the notable exception of Weiss et al.'s experiment, little empirical research has made use of teleoperated *humanoid* robots. This is deeply problematic because humanoid robots are uniquely suited to perform many tasks in environments designed for human beings [14], and because research has shown that humanoid robots may be perceived using the same cognitive processes normally reserved for perception of human agents [15]. Furthermore, all previous empirical research involving teleoperated robots has relied on joystick based or graphical interface based Wizard-of-Oz interfaces [16], [14]. For teleoperated humanoid robots, it is crucial for interaction studies to use teleoperation interfaces that replicate the natural motions of human teleoperators [17], [18] (as this may greatly increase the perceived human-likeness of the robot and significantly reduces the likelihood that a robot will be physically unable to comply with a given instruction) and that allow the teloperator to perceive the environment as if they were really there [19] (as the head motions executed while shifting gaze are a valuable source of information both for completion of task-based goals and for engaging in dialogue-based interaction).

III. Methodology

We will now describe the details of our hypotheses, experimental design, procedure, and measurements.

A. Hypotheses

Previous work has shown that humans' use of ISAs with robots is more common in contexts with conventionalized social norms [8]. We thus hypothesized **(H1)** that humans would likely use fewer ISAs when instructing robots versus humans, but ISA use would be higher when instructing teleoperated versus autonomous robots.

Previous research has suggested that robots' size, imprecision of movement, and *actual* impoverished capabilities all contribute towards *perceived* impoverished capabilities [20], [9], [14]. We expect this to be especially true for suit-controlled teleoperated humanoid robots like the one used in our experiment, which are disadvantaged on all of these fronts relative to their human teammate. We thus hypothesized **(H2)** that both autonomous *and teleoperated* robots would be perceived as less intelligent and capable than humans performing equivalent tasks.

And because previous research has suggested that higher levels of robot autonomy correlate with higher levels of blame and scrutiny [20], [21], we hypothesized **(H3)** that teleoperated robots would be perceived as more successful after completing a task than would an autonomous robot.

B. Experiment Design

We conducted a laboratory study in which each participant was required to teach a new skill to a **human** learner and to a **robot** learner. Participants were either told that the robot learner was **teleoperated (TC)** or **autonomous (AC)**. We used identical Wizard-of-Oz interfaces in both conditions, meaning that any differences between robots existed solely in participants' minds. We would expect participants in the **TC** condition to assume the teleoperator to have identical cognitive capabilities and reduced physical capabilities to a co-present human, and participants in the **AC** condition to assume the robot to have reduced cognitive *and* physical capabilities to a co-present human.

These conditions were combined to yield a 2x2 mixed-factorial study in which each participant interacted with two agents: a human and a robot (a within-subject manipulation). The order of these two interactions was counterbalanced to prevent ordering effects. Half of participants were told that the robot would be an autonomous robot, and half of participants were told that the robot would be a teleoperated, human-controlled robot (a between-subject manipulation).

Participants interacted with each agent by teaching them how to complete a task in a large experiment room divided into two areas: a *teaching* area in which the participant was seated, and a large *experiment* area. Participants were seated in front of a *diorama* which replicated the experiment area in miniature (Figs. 1 and 2). Both the diorama and experiment area were divided into four quadrants containing a variety of objects: four cardboard boxes (each of which was labeled with a different letter), and three colored towers (comprised of Lego blocks in the diorama and aluminum cans in the experiment area).

Participants were told to arrange their diorama *however they wished*, with only a few limitations (i.e., cans could not be translated, boxes could not be flipped over or stacked), after which they would be tasked with teaching a human or robot agent how to replicate that arrangement using the full-size objects found in the experiment area. In **AC**, participants were told that if the learner was a robot, it would be autonomous; in **TC**, participants were told that if the learner was a robot, it would be a teleoperated robot controlled by a human who, using an interface, could make the robot say a limited number of things. After participants

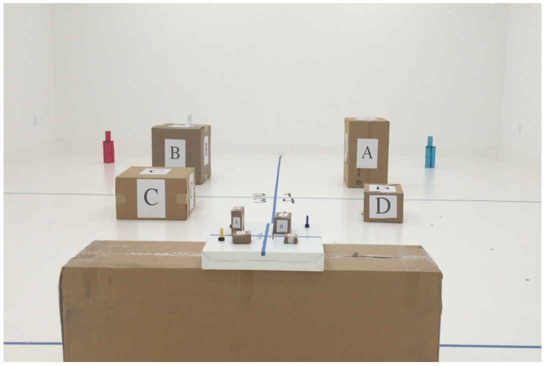

Fig. 1: Experiment room, including diorama.

finished arranging their diorama however they wished, the researcher retrieved the first agent. The agent moved in front of the participant, introduced themselves, and stated “Today I will be listening to your instructions to arrange this room in the manner you have done here”, gesturing towards the participant’s diorama. Participants then gave instructions to the agent to arrange the full-size objects to replicate the arrangement of their diorama, and the learner carried out the instructions to the best of their ability. Both human and robot learners restricted their utterances to “Okay”, “Yes”, and “No” whenever possible, but also asked “Are there any more instructions?” if it was not clear whether the interaction was over. The robot’s utterances were selected by a human confederate, and synthesized using a text-to-speech interface. Once the interaction was finished, the agent said “Goodbye” and left the room.

Let us now highlight several decisions made as part of this experimental design. First, in order to ensure participant engagement, naturalness of interaction, and prevent bias of the experimenter on participants’ utterances, participants in this experiment had *free control* over their arrangements and how those arrangements were described (c.f. [1], [2]). Second, key to this experiment are the specific robot and control interface that were used: a humanoid robot and one-to-one exo-suit developed by Kindred Systems, as seen in Fig. 3. The robot and exo-suit were coupled with an Oculus Rift virtual reality headset so that a human operator could

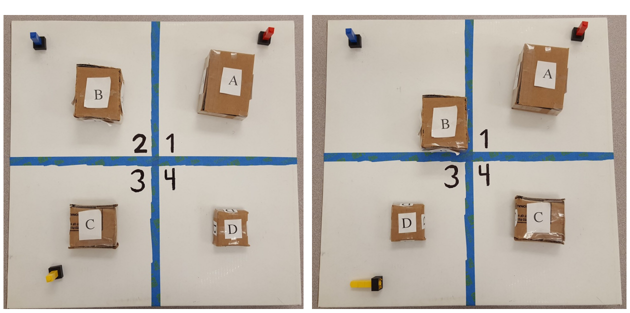

Fig. 2: Starting diorama and example arrangement.

Fig. 3: Teleoperation exo-suit and humanoid robot.

be visually immersed in the robot’s environment, using the stereoscopic cameras on the robot as the video feed for the human operator. Additionally, two microphones on the robot’s head delivered stereophonic auditory data so that language and sounds could be spatially localized even if the audio source was not in the robot’s line of sight. A set of 3 pedals were used to move the wheeled base of the robot. The robot’s voice output was controlled by a second operator using a limited text-to-speech interface which allowed the robot to utter the same introductory phrases and limited responses used by the human confederate.

C. Experimental Procedure and Participation

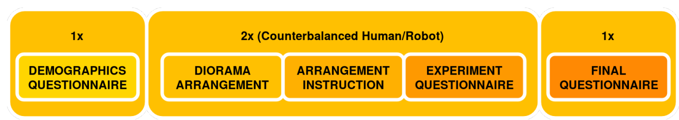

Fig. 4: Experimental Procedure

We will now discuss our experimental procedure (Fig. 4). Participants first completed a questionnaire gathering information on participants’ demographics and previous experience with robots. All questionnaires were carried out in a separate survey room. Participants then moved to the experiment room and conducted the main task. Next, participants completed a questionnaire assessing their perceptions of the agent and the success of the task. After completing this questionnaire, participants were told they would perform the same task with “another agent” and that they were again free to arrange their diorama however they wished. Participants were not told what type of learner they would interact with next, but in all cases the type of learner varied to counter the first interaction; if a robot learner was used in the first experiment, a human learner was used in the second, and vice versa. Upon finishing the second interaction, participants answered the experiment questionnaire again, as well as additional questions comparing the two tasks and agents.

Thirty-three students and university employees were recruited through fliers and university class forums. Participants (21 Female, 12 Male) ranged in age from 18 to 25 (M=20.85, SD=1.37). All participants were given \$10 as compensation for their time.

D. Measurement

In addition to the demographic survey, as previously described, questionnaires were used to gather data regarding participants' perceptions of their human and robot teammates. Participants' views on the following properties of the robot and human were analyzed: cooperativity, capability, annoyingness, creepiness, responsiveness, belief *before* meeting the learner that the learner would be capable of replicating the participant's block arrangement (1="strongly disagree" to 7="strongly agree"), attentiveness, gaze-following, tendency-to-ignore, understanding, belief *after* meeting the learner that the learner would be capable of replicating the participant's block arrangement (1="no" to 7="yes"), arrangement complexity (1="simple" to 7="very complex"), ease of interaction (1="easy" to 7="hard"), level of comprehension (1="low" to 7="high"), and successfulness (1="completely unsuccessful" to 7="very successful"). Finally, participants were asked to imagine if, in an alternate interaction with the robot, they believed that the robot would have been capable of understanding three commands within that new task.

In addition to these subjective, self-reported measurements, we also collected several objective behavioral measures. For each participant, video recording was used to assess the number of words used by participants, and the percentage of utterances used by participants that were ISAs, as well as the *complexity* of participants' arrangements, as assessed by the metric discussed below. Arrangement complexity was calculated to use as a covariate in our analyses: we are interested in the indirectness of participants' utterances and the number of words required to accomplish the given tasks *regardless of task complexity*. For example, using an external complexity estimate as a covariate will allow us to control for the fact that more complex tasks likely require more words to complete.

Arrangement complexity was calculated as $(b_0+b_1+b_2+b_3)+(t_0+t_1+t_2)+s$, where each box B_i contributed b_i points if moved (equal to the number of centimeters moved within the diorama), each tower T_i contributed t_i points if knocked down (equal to one-half its distance from the center of the diorama), and a "systematicity bonus" s was added equal to the smallest number of groups $c_0, ...c_n$ that could be formed by grouping the boxes by symmetry of motion[1], as depicted in Fig. 5.

IV. Results

Participants' questionnaire responses were analyzed using mixed Analyses of Variance (ANOVAs) with two independent variables: main experimental condition (autonomous **(AC)** vs. teleoperated **(TC)**, between subjects), and interaction order (robot first vs. human-first, between-subjects).

[1]For example, all four boxes moving one quadrant counter-clockwise yields one group; two boxes rotating counter-clockwise and the others not moving yields two groups; two boxes rotating counter-clockwise, one box not moving, and one box moving to the far right of its quadrant yields three groups; one box rotating counter-clockwise, one box not moving, one box moving to the far right of its quadrant, and one box moving to the center corner of its quadrant yields four groups.

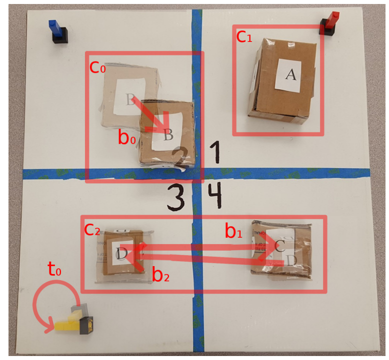

Fig. 5: Sample complexity diagram for Fig. 2 arrangements.

For each of these variables, we first established that there were no main or interaction effects involving order of interaction, and then used ANOVAs to examine whether there were significant differences between robot and human learners, or between teleoperated and autonomous robot learners.

A. Objective Measures

While no differences were found in the percentage of learner-directed directives that were phrased indirectly vs. directly, a factorial logistic regression analysis yielded a marginal interaction effect with respect to whether or not participants used indirect utterances at all (odds ratio=0.13, probability value (p)=.053): In **AC**, 70.59% of participants used at least one ISA when directing another human but only 29.41% of participants used one when directing a robot; in **TC**, 50.0% of participants used at least one ISA when speaking with another human, but 56.25% of participants used at least one when speaking to the teleoperated robot.

A significant difference was also found with respect to number of words used to describe the task to robot learners between **AC** and **TC**: participants used significantly more words to describe the task in the **TC** (Mean(M)=204.88, Standard Deviation(SD)=181.60) than in **AC** (M=72.82, SD=42.83), F(1,29)= 8.05, p=.008. An Analysis of Covariance (ANCOVA) using task complexity as a covariate attenuated this effect, F(1,29)=4.43, p=.02. Finally, a significant difference was found with respect to the number of words used by humans to describe the task to all learners: participants used more words to describe the task (to either learner) in **TC** (M=153.28, SD=103.40) than in **AC**(M=80.09, SD=40.02), F(1,29)= 6.91, p=.014, an effect attenuated in a subsequent ANCOVA, F(2,62)=4.72, p=.012. An interaction between condition and learner was also found: far more words were used with robots in **TC** (M=204.88, SD=181.60) than with *humans* in **TC** (M=101.69, SD=44.79), robots in **AC** (M=72.82, SD=42.83) or humans (M=87.35, SD=46.27) in **AC**, F(1,29)=7.79, p=.009, an effect that was strengthened in a subsequent ANCOVA, F(6,58)=3.25, p=.008.

B. Subjective Measures

Differences by Purported Autonomy: In this section, we will describe differences we found between **AC** and **TC**. The results of our analyses suggest that participants in **AC** judged their arrangements to be less complex in retrospect (M=2.53 SD=1.28) after interacting with robot learners than did participants in **TC** (M=4.00, SD=1.37), F(1,29)=9.92, p=.004. When arrangement complexity was treated as a covariate in a subsequent analysis of covariance, this effect was attenuated, F(2,29)=5.92, p=.007. Participants in **AC** less strongly agreed that robots could be conscious (M=3.06, SD=1.78) than those in **TC** (M=4.38, SD=1.59), F(1,29)=5.60, p=0.025, and less strongly believed that the robot learner had been following their gaze (M=4.06, SD=1.49) than did participants in **TC** (M=5.09, SD=1.19), F(1,29)=5.43, p=.027.

Differences by Agent: A number of significant differences were found between perceptions of the human learners and the robot learners, as seen in Tab. I:

TABLE I: Perceptions of Agents

	H(M, SD)	R(M, SD)	F(1,29)	p
Capable	6.88, 0.33	5.97, 1.04	28.07,	<.001
Annoying	1.36, 0.93	2.00, 1.17	7.02	.013
Creepy	1.67, 1.08	2.73, 1.72	11.16	.002
Conscious	6.97, 0.17	3.97, 1.78	91.63	<.001
Easy Interaction	2.06, 1.84	3.15, 1.73	6.67	.015
Comprehension	6.76, 0.56	5.94, 0.66	29.45	.007
Understanding	6.79, 0.48	6.27, 0.76	12.96	.001
Gaze Following	5.42, 1.85	3.70, 1.84	17.07	<.001
Perceived Success	6.78, 0.48	6.12, 0.93	12.99	.001

Participants were also less likely to believe that a robot would understand each of the three alternate-scenario commands than that a human would, as seen in Tab. II:

TABLE II: Alternate-Scenario Commands

	Human(M,SD)	Robot (M,SD)	F(1,29)	p
C1	4.67,1.99	5.76,1.79	9.16,	.005
C2	5.15,2.08	6.48,1.12	15.15	<.001
C3	2.85,1.84	6.70,0.92	105.27	<.001

Interaction Effects: A significant interaction between condition and learner was found on adjudication of task complexity: Participants in **TC** ranked the arrangements they gave to robots significantly more complex (M=4.00, SD=1.37) than they did the arrangements they gave to humans (M=2.93, SD=1.34) or the arrangements that participants in **AC** gave to either robots (M=2.53, SD=1.28) or humans (M=2.76, SD=1.09), F(1,29)=7.10, p=.012. This effect was attenuated by a subsequent analysis of covariance, F(6,58)=2.62, p=.026.

V. Discussion

We hypothesized **(H1)** that participants would use more indirect language when communicating with robots in **TC** than they would in **AC**, but less than when communicating with other humans. We did not find any evidence suggesting that participants used a higher *proportion* of ISAs when speaking with humans, but found that the use of a purportedly autonomous robot (whose use reinforced the difference in human-likeness between human-and-robot) may have caused participants to be more likely to use indirect language *at all* when directing their human teammate, and less likely when directing the robot. Overall, however, the lack of a significant difference in overall ISA use between humans and robots reinforces the importance of enabling robots to understand these types of utterances. In fact, some participants *exclusively* used ISAs, even when directing a purportedly autonomous robot (Fig. 6): We hypothesized **(H2)** that not

H: Alright Alex, can you take the box B... D over there in quadrant 4 and move it to quadrant 3?
R: OK.
H: Can you move the box D to your right of box C?
R: OK.
H: Um... can you move it to the other side of box C?
R: OK.
H: Perfect.
H: Can you go to quadrant 2 and knock over the red tower?
R: OK.
H: Um can you go to quadrant 1 and knock over the blue tower?
R: OK.
H: It's all done.

Fig. 6: Transcript excerpt: human instructing "autonomous" robot

only would robots described to participants as *autonomous* be perceived as less intelligent and capable than humans would be, but also that robots described to participants as *teleoperated* would be perceived with similarly diminished capabilities, even though in reality all three learners had identical cognitive capabilities. And in fact, this is just what we observed. Our results showed that participants rated both autonomous *and teleoperated* robots as less understanding of their instructions and less likely to understand high level commands such as "Arrange the blocks *like this*' (C3). This is striking, as such ratings should depend only on the *mental faculties* of the learner; and yet participants rated the human-teleoperated robot no differently in this respect than they did the purportedly autonomous robot. Furthermore, both autonomous *and teleoperated* robots were rated as more annoying, creepy, harder to interact with, and overall less capable *and conscious* than their human counterparts.

This suggests that regardless of whether or not a robot is human- or AI-controlled, humans are likely to see the robot's form as hindering its controller's capabilities *and intelligence*. This is particularly significant for human-robot collaboration, as it suggests that people may view not only a teleoperated robot, but also *its teleoperator*, as inferior to a present human counterpart, altering both social dynamics and expectations of success. In our experiment, such effects can be observed in exchanges such as that seen in the second transcript excerpt (Fig. 7), in which a human provided the following sequence of commands to a robot's teleoperator: What is especially concerning here is not only that this participant used direct, low-level language to command a (fellow human) teleoperator, but that the participant's use of this language then carried over into his interaction with a *co-present human teammate*. In the second half of the experiment (Fig. 8), the participant used this type of language

H: Turn right 90 degrees
H: Go forward point-two-five seconds
H: Turn right 90 degrees
H: Push box point-two seconds

Fig. 7: Transcript excerpt: human instructing teleoperator.

to instruct a co-present human:

H: Move box B towards the wall, uh, point-two seconds.
H: Move box B away from the line half a second.
H: Turn box B 45 degrees.

Fig. 8: Transcript excerpt: human instructing co-present human.

Finally, because higher levels of autonomy have previously been correlated with higher levels of blame and scrutiny, we hypothesized **(H3)** that autonomous robots would receive less credit for successful completion of the task than would teleoperated robots (i.e., that teleoperated robots would be rated as more successful). While we did not find evidence supporting this hypothesis, we did observe that participants in **TC** retrospectively judged the arrangements provided to robot learners to be more complex than did participants in **AC**, even when controlling for the actual complexity of their arrangements. This suggests that participants may have attributed more of the credit for task success to the *learner* in **TC**, but to have retrospectively assumed *simplicity of arrangement* in **AC**, which would indirectly support H3.

VI. CONCLUSIONS

In this paper, we have investigated the differences in how humans instruct humans and robots when choosing their own task, particularly examining the differences between instructions given to purportedly autonomous and teleoperated humanoid robots controlled through identical immersive virtual reality interfaces in which teleoperator motions are replicated by the robot in real time.

Our results suggest that humans will use politeness strategies with human teammates, autonomous robot teammates, and teleoperated robot teammates, at an equivalent rate, reinforcing recent findings that autonomous robots must be able to comprehend and appropriately respond to human utterances that follow such strategies. Our results also suggest variations in how these three types of teammates were perceived. Specifically, our results suggest that human-teleoperated robots were perceived as less intelligent than human teammates; a finding with serious implications for human-robot team dynamics.

Future research should investigate (1) differences in gaze and gesture patterns accompanying the instructions given to humans and both autonomous and teleoperated robots; (2) how humans' interaction patterns with autonomous and teleoperated robots will change across long-term interactions, and the effects that long-term teleoperation of a robot may have on the cohesiveness of mixed human-robot teams; (3) what aspects of a teleoperated robot's appearance and behavior contribute to the decreased perceptions of its teleoperator's intelligence and consciousness. Finally, (4) in this paper we specifically examined indirect speech act usage; future work will of course be needed to examine the host of other linguistic phenomena which may differ between human-human and human-robot interactions.

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