In-body Experiences: Embodiment, Control, and Trust in Robot-Mediated Communication

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ABSTRACT
Communication technologies are becoming increasingly diverse in form and functionality, making it important to identify which aspects of these technologies actually improve geographically distributed communication. Our study examines two potentially important aspects of communication technologies which appear in robot-mediated communication—physical embodiment and control of this embodiment. We studied the impact of physical embodiment and control upon interpersonal trust in a controlled laboratory experiment using three different videoconferencing settings: (1) a handheld tablet controlled by a local user, (2) an embodied system controlled by a local user, and (3) an embodied system controlled by a remote user (n = 29 dyads). We found that physical embodiment and control by the local user increased the amount of trust built between partners. These results suggest that both physical embodiment and control of the system influence interpersonal trust in mediated communication and have implications for future system designs.

Author Keywords
Computer-supported collaborative work; computer-mediated communication; videoconferencing; robot-mediated communication; embodiment; control; trust

ACM Classification Keywords
H.5.3. Information Interfaces and Presentation: Group and Organization Interfaces – *computer-supported cooperative work*. H.4.3. Information Systems Applications: Communications Applications – *computer conferencing, teleconferencing, and videoconferencing*

INTRODUCTION
The idea that technology could revolutionize the way we communicate, shrinking distances, leading to greater productivity, and increasing our leisure time, has inspired research and innovation for almost four decades [44]. Analog forms of distance communication (e.g., letter writing and talking over telephone lines) have been augmented by computer-mediated mediums such as e-mail, instant messaging, and videoconferencing. More recently, robot-mediated communication systems have been added to the mix.

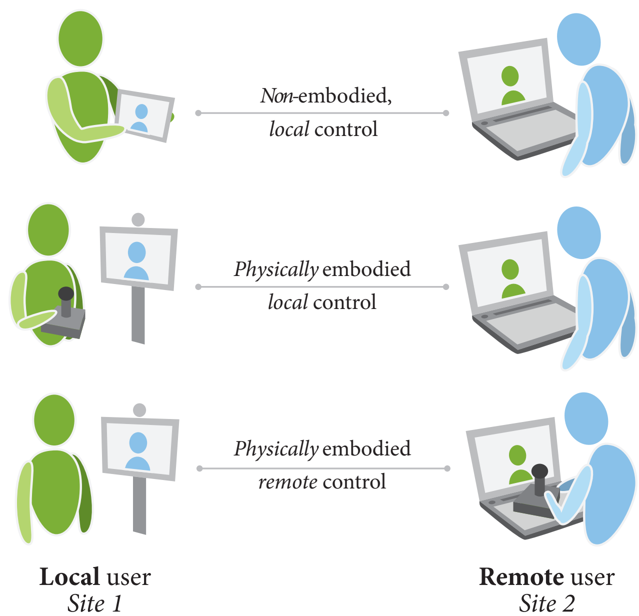

Figure 1. The study explored how physical embodiment and control shaped mediated communication by comparing collaborative outcomes across three conditions: (1) non-embodied, local control, (2) physically embodied, local control, and (3) physically embodied, remote control.

Telepresence robots have recently emerged as a viable option in today's market. By adding two key features, a human-sized physical embodiment and enhanced control for the remote user, these systems seek to increase the richness of the interaction and to improve communication channels by bringing them closer to face-to-face interaction. These systems range from screen-based telepresence robots [1, 10, 13, 32, 38, 43] to android representations of the remote user [24, 34]. By providing the remote user with a human-sized physical embodiment and with additional control over the system (e.g., its cameras, mobile base, mannerisms, etc.), these systems augment videoconferencing or audio communication. When discussing these robot-mediated communication systems, we refer to users that are physically present with the system as *locals*, and the user logged into the system from afar as the *remote user*. When remote users are able to exercise control over the system's movements, they are called *operators*.

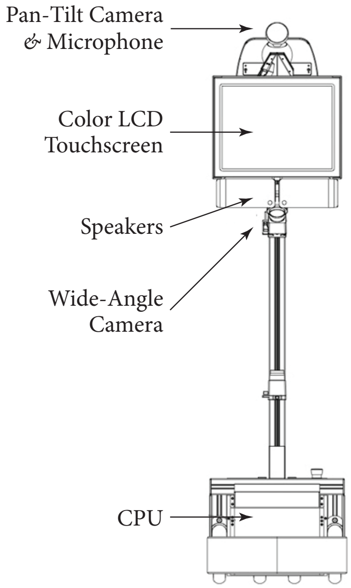

Figure 2. Diagram of a telepresence robot prototype, the Texai Alpha.

These enhancements of a physical embodiment and greater remote user control hold significant promise for increasing the remote user's presence and communicative efficacy [22]. While past research has investigated the details of how certain functionalities, such as navigation [29] or environmentally placed cameras [17], might be implemented, few studies have sought to identify the broader effects that the presence of a physical embodiment or overall control of the system might have upon the use of these systems.

In this paper, we focus on understanding how the addition of a physical embodiment and how the division of control might shape interactions between remote and local users. In particular, we compare how a difference in the level of physical embodiment (a physical body such as a telepresence robot vs. a no-body system such as a computer screen or tablet) and how the responsibility of control over the system (control by the local user vs. control by the remote user) affect interactions between two participants. We examine these effects in a controlled laboratory experiment where we simulated real world conditions of video delay, network latency, and differing environmental and social contexts (west coast and midwest). In order to do this, we recruited participants at two separate sites that were located approximately 2000 miles and two time zones apart.

RELATED WORK

Much of the work done to date in understanding the broader theoretical differences between mediated communication and face-to-face interaction has shown that while specific types of scenarios benefit from being conducted over mediated mediums, face-to-face interactions build trust more quickly [3, 25], are less vulnerable to betrayals of trust [3], take less time to achieve similar outcomes [4, 12, 37, 44], and are more spontaneous with less formality [16]. In addition, participants in face-to-face interactions are more likely to have an accurate perception of their spatial positioning [15] and are more likely to opportunistically engage in spontaneous encounters with others [27, 42] or to maintain parallel conversations [36].

In communication research, traits such as trust have been shown to be a cornerstone for increasing cooperation in large organizations [30]. This work underlines the importance of trust, particularly in relationships where interaction is infrequent and long-term relationships have not been established. In these types of relationships, cooperation has been shown to be less sustainable without trust because reputations are not given the time to develop [30].

In the following section, we review research in three main areas of communication that are mediated by technology: computer-mediated communication (CMC), video-mediated communication (VMC), and robot-mediated communication (RMC). We examine studies that have promoted collaborative outcomes through the cultivation of behaviors or traits that are naturally present in face-to-face communication.

Computer-mediated Communication

Much of the work in computer-mediated communication has targeted interactions that are carried out over synchronous or asynchronous text. Some of these studies have shown that text-based interactions may improve collaborative outcomes in specific scenarios such as in scaling creative tasks to large groups [12] and in equalizing roles [16,21,44]. Other work has focused on laying a framework for understanding the elements that CMC lacks when compared to face-to-face communication, such as status and position cues, absence of regulating feedback, and greater time limitations [20]. While each of these studies has examined specific ways or situations in which these mediated communications may be successful, they have also demonstrated the difficulty in achieving parity with face-to-face interaction.

Video-mediated Communication

Video-mediated communication work has built on the framework provided by CMC to explore how the addition of the ability to see the other person or the ability to share a viewable context, such as a workspace, might provide a richer experience. For example, the addition of the ability to see a visual representation of the other person has been shown to improve information transfer [4], and these positive effects extend to the facilitation of turn-taking [7] and increased development of trust [3] over text-based communication. In addition, further investigations have shown that how much of the other person is showing [26], the ability to share a work space in a collaborative task [39], and the ability to adjust the viewer's perspective to be spatially faithful in group-to-group mediated communication [25] alters the efficacy of the interaction. However, VMC also opens the door for user concerns over unintended viewers [5] and despite the addition of video, a large divide still exists between mediated and face-to-face interaction [15, 28, 36].

Robot-mediated Communication

Robot-mediated communication takes one step closer to face-to-face interaction through the addition of two key elements: physical embodiment and control. In this paper, we use the term *physical embodiment* to describe a physical entity that occupies a distinct volume in space, unshared by other individuals, whose perspective changes according to the orientation of the body, and with the capabilities to actively explore the environment through body movement [8]. These two elements offer a multitude of opportunities for how design elements unique to the embodiment of these systems shape user interactions and for design decisions on how the control structure should be divided amongst users. In previous communication systems these aspects have been limited by the medium, where remote users have been represented within the context of a system (e.g., through a phone or a on computer screen), without the option of a physically embodied representation, and where access to the remote environment has been controlled by user local to the system.

Previous work in telepresence has focused less on the effects that adding these functionalities might have and more on addressing challenges that occur in implementation [17, 29]. Other work has suggested features for future designs [9] or aimed at understanding the needs and preferences of potential users of these systems in field situations, such as in business [22, 42], home care [23], educational [11], and medical [14, 40] settings.

Several studies have begun to explore the rich design space that these systems afford to understand how the embodiment's appearance [31] or access to these systems in real-world settings [22, 42] shape local-remote user dynamics by increasing collaborative outcomes in teams. Related work has shown that locals perceive that remote users have a stronger form of presence when they are teleoperating an android, than when they are using a videoconferencing system [24, 34], and that this increased sense of presence promotes greater opportunities for ad-hoc or impromptu interactions than videoconferencing [22, 41].

While this work has directly compared individual systems or has examined how specific design aspects might affect interaction, how physical embodiment and control alter user behaviors to support traits critical to creating positive collaborative outcomes, such as trust or cooperation, has yet to be explored.

HYPOTHESES

Based on findings from previous work on how features such as the ability to see the remote user might shape mediated communication (e.g., [4, 6, 15, 25, 39]), we developed the hypotheses below on how *physical embodiment*, i.e., non-embodied systems such as computer screen or a tablet computer vs. physically embodied systems such as a telepresence robot, and *control*, i.e., local vs. remote user control of the mobility of the system, might shape task collaboration and communicative processes such as trust.

Hypothesis 1. Using a physically embodied communication system will result in more positive collaborative outcomes than using a non-embodied system.

Hypothesis 2. Using a communication system controlled by the remote user will have more positive collaborative outcomes than using a system controlled by the local user.

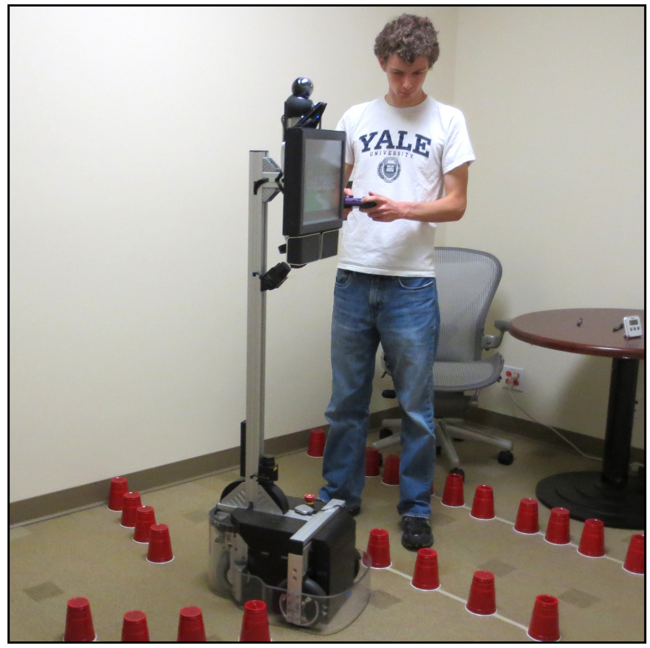

Figure 3. To gain familiarity with controlling the telepresence robot, local participants practiced steering it in a maze-like obstacle course for 10 minutes.

Hypothesis 3. Remote participants will have more accurate perceptions of the local participant's environment and their actions when they use a physically embodied system that they control than they will when they use a physically embodied system that the local participant controls or when they use a non-embodied system.

METHOD

In order to test the hypotheses stated above, we conducted a three-condition—(1) non-embodied and local-user controlled, (2) physically embodied and local-user controlled, and (3) physically embodied and remote-user controlled—between-participants experiment in which dyads of participants completed two tasks and a post-experiment questionnaire.

In order to test the effects of *physical embodiment*, we compared dyadic videoconferencing interactions using a handheld tablet, *non-embodied*, to those using a telepresence robot, *physically embodied*. In the non-embodied condition, participants used a 10-inch Samsung Galaxy tablet and in the physically embodied condition participants used a Texai Alpha telepresence robot standing at 61.5 inches (156.2 cm) tall, as shown in Figure 2. In both conditions, the local participant maintained full control over the movement of the system and the positioning of the cameras. All videoconferencing aspects of the both systems were handled using Skype.

To examine effects of *control*, we compared interactions in which the local participant maintained full control over the movement of the system and the positioning of the cameras to those in which the remote participant maintained control, i.e., *local user control* vs. *remote user control*. In both conditions, the participants interacted via the telepresence robot. These comparisons are illustrated in Figure 1.

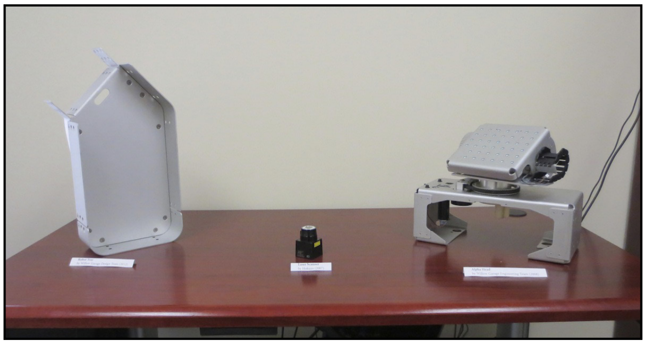

Figure 4. Example items from the Museum Tour. Each item had an accompanying nameplate that displayed the name, producer, and production date of the item.

Participants

We recruited pairs of participants, *dyads*, from two sites in cities that were approximately 2,000 miles and two time zones apart in order to simulate real world factors such as network latency, audio/video quality, and the lack of a shared environment. An experimenter was stationed at each site to administer the experimental protocol. A total of 58 adults, 29 from each site, whose ages ranged between 18 and 62 years, M = 30.64, SD = 12.73, volunteered to participate. Thirteen females and 16 males acted as local users at Site 1, and 13 females and 16 males acted as remote users at Site 2. Participants were randomly assigned to each dyad and to each experimental condition.

We recruited the participants via bulletin boards at local universities, posters placed around in the neighborhood of the sites, word of mouth from participants of previous studies, e-mail lists, and in-person enlistment. Participants reported that they were somewhat familiar with robots, M = 3.66, SD = 1.72 (1 = Not very familiar; 7 = Very familiar). For each hour of their participation, local participants at Site 1 received $20 and remote participants at Site 2 received $10. Compensation was higher for local participants due to transit time required to access Site 1. The study took approximately 90 minutes for participants at Site 1 and 75 minutes for participants at Site 2.

Tasks

In the experiment, participants collaboratively performed in two main tasks: the Museum Tour and the Daytrader game. These tasks were chosen because they provided multiple measures of task performance. The paragraphs below describe these tasks and the measures associated with each task are described in the Measures section.

Museum Tour

We designed the Museum Tour task to provide participants with a context that achieved a consistent amount of movement between systems and took advantage of the mobility afforded by telepresence robots and by other commercially available videoconferencing platforms such as tablets (Figure 6). This task also provided us with the ability to incorporate several quantitative measures of the remote user's spatial understanding of the local environment and of the local user's ability to interpret the remote user's non-verbal behaviors. Lastly, the tour task served as a realistic scenario in which it might be advantageous to use telepresence robots or tablets.

In order to meet these criteria, we created a "museum" of items from our work environment. A total of 22 items were placed in two rooms that were configured to prevent concurrent visibility. Each of these items was clearly labeled with name plates as shown in Figure 4. For each item, we generated a date of manufacture, a name, and 3–10 pieces of related trivia.

Because the Museum Tour task required the members of the dyad to perform different roles, we developed different task procedures for the local and remote participants. The paragraphs below describe these differences (also illustrated in Figure 5.

Local participant. The experimenter at Site 1 told local participants that they would be giving a tour to another participant from Site 2 and that a test on the names and locations of the items in the tour would be administered later in the study. The experimenter then conducted a pre-scripted training tour for the local participant that lasted 10 to 15 minutes, depending on participant questions. Immediately following the tour, a five-minute memory test was administered to measure a baseline for spatial recall in a face-to-face interaction.

Before the local participant gave the tour to the remote participant, the experimenter provided the local participant with information cards that listed talking points for each museum item and asked the local participant to track any items that the remote participant expressed interest in. The participant was given a 15-minute time limit to complete the tour.

After the tour, in order to measure the local participant's interpretation of the remote participant's non-verbal attention cues, the local participant ranked the top five items that the remote participant showed interest in.

Remote participant. The experimenter at Site 2 told remote participants that another participant from Site 1 would be giving them a tour of a product museum and that a test on the names and locations of the items in the tour would be administered later in the study. The experimenter also told remote participants that they would be asked for detailed knowledge on two specific items in the museum. Following the tour, a five-minute memory test was administered to measure the remote participant's spatial recall.

Daytrader Game

The Daytrader Game is a social dilemma task in which the short-term interests of the individuals conflict with the long-term interests or goals of the group. We chose this social-dilemma scenario because it has been used in several previous studies of computer- and video-mediated communication [3, 25], and it provides measures of trust that have been tested for reliability and validity [33].

Our use of the Daytrader Game followed the structure employed by previous work [3,25]. Based on this structure, the game involved three sets of five rounds. During a round, each participant was given 30 tokens that they could either keep or put into a pool that was shared between the two participants. Tokens that they chose to keep doubled in value at the end of

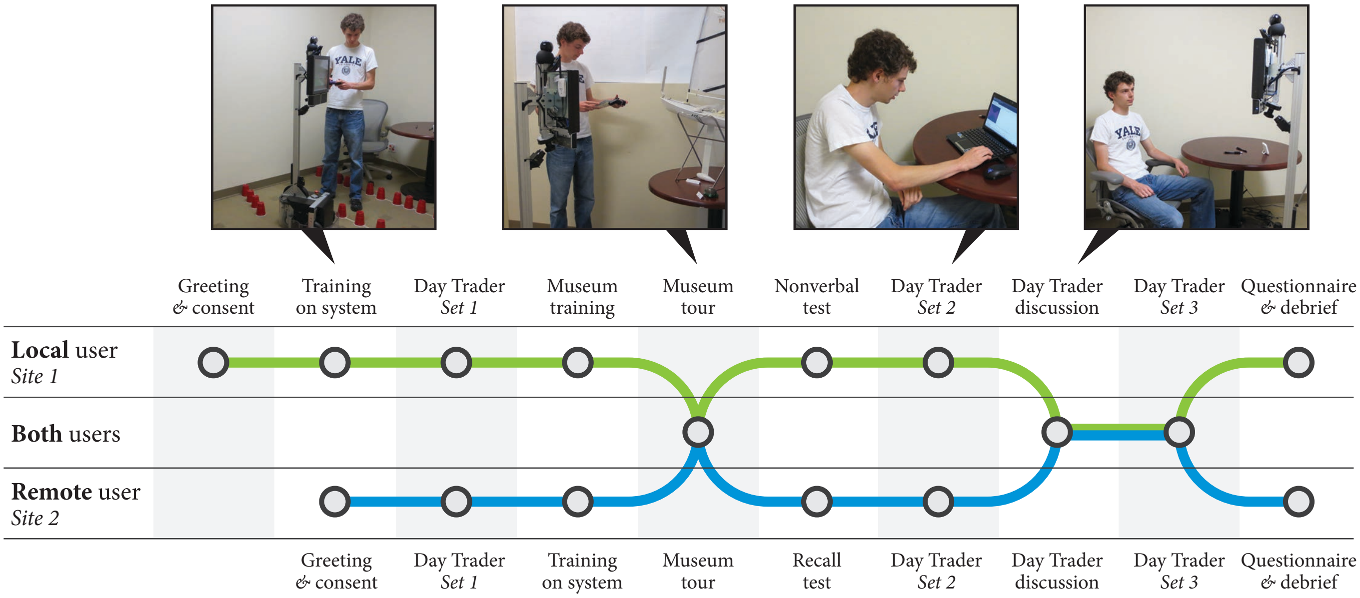

Figure 5. The steps in and timeline of the experimental protocol. Lines on top, middle, and bottom indicate the steps performed by the local participant, both participants, and the remote participant, respectively.

the round, while the tokens in the shared pool tripled and were then split evenly between the two participants. At the end of each set of five rounds, the participant earning the most tokens in that set received a 300-token bonus. If both participants earned the same amount, they both received the bonus.

In order to incentivize participants to earn as great a number of tokens as possible, the experimenter told the participants that they would receive an extra $0.10 for every 100 tokens that they received. At the end of the study, all participants received an extra $5, regardless of their performance on the task.

Procedure

The paragraphs below outline the procedure from the local participant's perspective in the *physically embodied, local user control* condition. Points where participant experiences diverged due to differences in participant roles and variations between Site 1 and Site 2 are also noted. These roles and a timeline of the tasks are illustrated in Figure 5.

Experimenters at both sites greeted the participants and sought informed consent.

Local participant. Following informed consent, the experimenter provided the local participant at Site 1 with an overview of the tasks that the participant would engage in and instructed the participant on how to control the telepresence robot using a handheld controller. The participant practiced steering the telepresence robot in a maze-like obstacle course for 10 minutes, as illustrated in Figure 3.

Following practice, the experimenters at both sites instructed the participants on the structure of the Daytrader Game and exited the room while the participants played. After the participants had completed the first set of five rounds, they engaged in the following separate tasks for 10–15 minutes.

Local participant. The experimenter at Site 1 guided the local participant through the training tour of the museum.

Remote participant. The experimenter at Site 2 instructed the remote participant on the controls for navigating in an online three-dimensional maze environment. This task was used in place of the 10-minute practice in the remote user control condition in which the participants would be controlling the telepresence robot.

After the separate training sessions, the experimenters at both sites set up a videoconferencing call on the telepresence robot. After the connection was established, the experimenter at Site 1 introduced the participants to each other who and asked them to begin the Museum Tour task. During the tour, the experimenter at Site 1 was present in the hallway to assist local participants with any technical issues. At the end of the allotted 15 minutes, the experimenters at both sites terminated the videoconferencing connection and administered recall tests.

After the recall tests, the experimenters at both sites reconnected the videoconferencing call, and the participants engaged in the second set of Daytrader Game rounds. The participants were then given five minutes to discuss their strategy for the game in preparation for the third set. In the third set of Daytrader Game rounds, the participants were connected and within sight of each other, but they were encouraged not to speak while playing.

Upon completion of the final set, the experimenters at both sites terminated the connection, administered a post-experiment questionnaire, and debriefed the participants.

Measurement

The effects of physical embodiment and control on communicative and collaborative processes were captured using a number of objective, behavioral, and subjective measures, as described in the paragraphs below.

Objective Measures

The objective measures were used to capture the effects of physical embodiment and control on the remote participant's awareness of the local environment and the local participant's understanding the remote participant's behaviors. The following three measurements were taken:

Museum recall. We provided participants with a blank map of the rooms that they toured to test their recall of the items in the museum. Participants were given five minutes to write down the names and indicate the locations of as many items as possible. The data was scored by two independent raters. An inter-rater analysis showed almost perfect agreement, Cohen's κ = .881, *SE* = .113.

Categorical item recall. Before the tour, remote participants were instructed to learn and remember three details about two of the items in the tour in order to measure deeper knowledge of items in the remote environment. The scoring of the data involved assigning one point for each correct item of information.

Nonverbal attention cues. To understand how physical embodiment and control of the system might affect the ability of local users to interpret the nonverbal cues of remote users, we asked local participants to items that were of interest to the remote participant. Local participants were provided with a list of the museum items and five minutes to rank the top five items of interest. The ranks assigned by the local participant to the two items chosen by the remote participant in the categorical item recall test were used as a measure of the local participant's ability to interpret the nonverbal cues of the remote participant.

Behavioral Measures

The participants' task-related behaviors in the Museum Tour and Daytrader Game tasks were used to capture the following quantitative behavioral measures:

Impromptu parallel conversations. Impromptu parallel conversations involved either of the participants speaking to the experimenter during an interaction with the other participant. These behaviors are similar to those considered in previous work, which showed that these types of conversations occur less frequently in all forms of mediated communication than they do in face-to-face interactions [36]. In order to trigger an impromptu parallel conversation with the experimenter, we manufactured a problem in the Museum Tour that prompted the remote participant to ask the local participant for information that was not provided on the information cards. During this exchange, the experimenter at Site 1 waited outside of the room but remained in view of both participants. The measure captured the number of times that either of the participants engaged with the experimenter to request the missing piece of information.

Trust. We used the sum of tokens earned by individuals in each set of Daytrader Game rounds as a measure of the development of trust and to detect *trust fragility*—how likely participants were to act outside of their agreement with the other person for personal gain. In the first set of rounds, the participants were only told that the person with whom they were playing was also a study participant. As a result, the total number of tokens earned in the first set measured the trust that participants had for a stranger. The participants played the second set of the Daytrader Game after they completed the Museum Tour. Thus, the difference between the sums of tokens earned in the first and second sets indicated the amount of trust gained from their interaction with the other person. The participants played the third set after they had discussed and formed a strategy for the last set together. As a result, the sum of tokens for the last set measured the fragility of the trust developed between participants.

Similar to previous work (e.g., [3, 25]), we also examined the total number of tokens that dyads earned over all sets of the game as a measure of overall cooperation and trust within the dyad.

Subjective Measures

A post-experiment questionnaire that was administered after the last set of the Daytrader Game collected data on participants' subjective evaluations of each other. The questionnaire included the following three measures:

Presence Questionnaire. We used a modified version of the Presence Questionnaire [45], which measured how immersed the remote user felt in the local user's environment using three sub-scales: involvement, sensory fidelity, and adaptation/immersion. Participants rated each item on a seven-point rating scale, for instance, 1 = Not at all, 4 = Somewhat, and 7 = Completely to rate the question "How much were you able to control events" and 1 = Extremely artificial, 4 = Borderline, and 7 = Completely natural to rate the question "How natural did your interactions with the other person seem?" Although the Presence Questionnaire contained 29 items with 6–12 items for each sub-scale, we used a subset of 3–15 of these items depending of the experimental condition because some of the statements did not apply when the participant was not in control of the system.

Networked Minds Measure of Social Presence. To measure perceptions of the other participant, we used a modified version of the Networked Minds Measure of Social Presence [2]. This measure consisted of 30 statements about the interaction between participants such as "The other person tended to ignore me," "The behavior of the other person was in direct response to my behavior," and "I could not act without the other person" using seven-point rating scales (1 = Strongly disagree, 7 = Strongly agree).

Specific Interpersonal Trust Scale. We used a truncated version of the Specific Interpersonal Trust Scale [18] to measure subjective trust between participants. This version contained 10 statements about the other person such as "If the other person was late to a meeting, I would guess there was a good reason for the delay," "I would expect the other person to pay me back if I loaned him/her $40," and "If the other person laughed unexpectedly at something I did or said, I would know s/he was not being unkind." The participants rated each item using a seven-point rating scale (1 = Strongly disagree, 7 = Strongly agree).

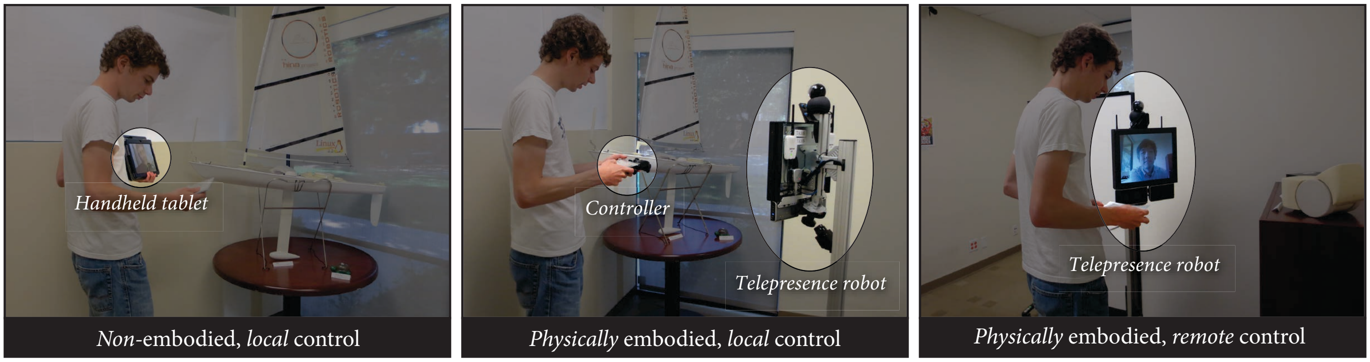

Figure 6. In the Museum Tour task, the local participant gave the remote participant a 15-minute tour of several items placed in two rooms across three conditions. In the *non-embodied, local control* condition (left), the participants communicated using a tablet computer, and the local participant demonstrated the items by controlling the movement of the tablet. The *physically embodied, local control* condition (middle) involved the participants communicating a telepresence robot that the local user controlled. In the *physically embodied, remote control* condition (right), the participants communicated via a telepresence robot that the remote participant controlled.

Analyses

Data analysis included two main statistical methods: independent-samples Student's t-tests and dyadic analysis.

Independent-samples t-tests

To compare measurements that were limited to comparisons of individuals in similar control conditions (e.g., local or remote participants who had control) or in similar roles (e.g., only local participants or only remote participants), across the three conditions, two-tailed independent-samples t-tests were used. These measures included museum recall, categorical recall, nonverbal attention cues, impromptu parallel conversations, and subjective measures from participants who controlled the system.

Dyadic analysis

Because our study involved pairs of participants rather than individuals, we were unable to assume independence in measurements from local and remote participants. Therefore, we employed *dyadic analysis methods* [19] in order to compare data between and within dyads across experiment conditions while taking the potential interdependencies in data from members of dyads into consideration. Dyadic analysis methods were used for all measures of participant interaction such as the trust measures from the Daytrader Game and the subjective evaluations of interaction partners.

Measurement of nonindependence. The first step in performing dyadic analysis was to establish the non-independence of measurements within dyads [19] in order to determine whether the dyad or the individual should be used as the unit of analysis. To test for non-independence, we computed partial correlations between measurements from members of the dyads for each measure considered for dyadic analysis, correcting for experimental condition. High correlations indicated that dyadic pairings were tightly bound and that a dyadic-analysis approach was appropriate.

Dyadic analysis methods. Once non-independence was established, we used a multilevel regression model, which treated participants as individuals nested within pairs and measurements from individuals as repeated measures within pairs, as described by Kenny [19]. Because local and remote participants significantly differed in their roles in and engagement with the tasks, we used heterogeneous compound symmetry, which allowed for unequal variances in data from members of dyads. The application of the multilevel regression model was followed by t-tests to test our hypotheses on the effects of embodiment or control. The degrees of freedom for the t-tests were calculated using the Satterthwaite approximation, as recommended for dyadic analysis [19].

RESULTS

Our results supported our first hypothesis: that using a communication system that provides remote users with a physical embodiment would result in more positive collaborative outcomes than using a non-embodied system.

When the system was controlled by the local user and the physical embodiment condition (non-embodied vs. physically embodied) was manipulated, we found the following results: participants using a physically embodied system (telepresence robot) showed a significant increase in trust after interacting $M = 37.55$, $SD = 200.10$, compared with participants who used non-embodied system (tablet) $M = 2.89$, $SD = 215.97$, $F(1, 17) = 6.449$, $p = .021$. Descriptive results showed that local participants tended to trust the remote user more when using a non-embodied condition system $M = 55.78$, $SD = 227.52$, than when they used a physically embodied system, $M = 20.25$, $SD = 224.10$. Conversely, remote participants tended to gain trust in the local participant when they interacted through a physically embodied system (telepresence robot), $M = 54.85$, $SD = 183.42$, and tended to lose trust when they interacted through a non-embodied system (tablet), $M = -50.00$, $SD = 202.62$, see Figure 7.

We found no significant effects of physical embodiment or control on subjective perceptions of the interaction along any of the scales used in previous work. However, analysis of single questionnaire items found a marginal difference in how much participants using a physically embodied system trusted each other not to laugh in an unkind manner $M = 5.06$, $SD = .94$, over those in the non-embodied condition, $M = 4.40$, $SD = 1.31$, $F(1, 17) = 3.240$, $p = .090$.

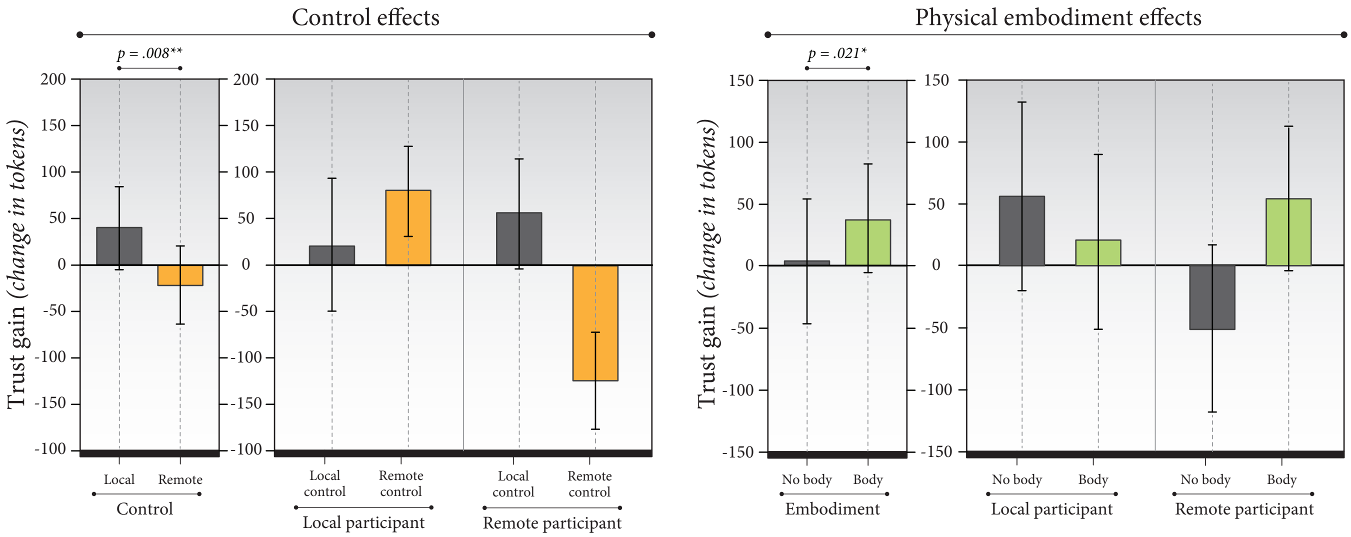

Figure 7. The results showed that trust between participants increased more when they used a physically embodied system than it did when they used a non-embodied system (left) and when the local participant controlled the system over when the remote participant controlled it (right). (*) and (**) denote $p < .05$ and $p < .01$, respectively.

Contrary to our second hypothesis, we found that participants using a system that was controlled by the remote user had fewer positive collaborative outcomes than those where the local user was in control.

When the system provided the remote user with a physical embodiment and control of the system was manipulated (local user control vs. remote user control), we found the following results: participants interacting through a system under local user control showed a significant increase in trust after interacting $M = 37.55$, $SD = 200.10$, and lost trust when the system was under remote user control $M = -23.70$, $SD = 187.04$, $F(1, 18) = 8.804$, $p = .008$. Descriptive results showed that local participants tended to trust remote participants more when the system was under remote user control, $M = 78.50$, $SD = 154.20$, than when they controlled the system (local user control), $M = 20.25$, $SD = 224.10$. However, remote participants tended to gain trust when the system was under local user control, $M = 54.85$, $SD = 183.42$, and tended to lose trust when they controlled the system (remote user control), $M = -125.90$, $SD = 163.91$ (see Figure 7).

Control of the system also had a marginal effect on trust between participants in the first set of the Daytrader game. When the system was under remote user control, participants initially tended to trust each other more $M = 567.30$, $SD = 178.67$, than when the system was under local user control $M = 528.10$, $SD = 196.73$, $F(1, 18) = 4.256$, $p = .054$. Descriptive results showed that local participants tended to trust the remote participant more when the system was under remote user control $M = 525.90$, $SD = 215.53$, than when they controlled the system (local user control) $M = 484.70$, $SD = 174.79$. In contrast, remote participants tended to trust the local participant more when the system was under local user control $M = 649.90$, $SD = 147.24$, than when they controlled the system (remote user control) $M = 530.30$, $SD = 175.29$.

We found no significant effects of physical embodiment or control on the fragility of trust, total cooperation in the Daytrader task, number of opportunistic interactions, and the local participant's ability to read the remote participant's nonverbal attention cues.

Analysis of individual questionnaire items showed that participants trusted that the other person would accurately represent them significantly more when the system was under local user control $M = 4.80$, $SD = 1.36$, than when the system was under remote user control $M = 4.15$, $SD = .875$, $F(1, 18) = 4.40$, $p = .050$. Participants also trusted that the other person would repay a loan significantly more when the system was under local user control $M = 5.20$, $SD = 1.436$, than when the system was under remote user control $M = 4.50$, $SD = 1.051$, $p = .032$.

DISCUSSION

Our results showed support for our first hypothesis; participants communicating through a system under local user control gained more trust when the system provided the remote user with a physical embodiment system (telepresence robot) than they did in the non-embodied condition (tablet). Contrary to our second hypothesis, participants using a system that provided the remote user with a physical embodiment gained trust when the system was under local user control and lost trust when the system was under remote user control. We found no support for our third hypothesis; there were no significant main effects of physical embodiment or control of the system on the accuracy of the remote participant's perceptions of the local environment or their actions within it.

While there was a main effect of control on trust between participants, further investigation showed that participants gained more trust in the other person when that other person controlled the system. We believe that these results may reflect the findings from management research about the development of trust in relationships. This research suggests that "perceived risk moderates the relationship between trust and risk taking," and that trust is a willingness to take risk and to be vulnerable to another party [33, 35]. Within this framework, when remote participants interacted with a local that controlled the system, they were placed in a position of vulnerability, and the same was true for local participants interacting with a pilot. The other participant showing reliability and dependability in controlling the system (e.g., avoiding collisions, moving the system carefully, making an effort to engage with the other person) elicited positive expectations and an increased willingness to take risks within the relationship [33]. However, when participants had control of the system themselves, there was no perceived risk and, as a result, trustworthy actions may not have been attributed to the other person, inhibiting the development of trust [35].

Design Implications

We have demonstrated how two key features, physical embodiment and control, affect user interactions. Our results show that systems that allow users to interact through a physical embodiment may increase the development of trust between users, while systems controlled by the remote user may not. While our study indicates that systems controlled by remote users may inhibit the development of trust, other factors, such as perceived autonomy and lack of local user support, may still make remote control desirable. Designers should be aware of these potential tradeoffs and may consider incorporating local user control in situations where the establishment of trust is important. This work not only aids designers of future mediated-communication systems in understanding the broader effects that variations of physical embodiment and control might have, but also illustrates the need to carefully consider the contexts in which these communication tools may be used when making decisions about who will ultimately control the system.

Limitations and Future Work

Our study was subject to several limitations. Although we attempted to formulate a task that might mimic real-world interactions, we were unable to capture the full breadth of activities in which people engage. While we did not observe any significant latency differences between the remote user and local user control conditions in driving the telepresence system, we were unable to control latency between sites. Furthermore, due to the exploratory nature of this study, the sparsity of questionnaire results suggests that more work may be required to appropriately tailor a measure for understanding the subjective effects of physical embodiment and control on technology-mediated communications.

Extensions of this work may investigate how the presence of other high-level features, such as mobility, the addition of autonomic control, or the ability to switch control between the local and remote users, affect mediated communications. Future work may also be needed to investigate how functionalities that are not currently afforded in telepresence systems, such as the ability to manipulate objects, might moderate the effects of embodiment or control. Additional work in this area may also focus on the development of new tools and measures to aid in the study of complex mediated interactions.

CONCLUSION

With the proliferation of cutting-edge mediated-communication systems, the need to understand how their functionalities affect communication is critical. Robot-mediated communication systems are an example of an advanced communication technology that has recently been introduced to the market. These systems provide remote users with proxy physical embodiments in distant locations and the ability to control them. While these functionalities hold great promise for a more physically co-located experience for local and remote users, we have yet to fully understand how they shape communicative and collaborative outcomes.

In this paper, we investigated the effects of two features, *physical embodiment* and *control*, on communicative and collaborative outcomes. We found that participants who used a physically embodied system gained more trust and that, contrary to our prediction, participants gained trust when the system was under local user control and lost trust when the system was under remote user control. Our work illustrates how the addition of features that afford physical embodiment and control may influence user interactions while demonstrating the decoupling of functionality from system implementation. Our findings also offer insight into how these features and systems may be used in the future, and the geographically disperse context of our study might inform designers about the real-world user interactions that these systems afford.

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