How Telepresence Robots Shape Communication

by

Irene Rae

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The dissertation is approved by the following members of the Final Oral Committee:

Bilge Mutlu, Assistant Professor, Computer Sciences
Jeffrey F. Naughton, Professor, Computer Sciences
Catalina L. Toma, Assistant Professor, Communication Science
John D. Lee, Professor, Industrial and Systems Engineering
Leila Takayama, Senior Researcher, Google[x]

To my husband, Ian.

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Abstract

Nowadays, communicating with others across distances is commonplace. We use a number of mediating technologies to stay in contact, ranging from e-mails to text messages, phone calls to videoconferencing. Robot-mediated communication systems are the newest addition to this selection of platforms, inspired by recent innovations in robotics and networking. These robotic platforms, such as telepresence robots, have a rich design space and offer a wide breadth of features, such as a proxy physical embodiment for the remote user, that promise to bring us closer to the sensation of "being there."

Theory in embodied cognition, ecological psychology, and communication research suggests that this higher level of embodiment should increase feelings of user presence and improve their ability to achieve collaborative outcomes. Although field studies have shown qualitative support for these effects, we have yet to fully understand the contributing variables and the way that they interact.

In this dissertation, I investigate a subset of the features that exist in the design space of embodied robotic telepresence to find empirical evidence to support these predictions. To do this, I isolate specific variables and systematically test their effects on collaborative outcomes in a series of five controlled laboratory studies. I found that although features of the system embodiment did improve user feelings of presence, there was little evidence of a connection between presence and other outcomes in collaboration, such as cooperation or trust. My findings provide insights into the need to isolate the concept of presence and to place less emphasis on the goal of simulating the sensation of "being there," particularly in collaborative settings. By creating a separation between the concept of presence and other outcomes, researchers may gain a more nuanced understanding of the effects that various features have, aiding designers in creating future systems that more effectively match user needs.

1 | Introduction

Communicating with others while being colocated is easy; we interact with people face-to-face almost every day of our lives. As a result, we are very good at interpreting people's facial expressions, postures, gestures, and a whole host of other non-verbal cues [74]. We understand how to coordinate movements when we are working in the same space and how the other person's proximity and position conveys meaning [48, 73]. We gather unspoken information, not just from the other person, but also from our shared environment, history, and context to develop a common ground. In face-to-face interactions, we use all of these tools to go beyond the spoken word, gaining a nuanced understanding of each other's meaning.

When we are no longer colocated, however, we lose a lot of the information that makes communicating with others so effortless. To address this, we have used technology as a way of mediating communication across distances. For example, phones allow us to convey our verbal content, changes in vocal pitch, and temporal information, such as pauses. Videoconferencing goes one step further, adding the ability to see the other person's face, upper body, and some of their environment. In both of these technologies, we supplement the message that we receive with non-verbal cues and alternate information that is provided by the medium, such as where the person is calling from, the time since the last call, and other metadata.

Recently, advancements in robotics have allowed us to build increasingly complex communication systems, augmenting existing products (e.g., telepresence robots that put videoconferencing on a mobile base [3, 38, 146, 168]), or creating completely new platforms (e.g., humanlike androids [115, 132]). These *robot-mediated communication systems* provide a vast range of possibilities for improving user interactions through design. For example, presenting a proxy embodiment of the *remote* user (the user logged into the system) for the *local* user (the user in the same location as the system) to interact with, empowering the remote user to drive around the local environment or autonomously mirroring user non-verbal cues. Prior work has argued that the addition of these features will enhance user feelings of presence—*telepresence* [100]—over past platforms. However, much of the work done to date has focused on the challenges of implementing these systems or in situ investigations on how they are received in organizations. While these studies have shown some evidence for specific systems increasing user participation [88, 166], how specific elements contribute to feelings of telepresence and provide benefits for collaboration have yet to fully be explored. As a result, identifying what aspects of the system to develop for and translating these findings into actionable design decisions remains a challenge.

1.1 My Approach

The central premise of my work is that *telepresence robots*—a subset of robot-mediated communication systems shown in Figure 1.1—offer a unique design space for creating embodied experiences, increasing user telepresence and improving remote collaboration. My work empirically examines the role that specific features and variables have in shaping user communication and outcomes in the context of telepresence robots in collaborative tasks. To accomplish this, I use a systematic approach to isolate specific variables in the robot-mediated communication design space. I test the effects that changes to these variables have in a series of targeted laboratory studies, showing empirical support for their effects and making the following contributions to the field:

- **Practical Contribution**: The creation of actionable guidelines that allow designers to make conscious and deliberate choices when developing robot-mediated communication systems.
- **Theoretical Contribution**: The construction of a body of knowledge on how aspects of the telepresence design space affect user interactions.

- **Methodological Contribution**: The development of tasks and measures to test the effects of variables within the robot-mediated communication design space.

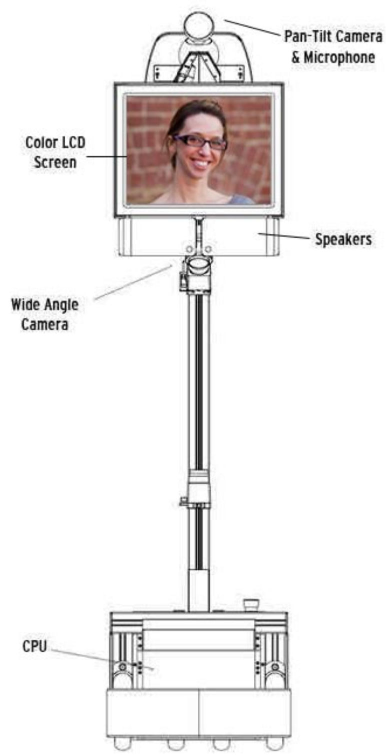

Figure 1.1: An example of a robotic telepresence system.

1.1.1 Context and Scope

Robotics facilitates the creation of telepresence systems that have features above and beyond what videoconferencing systems provide. For example, the ability to control a proxy embodiment, mobility of the system, and even to manipulate objects. These features are accompanied by a host of variables that require decisions by designers, such as the height, appearance, or decoration of the embodiment, the speed, proximity, and acceleration of the system movement, or the form, degrees-of-freedom, and control of the manipulators [107], as illustrated in Figure 1.2. In this work, I use telepresence robots to examine how design *features*—options or capabilities of the system—and *variables*—atomic characteristics that define these features—shape user perceptions, behaviors, and outcomes in the context of collaborative work.

Telepresence Robots and Design Space

As reliable wireless networks have become widespread, robotic telepresence systems—a subset of robot-mediated communication platforms shown in Figure 1.1—have become a viable alternative to videoconferencing and have begun to see commercial use in business [88], home [8], medical [85, 145, 167], and educational [176] environments. In fact, these systems are already being explored as alternatives to recreational travel [38], business meetings [146], and on-site medical experts [65]. With telepresence robots decreasing in cost and increasing in availability, these systems are poised to become a commonplace way for people to communicate in a wide variety of contexts. These systems also share a design space with the greater set of robot-mediated communication platforms, such as androids and telepresence flyers.

However, the decision-making process of how to apply robotics to the development or modification of existing systems has generally been organic, based on availability, guesswork, or manufacturing needs. While this approach may have worked in the past, it is no longer viable given the breadth of options that robotics offers us. As a result, we need a new way of guiding our efforts that provides greater insight into the features that these platforms should support and how they are affected by changes to the variables related to them.

Why Collaboration?

Although a large body of work in teleoperation has examined the ability of users to accomplish tasks in isolated remote environments, the ubiquity of wireless connectivity has facilitated the development of platforms that are seeing increased use in collaborative human settings. With this increased accessibility, users envision a wide breadth of scenarios where these systems may be used, including shared meals, attending class remotely, exploring new places together, and social mingling [127]. Although some of the contexts that users envisioned were solo, a majority involved interacting

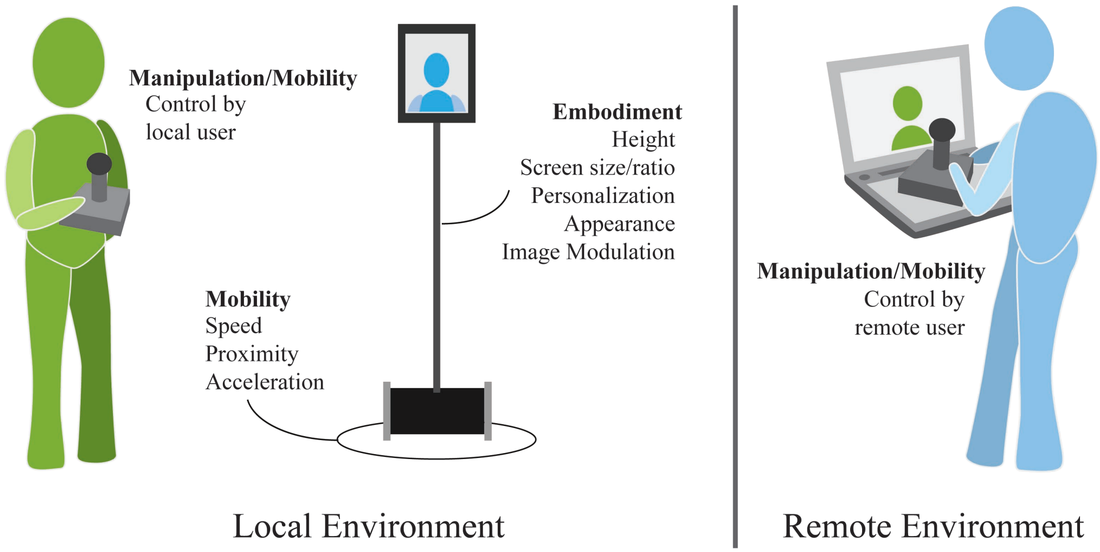

Figure 1.2: An illustration of some of the features and related variables in the design space for telepresence robots (adapted from Mutlu [107]).

with others as a primary function; additionally, collaborating toward a shared goal was cited as one of the major motivators for using these systems [127]. In these collaborative scenarios, the transition and integration between person space and work space, or user and environment, are critical elements to achieving success, suggesting that it may be where the design space enabled by a physical embodiment has the highest impact.

1.1.2 Theoretical Background

The idea that a physically embodied system can provide a richer user experience and improve collaborative outcomes is not new, having been argued for the last three to four decades. Past work has compared videoconferencing to the one-sided experience of looking through a window, suggesting that a system with a stronger embodiment would provide users with a more immersive experience, better enable them to stitch their visual experiences into a coherent picture, and support a more diverse set of communication levels, such as directed gaze, gesture, and *reflexivity*—seeing the actions resulting from user commands [121].

Other literature has identified two spaces that must be supported in distance communication, the *person space*—the feeling of presence between group members—and the *task space*—where the task is being undertaken [21]. This work has argued that in order to create successful telepresence systems, the platform must support seamlessly transitioning between the two [21]. While some interactions, such as negotiation, may have a task space that is focused on the facial expressions and non-verbal cues of the other person, many require navigation or use of a physical space. By extending the remote user's movements and presence through a strongly embodied system, robot-mediated communication has the potential to better support these transitions. Furthermore, theories in embodied cognition, ecological psychology, and communication suggest that having a strongly embodied system may increase the user's integration with the physical environment, facilitating better collaborative outcomes. Central to these theories is the concept of an *affordance*, defined as what an environment offers as opportunities of interaction in relation to the user [51]. Although similar to what I call *features*, affordances in this context are defined specifically with respect to the environment and the interacting entity, not necessarily the object or system itself. To avoid confusion in this work, I use the term affordance as described by Gaver [49], encompassing the properties of the medium that relate to the actions that it affords.

Embodied Cognition

The theory of embodied cognition highlights the role that the environment plays in user processes, positing that cognition inherently involves perception and actions within an environment [27, 179]. In this theory, the mind and the environment are densely and continuously intertwined, with people using the environment to offload cognitive work and as a framework for situating behaviors and actions. Prior mediated communication platforms have had limited support for allowing users to situate themselves in the remote environment or to act within it. However, the strong embodiment of robot-mediated communication systems opens up the design space for empowering the remote user and allowing them to benefit from using their environment to augment their cognitive capacity.

Ecological Psychology

Ecological psychology shares many of the same premises as embodied cognition, stressing the need for bodily movement and ecological context to inform user perceptions. In particular, the central concept in ecological psychology is the idea of the *affordance*, focusing on the possibilities for use and action that the physical world, specifically the environment, offers a user [27, 51]. By constantly coordinating the relationship between the user's capabilities and the available actions in the environment, the user is able to accomplish their goals [24]. Similar to perspectives in embodied cognition, ecological psychology stresses the necessity of interaction with the environment, suggesting that a strongly embodied system would enable remote and local users by more directly placing them in the physical world.

Communication Research

Theories in computer-mediated communication examine the interaction between users and how messages are conveyed. In many of these theories, the restrictions imposed by the technology on the information that is available causes users to adapt, finding alternate cues to draw meaning from [171, 173]. Additionally, some of these theories suggest that while mediated communication may result in the same quality outcomes as face-to-face interaction, they may take longer to achieve and affect other aspects of the interaction, for example, decreasing trust or increasing cooperation [14, 62, 158, 173].

In addition to providing us with a structure for predicting some of the outcomes in robot-mediated interactions, these theories also highlight new avenues for research. For example, suggesting that strongly embodied systems may provide additional information in interactions, decrease the time required to achieve task goals, or shape social outcomes.

1.2 Dissertation Outline

In this work, I use telepresence robots to identify and focus on five variables located within the design space of telepresence robots: (1) System Embodiment and Control; (2) Height; (3) Visual Framing/Appearance; (4) Distance and Embodiment; and (5) Mobility. Although the set of variables within the design space is large and may vary by system type, the aspects that I examined have the advantage of being generalizable to a large number of robot-mediated platforms that are in current use, as well as being applicable to future systems.

1.2.1 Embodiment and Control *(Chapter 3)*.

My first study examined the effects that the strength of the embodiment and control over the system had on the development of interpersonal trust using three conditions: (1) a weakly embodied handheld tablet controlled by a local user, (2) an strongly embodied telepresence robot controlled by a local user, and (3) a strongly embodied telepresence robot controlled by a remote user. I found that having a strong physical embodiment and control by the local user increased trust, showing support for the position that embodied systems improve the remote user's experience [121]. My results also confirm findings from management research about vulnerability fostering the development of trust [131, 133]. These findings suggest the importance of creating a stronger sense of embodiment, particularly in situations where trust is important, and highlight the need to consider the interaction between system control and perceived vulnerability.

1.2.2 Height and Authority *(Chapter 4)*.

My second study focused on understanding how the height of the robotic system affects dominance and persuasion, supporting or undermining the remote user's authority in a two (relative system height: shorter vs. taller) by two (team role: leader vs. follower), between-participants study. I showed that participants were more dominant when assigned the role of leader and were least persuaded when they were a follower interacting with a robot that was shorter than they were. My results confirmed findings in psychology that a shorter relative height decreased persuasion and cooperation [19, 60, 89, 183]. I also showed that although participants that were assigned leadership exhibited more conversational dominance, using a shorter robot undermined the remote user's authority. These findings provide actionable guidelines for designers, suggesting that in contexts where authority is needed, robot-mediated communication systems should be the same or a greater height than the people that are interacting with it.

1.2.3 Visual and Verbal Framing *(Chapter 5)*.

My third study explored how the ability to decorate (*visually frame*) the robot affected feelings of group membership in a two (visual framing: decoration vs. no decoration) by two (verbal framing: interdependent vs. independent performance scoring) between-participants study. I found that verbal framing of the task as interdependent produced more in-group oriented behaviors, but that visual framing and decoration of the system weakened team cohesion. These findings support theories in self-extension and provide further evidence that when a sense of agency is added to the object, feelings of self-extension disappear [78]. My results also point to the need for designers to be aware of the decorations that local users may place on the system [88] and the detrimental effects that this may have on team cohesion.

1.2.4 Distance *(Chapter 6)*.

In my fourth study, I compared two competing arguments—that physical distance decreases cooperation and honesty vs. that a strong embodiment represents the distant user, mitigating the negative effects of distance—in a two (level of embodiment: weak (video screen) vs. strong (telepresence robot)) by two (perceived distance: on-campus vs. across the country) between-subjects experiment. I showed that participants who believed the other user to be on-campus with them exhibited greater self-deception. I also found that participants who believed the other person to be across the country had more similar outcomes in negotiation when using a strongly embodied system, but less similar outcomes in a weakly embodied system. These findings show evidence that a strong embodiment mitigates some of the negative effects of distance and also highlights a new factor for consideration, the perceived need for use of the technology.

1.2.5 Mobility *(Chapter 7)*.

My last study explored the role that mobility plays in aiding task completion and shaping the remote user's sense of presence in a two (system mobility: stationary vs. mobile) by two (task demands for mobility: low vs. high) between-subjects experiment. My findings showed that mobility significantly increased the remote user's feelings of presence, particularly in tasks with high movement requirements, but decreased task performance. These results highlight the positive effects of mobility on feelings of "being there," while illustrating the need to design support for its effective use.

These studies investigate the new set of embodied features offered by telepresence robots. Prior work has argued that these features may hold the key to offering a stronger sense of telepresence, improving user experiences. My findings show empirical support for specific design features, such as the strength of embodiment or mobility of the system, increasing user feelings of presence. I also used my explorations to create of actionable design guidelines for the construction of future systems, such as the need to create systems that are relatively taller than local users or the importance of discouraging system decoration. Next, I highlight work in robotic telepresence, embodied cognition, ecological psychology, and communication that informed these explorations. Following this, I detail each study, covering my experiment design, methodology, and results. Last, I summarize my findings, placing them in the context of the overarching design space, and propose avenues for future work.

2 | Related Work

As a field, telepresence research spans a wide variety of systems, ranging from virtual reality to telepresence robots [42, 90]. These systems share the goal of realizing Minsky's vision of telepresence—the feeling of "being there" [100]. Since the creation of this definition, researchers have taken a number of different approaches to achieving telepresence, arguing that it may be facilitated through greater immersion [141], improved synchrony between the operator and the interface [42, 45], embodied interaction [59, 121, 137, 154], the seamless transition between person and workspace [13, 21, 67, 92, 93], increased view [50], long-term communal connectivity [40], or high vividness and interactivity [143].

In this work, I focus on exploring how embodied interaction can increase feelings of telepresence and improve collaborative outcomes. First, I highlight work in telepresence that informs my approach of exploring the features and variables provided in the robotic telepresence design space. Next, I introduce theories in embodied cognition, ecological psychology, and communication research, that predict that a more embodied interaction will improve feelings of telepresence. Last, I outline work in robotic telepresence that shows evidence for embodied interaction improving user outcomes in collaborative contexts.

2.1 Work in Telepresence

Embodiment in the context of telepresence is commonly defined as a system that enables active participation in the world [59]. Work in embodied telepresence has been subdivided into three states [42]:

Simple Telepresence: The ability to operate in a computer-mediated environment.

Cybernetic Telepresence: The operational characteristics of the human-machine interface.

Experiential Telepresence: When the user is in a mental state of feeling physically present in the computer-mediated environment.

Literature in the field of telepresence has covered all three of these states, with much of the work in simple telepresence describing the implementation challenges of creating novel systems (e.g., the creation of humanlike telepresence androids [132] or the development of autonomous control systems [161]). Research in the area of cybernetic telepresence has fallen under the purview of teleoperation, focusing on how to better support users expressing their intentions through the system [45, 95, 99]. Recently, a growing body of work in telepresence has lain in the realm of experiential telepresence, exploring how a highly embodied system may increase feelings of user presence.

Prior work in experiential telepresence has suggested that an embodied interaction will enhance a user's sense of telepresence for a number of reasons. For example, Paulos & Canny [121] argued that a system with a stronger embodiment would provide users with a more immersive experience, better enable them to stitch their visual experiences into a coherent picture, and support a more diverse set of communication levels, such as directed gaze, gesture, and *reflexivity*—seeing the actions resulting from user commands.

Related work has highlighted the *affordances*—the properties of the medium that relate to the actions that it affords [49], or *features*, of the embodied design space as tools to enhance presence and improve interactions. Research has explored these features in videoconferencing and teleoperation contexts, providing qualitative support for their benefits in field explorations. For example, prior literature on the preservation of embodied spatial information, such as personal space, location, and perceived proximity [40, 137, 154], has shown evidence that providing this information can increase the ability to tell who is speaking, track availability, and engage in opportunistic interactions. Similar work has highlighted spatial information in the context of media spaces—a technologically created environment to support collaborative work—showing that users perceive these as supporting coworker awareness and group discussions [13, 21, 67, 92, 93].

Further literature has highlighted that having an embodied system under the user's control may have benefits for improving spatial cognition, environmental awareness, and the remote user's ability to navigate [50, 121, 148]. A growing body of work has also sought to implement ways of conveying many of the non-verbal cues found in face-to-face interaction, such as nodding [140], eye contact [114], head motion [132], facial expressions and direction [109, 115], and physical contact [111], arguing that the inclusion of these cues will improve the fluency of interactions between users.

These past studies have shown evidence that the use of specific systems in field settings increased the inclusion of remote coworkers [9, 153, 166] and facilitated collaborative work [88, 166]. However, so far there has been little empirical evidence that embodied interaction improves user feelings of telepresence (or *presence*). Furthermore, although there have been implications that higher levels of embodiment promote telepresence, the connection between telepresence and task related outcomes has yet to be firmly established.

2.2 Theories Supporting Embodied Interaction

A number of theories support the premise that embodied experiences will increase user feelings of telepresence, improving collaborative task outcomes. In this section, I outline the theories that are most relevant to predicting this premise.

2.2.1 Embodied Cognition

The central theory in embodied cognition is that "cognition is deeply rooted in the body's interactions with the world" [27, 179]. In this theory, we not only off-load cognitive work onto the environment, but also use our sensorimotor interactions to guide our actions, perceptions, and memory [179]. This premise has been used as a motivator for the movement of physical computing [119] and the development of tangible user interfaces that interact with more than just our visual senses. Informed by the concept that the way that a user physically interfaces with a system will not only affect their experience at a surface level, designers seek to leverage the user's sensorimotor system to promote absorption of computing tools into the user's conceptual understanding [79].

By considering embodiment as a critical part of a user's ability to make sense of and take action in an environment, research in robotics [97], virtual reality [134], and human-computer interaction [80] has sought to create seamless interfaces between humans and technology. In the context of telepresence robots, an embodied cognition perspective suggests that using a strongly embodied system to act within the local user's environment will grant remote users a better conceptual understanding and more accurate perceptions over weakly embodied systems (e.g., videoconferencing). Furthermore, the theory suggests that being better able to understand and to act within the local user's environment will help the remote user to achieve task outcomes and aid local user cognition.

2.2.2 Ecological Psychology

Ecological psychology shares many of the same characteristics as embodied cognition, but is more directly tied to perceptual information and action [98]. The main concepts in ecological psychology are that the user must directly perceive properties in the spatial world and that affordances are ways of measuring the world, capturing the potential for the environment to be acted upon [98]. This definition of affordance differs from the way it is being used in this work based on arguments by Gaver [49]. In this theory, a user is able to analyze an environment for available actions by directly perceiving it and a user's behavior may be explained by their environment.

By viewing the user and their environment as so closely entwined, ecological psychology suggests that users must be physically situated in an environment and able to physically perceive the available affordances. This premise suggests that interacting with distant others via a more strongly embodied system should increase the remote user's capacity for perception and action in the environment, while a weaker embodiment—the experience of remote collaborators using videoconferencing or phone systems—may be detrimental for users.

2.2.3 Communication Research

Although a number of theories exist in communication research that may be applicable to telepresence robotics, there are three main theories that suggest that an embodied experience and greater feelings of telepresence will increase collaborative outcomes: the hyperpersonal model, social information processing theory, and the social identification/de-individuation model.

Hyperpersonal Model

In the hyperpersonal model [171], the process of building relationships is accelerated and intensified when communicating via computer-mediated communication. In these interactions, the mediating technology has different effects on the interactants:

Sender

The sender uses the constraints of the medium to engage in selective self-presentation, consciously choosing and controlling how they are perceived.

Receiver

Due to the sparsity of information that is available in CMC when compared to face-to-face interactions, the receiver of the message overattributes information, assigning stronger values to cues and information than they would in a face-to-face interaction.

Channel

In both synchronous and asynchronous communication, the editability and additional time required to generate a message allows time for the careful crafting of what is said, resulting in a reallocation of cognitive resources as the sender deliberately tailors their message.

Feedback

When interacting through a computer-mediated technology, people engage in behavioral confirmation—picking up that the other person expects a certain behavior and then acting it out to confirm the expectation.

The hyperpersonal model suggests that these user behaviors occur because of a sparsity of information when compared to face-to-face interactions and a number of studies have found support for this in text-based communication systems [68, 172]. However, highly embodied systems, such as telepresence robots or humanlike androids, hold the potential for providing information that is similar to being there face-to-face, such as the remote user's proximity, orientation, and physical actions. As the amount of information generated and provided increases, the hyperpersonal model seems to suggest that behaviors such as self-presentation, overattribution, and feedback, should decrease, lending to outcomes that more closely resemble those when physically present.

Social Information Processing Theory (SIPT)

Social information processing theory suggests that the outcomes from tasks where text-based CMC is used are identical to those reached in face-to-face interactions [173]. However, due to the slower rate of exchange, reaching these outcomes in CMC will take more time. Work in computer-mediated communication has lent support to SIPT, demonstrating that text-based groups reach the same objective quality of outcomes as face-to-face interactions [15, 47, 62, 144, 175].

Although videoconferencing already increases the rate of exchange over the text-based messaging that forms the basis of this theory, highly embodied interaction has the potential to offer further benefits by increasing the fluidity of transitions between work and person (or social) spaces. For example, while weakly embodied systems support a field-of-view that is limited to what is in front of the camera, more strongly embodied telepresence robots support the exchange of aural information, visual information on the screen, and workspace or contextual information drawn from the environment. By providing a greater rate of information exchange, this theory suggests that strongly embodied systems may decrease the time required to achieve task outcomes.

SIPT also posits that in reaction to the relative sparsity of information in CMC, when compared to face-to-face interactions, people will draw on other available data, such as chronemics (e.g., how long it takes you to respond to an e-mail), to imbue messages with social information. Work validating SIPT has shown that users will incorporate the available cues, such as response latencies and silences, when assessing others, using them in conjunction with the text to derive alternate interpretations or new meaning [72]. An extension of this use of additional cues was demonstrated by Steuer & Nass [142], who showed that when computers were given voices, people used the voice to not only distinguish between computers, but also to apply social rules, resulting in evaluations of some computers being more friendly or critical, despite presenting the same verbal content. When provided with a strongly embodied system where the design space offers a nearly infinite number of variables that users may draw information from, the question of what variables users find to be the most meaningful arises. Additionally, in the context of this theory, if embodied robot-mediated communication systems are able to provide greater amounts of information than face-to-face interactions, will collaboration over these systems be faster and more efficient than being present in person?

Social Identification/De-individuation Model (SIDE)

The Social Identification/De-individuation Model suggests that people cognitively adjust to form their impressions of others with minimal information, adapting their communication to reduce uncertainty [86]. In this theory, the anonymity when using technology increases depersonalization and may strengthen or weaken feelings of group membership. Group membership is of particular importance in collaborative settings, where research has shown that high group cohesion is associated with promoting cooperation between group members [11, 116] while low cohesion may lead to less trust and even sabotage [11].

Video-based research has suggested that in the context of workplace collaboration, remote users may feel less able to contribute and have decreased feelings of group membership due to perceptions of being less present [9, 20, 116]. Strongly embodied systems, however, may increase feelings of telepresence for remote users, enhancing feelings of group participation.

Across multiple disciplines, the theories presented here lay a groundwork for predicting that communication systems that provide strongly embodied experiences will enhance user feelings of presence, or telepresence. Additionally, these theories suggest that increasing feelings of presence will lead to increased fluency of interactions between users as well as beneficial outcomes for collaboration.

In the next section, I discuss current work in the field of telepresence robotics that has thus far examined the use of these systems in the field.

2.3 Robot-mediated Communication and Telepresence Robots

As the field of robotics has matured, the number of robot-mediated communication systems has grown to encompass a wide variety of platforms; for example, telepresence blimps [121], telepresence robots—videoconferencing systems that are mounted on a mobile robotic base [66, 83, 109, 182], and teleoperated humanlike androids that autonomously generate or mimic the remote user's non-verbal behaviors [104, 115]. Even within the subset of telepresence robots, the number of systems and their permutations have multiplied recent years [3, 38, 52, 54, 65, 130, 146, 168].

Although these systems are relatively new, a growing body of research has explored their viability in field settings. These studies have examined the use of these systems in situ, gathering longitudinal data about their acceptance from remote and local users, often showing qualitative support for telepresence robots increasing user feelings of presence. For example, highlighting that telepresence robots increased perceptions of the remote user's participation [9, 88, 166], allowed hospitalized children to attend school with their classmates [176], and decreased health care costs while maintaining quality of care [85, 167]. Work by Takayama & Go [150] investigated the metaphors that are used in the field, highlighting the negative effects that result when user metaphors are mismatched.

Another approach has identified the features that negatively impact the user experience or alternately, features that should be supported in successful telepresence systems. A number of studies in this area have identified technological bottlenecks for system success, such as connectivity issues or feedback delay [36, 162], or have proposed general design factors for consideration [23, 25, 29, 36, 162]. Other work has centered less on the system itself and more on the barriers to adoption in various settings, seeking to understand user needs in business [88, 160, 166], home care [8, 99], educational [44], medical [53, 163], and other contexts [127].

Last, a growing body of literature has begun to investigate the effects of particular aspects of telepresence robots in controlled laboratory settings, seeking to deepen our understanding of how variables in the design space affect user experiences. For example, Takayama & Harris [151] showed that remote users altered their self-presentation after gaining awareness of how they looked when using a robotic telepresence system, but also rated their experience with the system as less enjoyable. Other investigations have shown evidence that local users believe remote users to feel more present when using a robotic telepresence system [9] and that these systems promote greater opportunities for ad-hoc or impromptu interactions [88, 160]. Further studies have also found that other features, such as assistive driving, helped users to avoid obstacles but also increased the time required to complete the course [152].

While these studies have scratched the surface of the design space, thus far there has not been empirical evidence showing strong support for the embodied interaction of telepresence robots increasing feelings of presence, leading to improved collaborative outcomes.

3 | Embodiment and Control

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 [175]. Analog forms of distance communication (e.g., letter writing and talking over telephone lines) have been augmented by computer-mediated systems, such as e-mail, instant messaging, and videoconferencing. Lately, robot-mediated communication systems, such as telepresence robots, have been added to the mix.

Telepresence robots have recently emerged as a viable option in today's market. By adding two key features, a human-sized strong 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 [3, 38, 52, 130, 147, 168] to android representations of the remote user [104, 132]. By providing the remote user with a human-sized strong embodiment and 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, we call them *operators*.

Telepresence robots facilitate greater levels of embodiment and control than prior platforms, opening up the design space for exploring these features. These enhancements of a more embodied and remote user control hold significant promise for increasing the remote user's feelings of presence and communicative efficacy [88]. Additionally, by having an embodied presence in the environment,

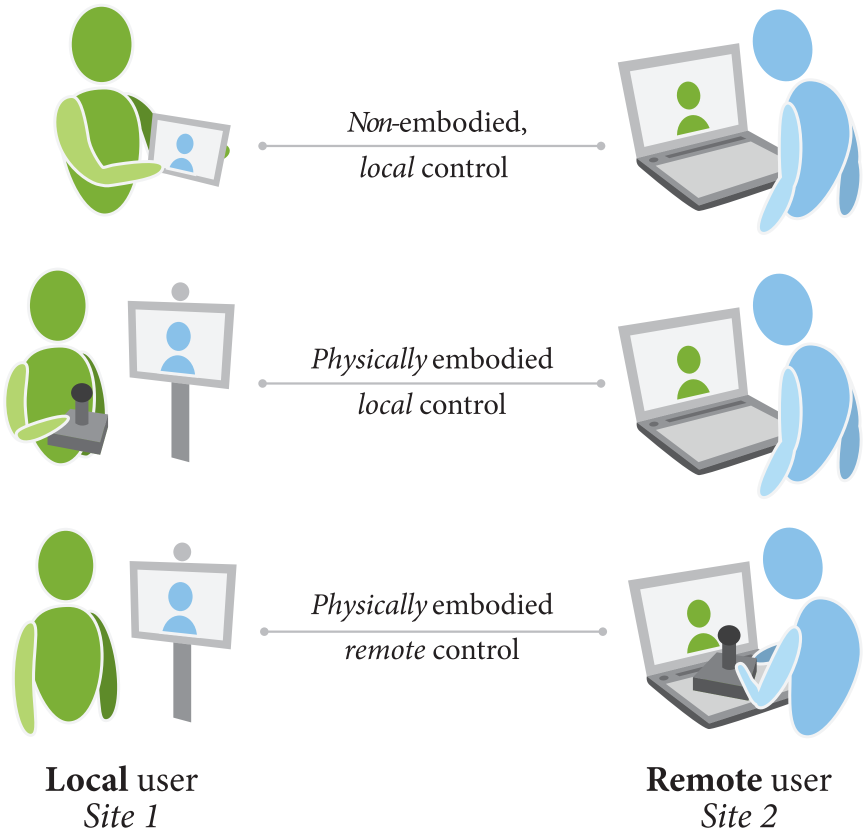

Figure 3.1: The study explored how strong embodiment and control shaped mediated communication by comparing collaborative outcomes across three conditions: (1) weakly-embodied, local control, (2) strongly-embodied, local control, and (3) strongly-embodied, remote control.

local users may more easily be able to perceive and act with the remote user [27, 51, 98, 179]. While past research has worked to implement these features [66, 121], few studies have provided empirical evidence for how they might create more embodied experience and improve collaborative outcomes.

In this section, I focus on understanding how the addition of a strong embodiment and how the division of control might shape interactions between remote and local users. In particular, I compare how a difference in the level of strong embodiment (a strongly-embodied telepresence robot vs. a weakly-embodied 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. I examine these effects in a laboratory experiment where participants were exposed to real-world conditions of video delay, network latency, and differing environmental and social contexts (west coast and midwest). To do this, we recruited participants at two separate sites that were located approximately 2000 miles and two time zones apart.

3.1 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 [14, 114], are less vulnerable to betrayals of trust [14], take less time to achieve similar outcomes [15, 47, 144, 175], and are more spontaneous with less formality [62]. In addition, participants in face-to-face interactions are more likely to have an accurate perception of their spatial positioning [61] and they are more likely to opportunistically engage in spontaneous encounters with others [116, 166] or to maintain parallel conversations [136].

In communication research, traits such as trust have been shown to be a cornerstone for increasing cooperation in large organizations [122]. 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 [122].

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.

3.1.1 Computer-mediated Communication

Much of the work in computer-mediated communication has targeted synchronous or asynchronous interactions that are carried out over text messages. 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 [47] and in equalizing roles [62, 77, 175]. 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 [76]. While each of these studies has examined specific ways or situations in which mediated communication may be successful, they have also demonstrated the difficulty in achieving parity with face-to-face interaction.

3.1.2 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 [15], and these positive effects extend to the facilitation of turn-taking [28] and increased development of trust [14] over text-based communication. In addition, further investigations have shown that how much of the other person is showing [113], the ability to share a work space in a collaborative task [153], and the ability to adjust the viewer's perspective to be spatially faithful in group-to-group mediated communication [114] alter the efficacy of the interaction. However, VMC also opens the door for user concerns over unintended viewers [17], and despite the addition of video, a large divide still exists between mediated and face-to-face interaction [61, 117, 136].

3.1.3 Robot-mediated Communication

Robot-mediated communication takes one step closer to face-to-face interaction through the addition of a strongly-embodied system and control over that system. We use the term *strong 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 [34]. These two features offer a multitude of opportunities for designers of telepresence robots. In particular, the unique design variables present in a strong embodiment may shape user interactions and the addition of control raises questions about how it should be structured and divided among users. In previous communication systems, these aspects have been limited by the medium. Remote users have been represented within the context of a larger system (e.g., through a phone or a on computer screen) without the option of a strongly-embodied representation, and where access to the remote environment has been controlled solely by users local to the system.

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 [104, 132] and that this increased sense of presence promotes greater opportunities for ad-hoc or impromptu interactions than videoconferencing [88, 160].

While this work has directly compared individual systems or has examined how specific design aspects might affect interaction, how strong 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.

3.2 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., [15, 26, 61, 114, 153]), we developed the hypotheses below on how *strong embodiment*, i.e., weakly-embodied systems such as a computer screen or a tablet computer vs. strongly 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 strongly-embodied communication system will result in more positive collaborative outcomes than using a weakly-embodied system.

Hypothesis 2. Using a communication system controlled by the remote user will have more

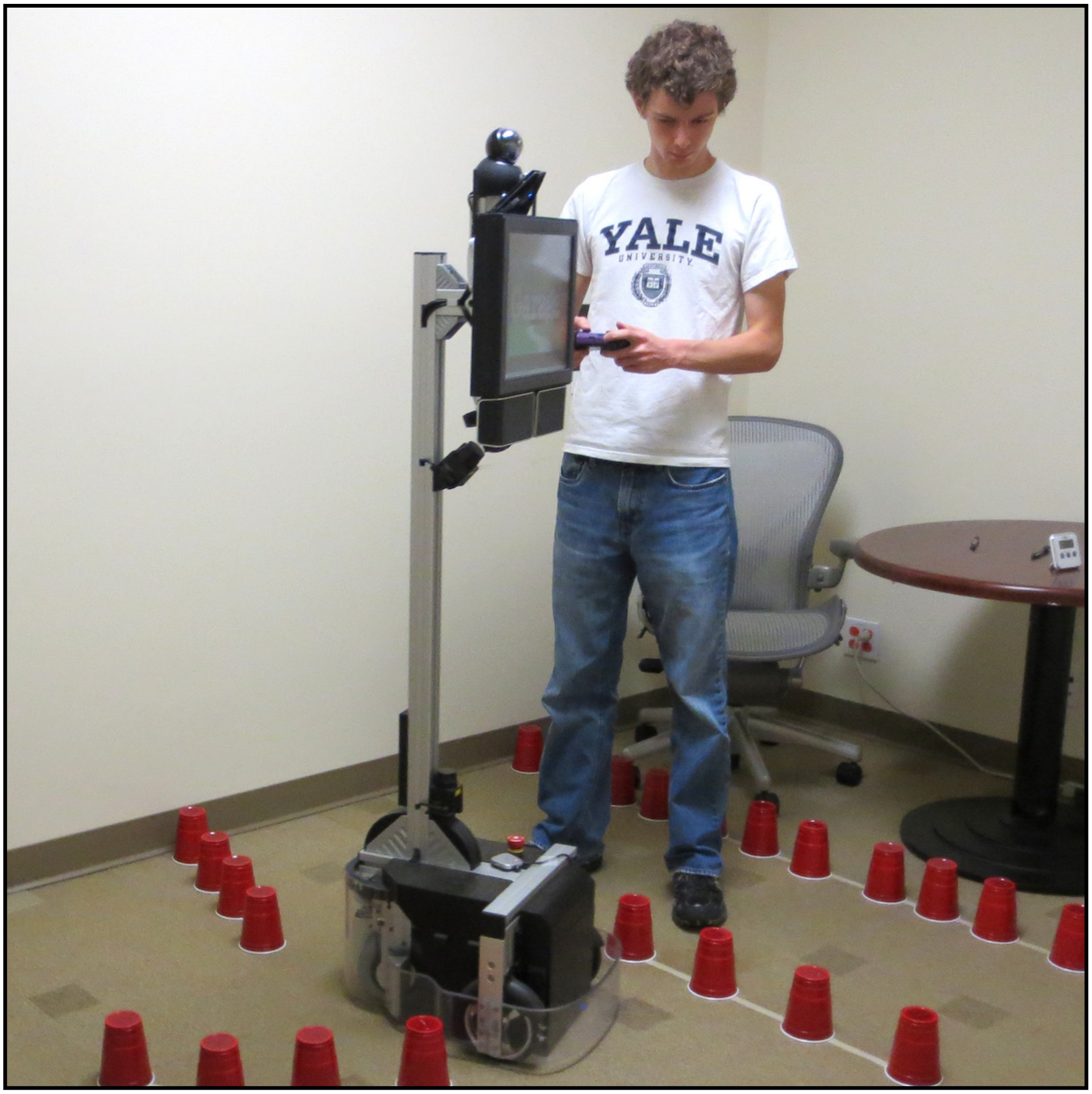

Figure 3.2: To gain familiarity with controlling the telepresence robot, local participants practiced steering it in a maze-like obstacle course for 10 minutes.

positive collaborative outcomes than using a system controlled by the local user.

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

3.3 Method

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

To test the effects of *strong embodiment*, we compared dyadic videoconferencing interactions using a handheld tablet, *weakly-embodied*, to those using a telepresence robot, *strongly-embodied*. In the weakly-embodied condition, participants used a 10-inch Samsung Galaxy Tab 2 10.1 tablet, and in the strongly-embodied condition, participants used a Texai Alpha telepresence robot standing at 61.5 inches (156.2 cm) tall, as shown in Figure 1.1. 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 systems were handled using Skype.

To examine the 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 3.1.

3.3.1 Participants

We recruited pairs of participants, *dyads*, from two sites in cities that were approximately 2000 miles and two time zones apart to impose 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.

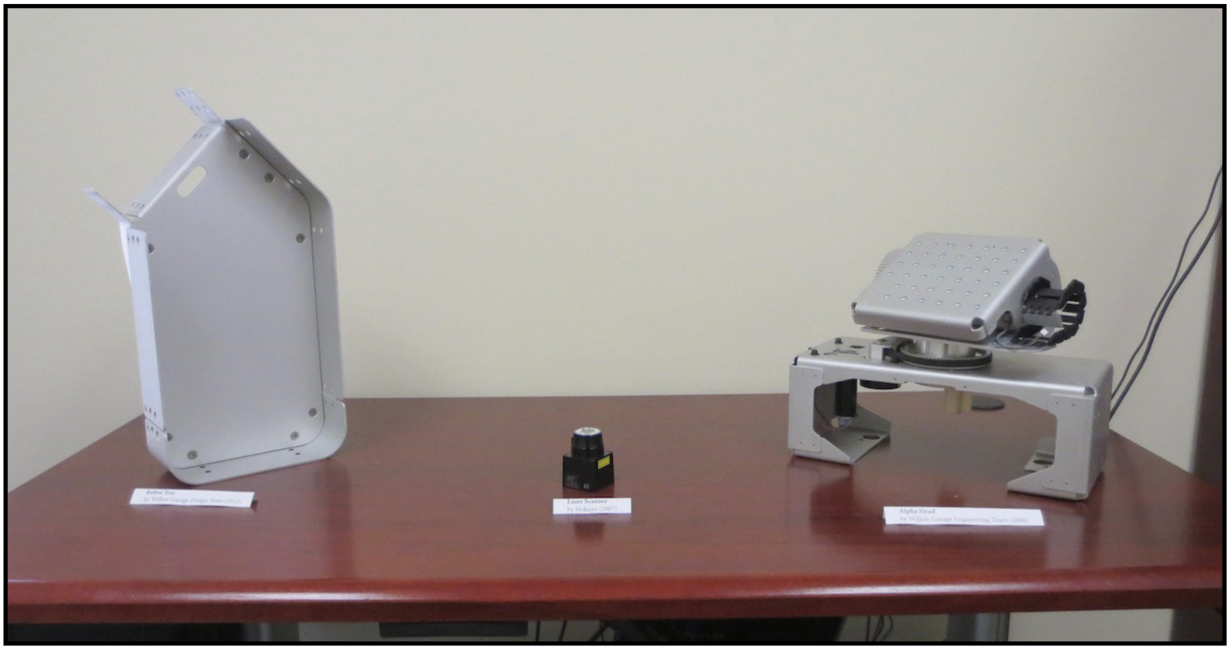

Figure 3.3: Example items from the Museum Tour. Each item had an accompanying nameplate that displayed the name, producer, and production date of the item.

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.

3.3.2 Tasks

In the experiment, participants collaboratively performed 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 3.5). 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.

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 3.3. 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 3.4).

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 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, the local participant ranked the top five items that the remote participant showed interest in to measure the local participant's interpretation of the remote participant's non-verbal

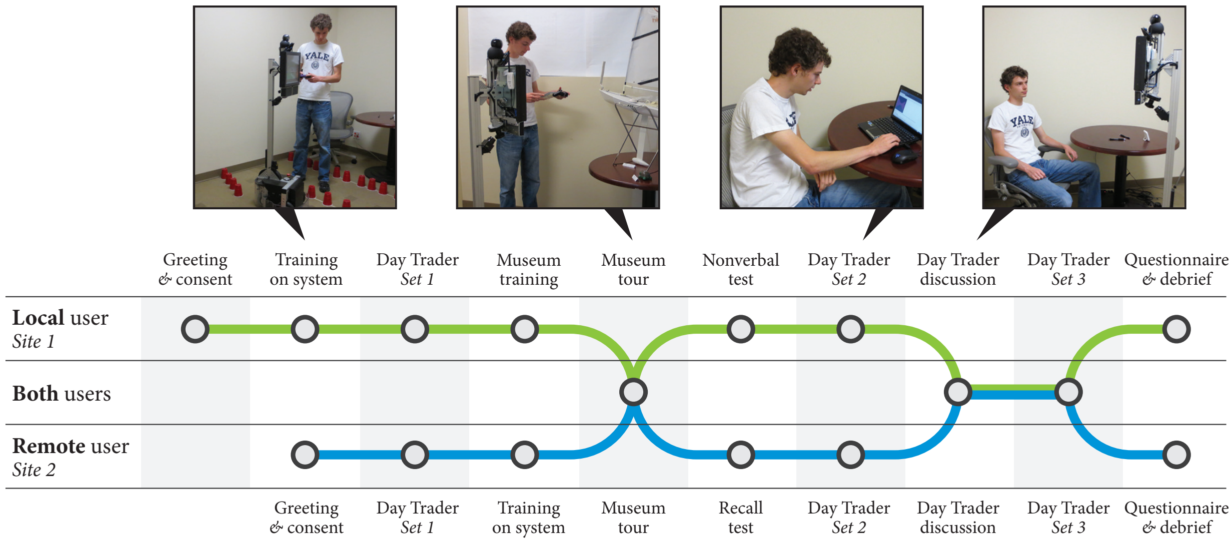

Figure 3.4: The steps in and timeline of the experimental protocol. The top, middle, and bottom lines indicate the steps performed by the local participant, both participants, and the remote participant, respectively.

attention cues.

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 [14, 114], and it provides measures of trust that have been tested for reliability and validity [131].

Our use of the Daytrader Game followed the structure employed by previous work [14, 114].

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. At the end of the round, tokens that they chose to keep doubled in value, 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.

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.

3.3.3 Procedure

The paragraphs below outline the procedure from the local participant's perspective in the *strongly-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 3.4.

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 3.2.

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 a virtual 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 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 instructed 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.

3.3.4 Measurement

We captured the effects of strong 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

We used objective measures to capture the effects of strong 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:

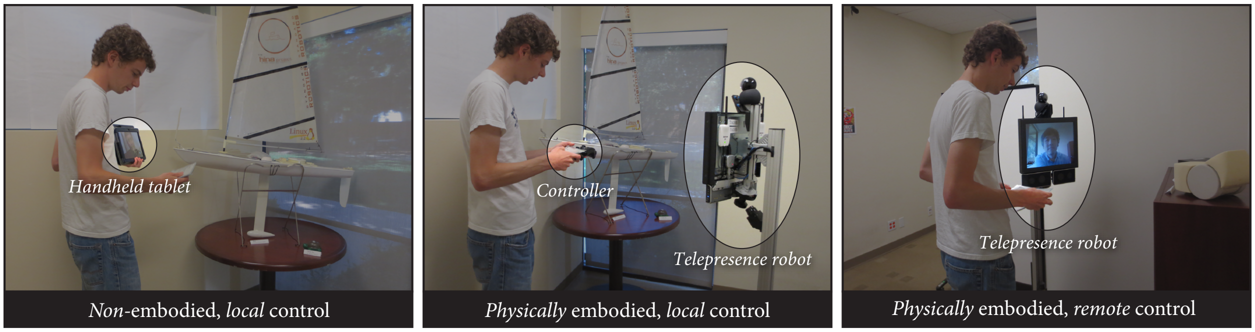

Figure 3.5: The Museum Tour task in the *weakly-embodied, local control* condition (left), *strongly-embodied, local control* condition (middle), and *strongly-embodied, remote control* condition (right).

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 $\kappa = .881$, $SE = .113$.

Categorical item recall. Before the tour, remote participants were instructed to learn and remember three details about two of tour items (selected by the experimenter) 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 strong 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 mark 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 [136]. 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 told only 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., [14, 114]), 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[180], 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 on 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 [10]. 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 [69] 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).

3.3.5 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* [75] to compare data between and within dyads across experimental 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 [75] 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 re-

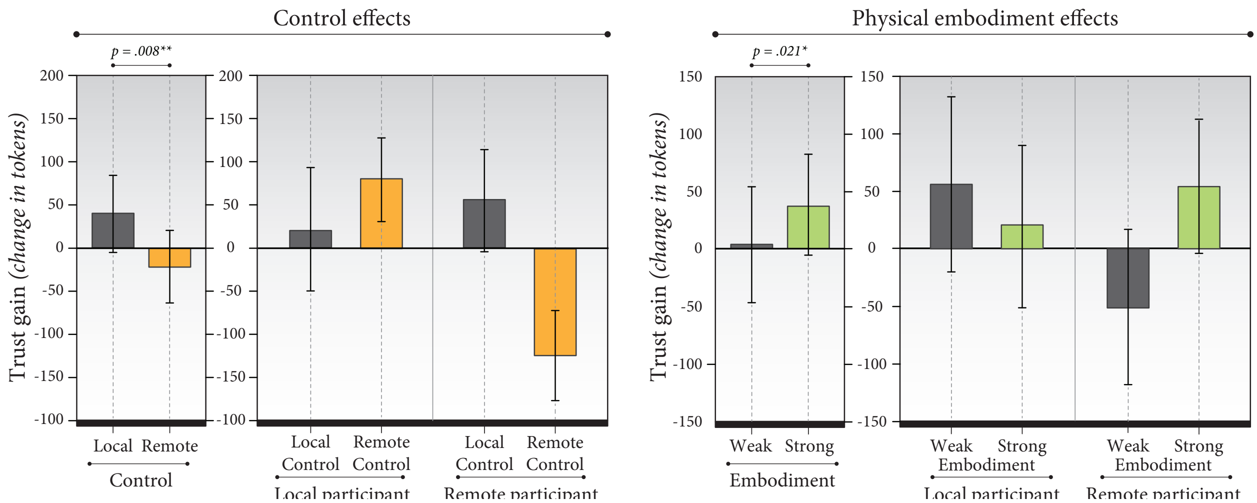

Figure 3.6: The results showed that trust between participants increased more when they used a strongly-embodied system than it did when they used a weakly-embodied system (left) and when the local participant controlled the system over when the remote participant controlled it (right). (*) and (**) denote $p < .05$ and $p < .01$, respectively.

gression model, which treated participants as individuals nested within pairs and measurements from individuals as repeated measures within pairs, as described by Kenny [75]. 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 [75].

3.4 Results

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

When the system was controlled by the local user and the embodiment condition (weakly-embodied vs. strongly-embodied) was manipulated, we found the following results: participants using a strongly-embodied system (telepresence robot) showed a significant increase in trust after interacting $M = 37.55$, $SD = 200.10$, compared with participants who used a weakly-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 weakly-embodied condition system $M = 55.78$, $SD = 227.52$, than when they used a strongly-embodied system, $M = 20.25$, $SD = 224.10$. Conversely, remote participants tended to gain trust in the local participant when they interacted through a strongly-embodied system (telepresence robot), $M = 54.85$, $SD = 183.42$, and tended to lose trust when they interacted through a weakly-embodied system (tablet), $M = -50.00$, $SD = 202.62$, see Figure 3.6.

We found no significant effects of strong 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 strongly-embodied system trusted each other not to laugh in an unkind manner $M = 5.06$, $SD = .94$, over those in the weakly-embodied condition, $M = 4.40$, $SD = 1.31$, $F(1, 17) = 3.240$, $p = .090$.

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 strong 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 3.6).

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 strong 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 $M = 4.50$, $SD = 1.051$, $p = .032$.

3.5 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 strong embodiment system (telepresence robot) than they did in the weakly-embodied condition (tablet). Contrary to our second hypothesis, participants using a system that provided the remote user with a strong 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 strong 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 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 [131, 133]. 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 remote. By showing reliability and dependability (e.g., avoiding collisions, moving the system carefully, making an effort to engage with the other person), the participant in control elicited positive expectations and an increased willingness to take risks within the relationship [131]. 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 [133].

3.5.1 Design Implications

We have demonstrated how two key features, strong embodiment and control, affect user interactions. Although 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 strong embodiment and control might have, but it 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.

3.5.2 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 strong embodiment and control on technology-mediated communication.

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, affects mediated communication. Future work may also be needed to investigate how functions 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 or on other CMC theories that may provide further insight.

3.6 Conclusion

With the proliferation of commercial telepresence robots, the need to understand how their functions affect communication is critical. Robot-mediated communication systems are an example of an advanced technology that has recently been introduced to the market. These systems provide remote users with proxy strong embodiments in distant locations and the ability to control them. We found that the strong embodiment and local user control increased trust between users over a weakly-embodied or remote controlled system. Our results also have implications for the design of future systems, illustrating the benefits and tradeoffs that may occur when these systems are used in supporting collaborate tasks.

4 | Height and Authority

From articles about the importance of making a good first impression to dressing up for an important interview, physical appearance has been shown to play a large part in how we are perceived, judged, and treated by others. While there are a multitude of ways in which individuals alter how they present themselves, there are also many characteristics that we have very limited control over, such as our height.

Research in human communication has shown that height can be critical to how people are perceived; being taller is associated with a number of positive traits such as being more poised, self-assured, composed, relaxed, expressive, and persuasive [18, 60]. These traits may also extend to benefits such as higher pay [70] and being judged to be more attractive [129, 139]. While researchers have investigated such benefits in contexts where height is not malleable, how these effects might extend to robotic systems, where designers are able to dictate physical appearance, has yet to be explored.

Telepresence robots are one such system that provides designers with the ability to control an alternate physical representation of the remote user. By altering aspects or variables of these physical embodiments, designers can shape the relationship between the remote and local users both positively or negatively. For example, positive effects might make remote team members feel closer to their local counterparts [125], improving productivity, while negative outcomes may include subverting a remote doctor's authority and causing less treatment compliance in patients [53].

Due to the newly emerging market for telepresence robots and the nascent nature of research in the area, designers and developers lack guidelines for specifying the physical characteristics of these systems. As a result, today's commercially available systems drastically vary in many physical

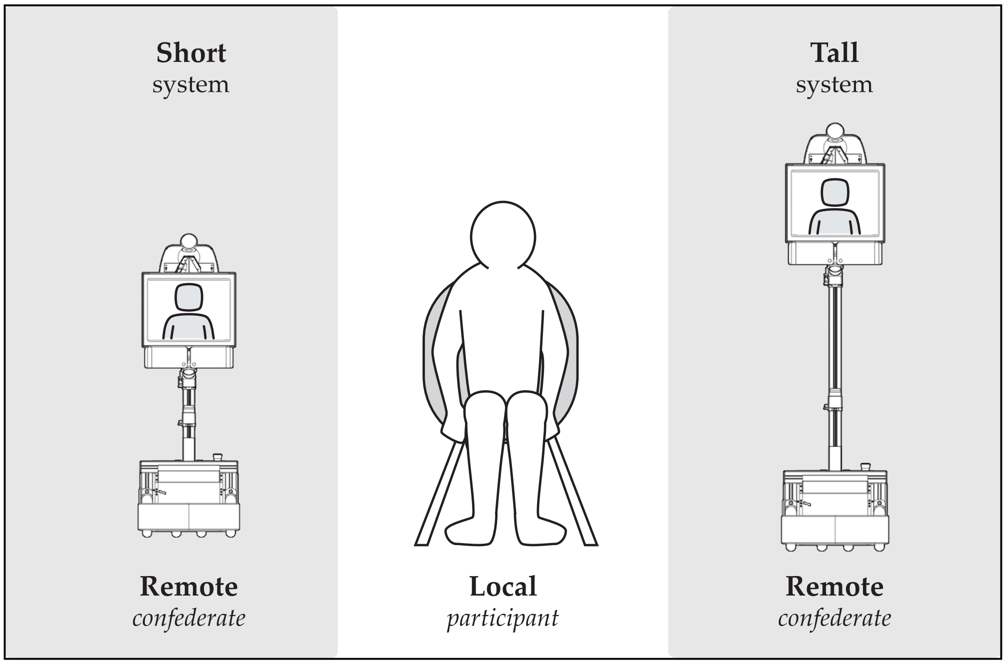

Figure 4.1: Example of height differences between a shorter telepresence robot (left), a taller (right) telepresence robot, and a participant.

characteristics, such as height. Systems currently on the market stand at static heights of between 40 – 72 inches (101.6 – 182.9 cm) tall [52, 54, 130, 147, 168] and heights that are adjustable within the range of 30 – 72 inches (76.2 – 182.9 cm) [3, 38].

In this section, we explore how the *height* of the system, and thus the perceived height of the remote user relative to that of the local user, affects robot-mediated communication.

4.1 Related Work

Here we discuss related work that provides background for the effects that height has in face-to-face and mediated communication, informing our efforts to untangle the role it plays in communication using robotic products.

4.1.1 Height in Human Communication

Research in human communication has shown that differences in height impact how people are perceived [101] and treated [70]. People who are taller relative to the perceiver are associated with being more dominant and thus possessing a host of other positive characteristics, such as being perceived as more relaxed, composed, expressive, dramatic, persuasive, poised, self-assured, having more leadership qualities, and exhibiting less self-censorship [18, 60]. Prior work has observed that taller people are often judged to be more attractive [129, 139] and have received higher pay [70] than their shorter counterparts. These effects are most prevalent in short-term interactions and may diminish in interactions that occur over longer periods [89].

The effects of height on people's perceptions of others and on their subsequent interactions have also been shown to extend into video-mediated communication and virtual reality [63, 183]. Research in these contexts has found that participants communicating via videoconferencing [63] or in virtual reality [183] had increased influence when they perceived themselves to be taller than the person with whom they were interacting.

4.1.2 Height in Human-Robot Interaction

Human-robot interaction (HRI) research has explored how people's perceptions of a robot and their interactions with it are affected by its height. For instance, Walters [170] found that participants judged shorter humanlike robots to be less conscientious than taller humanlike robots. In a design study, users preferred the taller robot version of 56 inches (142 cm) to shorter versions because they did not want to bend down to interact with it [87]. While these findings highlight the importance of height in HRI, how they might translate to the domain of robot-mediated communication is an open question.

4.1.3 Height in Robot-Mediated Communication

While prototype and research models of telepresence robots such as the Personal Roving Presence [121] have been in existence for over 15 years, advances in robotic technology and wireless networking over the past decade have enabled these systems to become more widely available [3, 38, 52, 130, 147, 168]. This availability has created many opportunities for designers and for research aimed at creating design guidelines.

Recent studies have explored how telepresence robots are used in naturalistic settings, particularly in organizations [88, 160], in home healthcare [99], and with older adults [8]. Other studies have examined how system appearance and feelings of ownership might affect interactions [125] or have pushed the boundaries of robotic telepresence systems by creating humanlike physical representations of the remote user [115, 132]. While this research has delved into the question of how the visual framing or humanlike qualities of the system affect interactions between the local and the remote, how the relative height of the system might shape interactions between local and remote users has yet to be explored.

4.1.4 Roles in Communication

Research in human communication has shown that the roles assigned to individuals in a group may drastically alter behavior in terms of perceived authority, dominance, and aggression [184]. While some work in human-robot interaction has shown that this type of verbal framing can be effective in altering people's perceptions of robotic systems [181], further investigation is needed to understand how this may affect people's perceptions of other humans when their communication is mediated by a robotic telepresence system.

Our study seeks to understand the extent to which the effects of height observed in human communication and human-robot interaction settings generalize to robot-mediated communication. In particular, we look at how height may serve to undermine or support a user's role when a disparity exists between the user's physical and assigned levels of authority. This understanding will provide design guidelines for future development of robotic communication products and promote longer and more natural interactions between geographically distributed people.

4.2 Hypotheses

Based on this body of prior work, we formulated the central hypothesis that the height of the telepresence robot relative to the height of the local user would support or undermine the local user's feelings of authority when interacting with a remote user. In particular, the height of the system will have the following predicted effects under different authority structures:

Hypothesis 1: When interacting with a remote that is using a shorter telepresence robot, local participants who are assigned a leadership role will exhibit the most dominance.

Hypothesis 2: When interacting with a remote that is using a taller telepresence robot, local participants who are assigned a follower role will exhibit the least dominance.

Hypothesis 3: Local participants interacting with a remote that is using a shorter telepresence robot will exhibit more dominance, regardless of their assigned role, than those who interact with a remote that is using a taller telepresence robot.

4.3 Method

To test these hypotheses, we conducted a 2 (relative system height: shorter vs. taller) by 2 (team role: leader vs. follower) between-participants controlled laboratory experiment. All study participants acted as local users and a confederate operated a telepresence robot that was either *shorter* or *taller* than the participant. Participants were also assigned a role as either the *leader* of the team or the *follower* in the team to create differing levels of perceived authority between the users. The confederate was a 20-year-old female logged into the telepresence robot from a remote location, approximately $2,000$ miles away from the local site. The same confederate operated the robot across all trials.

4.3.1 Participants

Forty adults (5 females and 5 males in each condition), whose ages ranged between 18 and 70 years, $M = 35.1$, $SD = 15.7$, volunteered to participate. We recruited via a local university's online bulletin board, e-mail lists, word of mouth from participants of previous studies, and posters placed around the neighborhood. Participants reported that they were somewhat familiar with robots, $M = 4.20$, $SD = 2.27$ (1 = not very familiar; 7 = very familiar). They were compensated $20 for each hour of study participation.

4.3.2 Tasks

During the study, participants completed two main tasks: the Desert Survival Task and the Ultimatum Task. Both tasks involved negotiation between the local participant and the remote confederate. During each task, we collected video footage from three cameras positioned in the experiment room. The paragraphs below provide more detail on each task.

Desert Survival Task

The first task involved a version of the Desert Survival Problem [84] that had been modified to include items which would be recognizable and relevant in a present-day survival situation [125]. We gave participants written instructions describing a bus crash in a desert in New Mexico and asked them to rank a list of nine items in order of each item's importance to their survival. This initial ranking served as the baseline measurement for agreement between the participant and the confederate. The items included a map of New Mexico, a book called *Edible Animals of the Desert*, duct tape, a first-aid kit, a cosmetic mirror, a flashlight (four-battery size), a magnetic compass, one two-quart flask of 100-proof vodka per person, and one plastic raincoat per person.

We chose the Desert Survival Task for several reasons. First, it has been used in previous mediated communication studies (e.g., [63, 125]) and has been tested for both reliability and validity.

Figure 4.2: A telepresence robot shorter than the local (left) and taller than the local (right).

Second, the task includes a measure of agreement. Third, participants are inclined to believe that they should be good at the task, which results in a large amount of variance.

After the participant's initial ranking, we algorithmically generated a set of initial rankings for the confederate that was consistently different from those of the participant [125], shown in Appendix A.2. The confederate and the participant then discussed the differences in their rankings. During the discussion, the participant and the confederate sought to come to a consensus on a final ranking of the items. The confederate followed a pre-scripted dialog, as in previous work [125].

Ultimatum Task

Our second task was the Ultimatum Task [46], a negotiation-based economics exercise that has been used in previous work to study perceptions of dominance in a virtual reality setting [183].

The task involves a total of four rounds and a hypothetical pool of $100 to be split between the participant and the confederate in each round. The participant proposes a split of the money in the pool and the confederate has the option of accepting or rejecting the split, or vice versa. We also told the participant that if the split was accepted, then the money would be shared accordingly, but if the split was rejected, then neither person would receive any money.

The participant designated the split in the first and third rounds and the confederate proposed the split in the second and fourth rounds. As in previous work [183], the confederate accepted any proposals where she received more than $10 out of the $100. During the second round, the confederate always proposed a 50/50 split, and in the fourth round, the confederate offered a 75/25 split with $75 going to the confederate.

4.3.3 Measures

We used measures of agreement from the two tasks, subjective measures via a post-experiment questionnaire, and behavioral data collected through qualitative coding of significant behaviors that indicate the dominance of the participant toward the confederate.

Task Measures

In the Desert Survival Task, we measured the compliance of the participant using the difference between the confederate's initial scores and the final consensus rankings. The confederate's initial rankings were calculated to be consistently distant from the participant's; therefore, the difference between the initial rankings of the participant and those of the confederate was consistent across trials. Thus, the difference between the final consensus ranking and the confederate's initial ranking measured how much influence the confederate had on the participant. A larger difference meant that the participant was less persuaded by the confederate's arguments, whereas a smaller difference indicated that the confederate's arguments had more of an impact. In the Ultimatum Task, we used three measures: the initial split proposed by the participant in the first round, the split proposed by the participant in the third round, and whether or not the participant accepted the unfair 75/25 split proposed by the confederate in the last round.

Subjective Measures

We used questions from two separate scales that have been tested for reliability and validity in our questionnaire.

Interpersonal Dominance Scale. To measure perceived dominance, we used the Interpersonal Dominance Scale [19], which measures dominance along five dimensions: poise, persuasion, conversational control, panache, and self-assurance. The scale is comprised of 32 statements on perceptions of the other person (e.g., “the other person is more of a follower than a leader”; “the other person had a dramatic way of interacting”; “the other person did more talking than listening”). Participants expressed their agreement with each statement using a seven-point rating scale (1 = strongly disagree; 7 = strongly agree).

Subjective Value in Negotiation Tasks. We used a modified version of the 16-question Subjective Value in Negotiation Tasks scale which has been tested for validity and reliability [33] to measure the participants’ feelings about the tasks. These questions were divided along four dimensions with three to five questions per dimension: feelings about the instrumental outcome of the task, feelings about the self, feelings about the process, and feelings about the relationship.

Behavioral Measures

We used research in human communication to identify and to code for behaviors indicative of interpersonal dominance or submission in our video data [19]. These indicators included the percentage of time spent speaking, the ratio of time spent looking at the other person while speaking, and the number of attempts to interrupt the other person. We also coded for indicators of submission such as the amount of time spent listening and the ratio of time spent looking at the other person while listening. In addition, we made qualitative observations on the postures that participants took [22]. Videos were coded by three independent coders and inter-rater reliability was tested using Spearman’s rank coefficient with an inter-rater reliability between coders 1 and 2 of $\rho(36) = .92$, $p < .001$ and an inter-rater reliability between coders 2 and 3 of $\rho(18) = .98$, $p < .001$.

Other Measures

Following the questionnaires, we administered a manipulation check. To determine whether the manipulations of robot height and assigned role in the team were successful, we asked participants whether they had to look up, down, or straight to interact with the remote user and who the leader of the team was. We also collected demographic information which included gender, participant height, age, occupation, and experience with robots.

4.3.4 Manipulations

In the following section, we describe our manipulations of the relative height of the telepresence robot system and of the assigned role of the participant in the team.

Height

We used Texai Alpha prototypes, which are telepresence robots equipped with touch screens mounted on mobile robotic platforms as shown in Figure 4.2. These systems stream video of the remote user onto the screen while providing them with the ability to physically navigate through the environment and to control the positioning of the cameras. The *short* telepresence robot measured 41 inches (104.1 cm) to the top of the screen and 46.5 inches (118.1 cm) to the top of the camera. The *tall* system measured 56.5 inches (143.5 cm) to the top of the screen and 61.5 inches (156.2 cm) to the top of the camera. These measurements were adjusted during pre-testing to create a 6 inch (15.2 cm) difference between the eye level of the participant and the perceived height of the remote. At the beginning of each session, participants adjusted the height of their chairs so that their eye levels were at 47 inches (119.4 cm) as depicted in Figure 4.2.

Roles

Participants were randomly assigned a role at the beginning of the study as either the team *leader* or a *follower*. Roles were assigned after the remote confederate and the participant had been introduced. While addressing both the confederate and the participant, the experimenter assigned one of them team leadership and explained that the team leader would be responsible for ensuring that the team reached a consensus in the Desert Survival Task in the time provided and that their final rankings matched.

4.3.5 Procedure

Following informed consent, we asked participants to seat themselves and told them that we first needed to calibrate the camera. We placed a checkerboard on the wall next to the seat, and the experimenter asked the participant to adjust his or her chair until the participant's eyes were level with a line measuring 47 inches (119.4 cm) from the ground as shown in Figure 4.2. The experimenter instructed participants on the Desert Survival Task. Participants reviewed the survival scenario and then took three minutes to record their initial rankings of the survival items. Following the initial rankings, the remote confederate drove into the room, and the experimenter introduced the confederate and the participant to each other as participants. The experimenter then assigned the role of team leader and told the participant and the confederate that they would have 12 minutes to discuss and to reach a consensus on a set of final rankings. After the discussion period was completed, the experimenter re-entered the room, instructed the participant and the confederate on the Ultimatum Task, and exited the room to allow the participant and confederate to complete the exercise. Upon completion of the task, the confederate exited the room and the experimenter administered the post-experiment questionnaire.

4.3.6 Analyses

In an exploratory analysis, we sought to determine potential covariates, testing effects of gender, age, and participant height on the dependent variables, and found only height to have a significant effect. We therefore included participant height as a covariate in all final analyses.

Task Measures

An analysis of covariance (ANCOVA) was conducted to analyze the measures of agreement from the Desert Survival Task, using the difference between the final consensus ranking and the confederate's initial ranking as the response variable and participant height as a covariate. An ANCOVA was also used to analyze participant's proposed splits in the Ultimatum Task. The first split proposed by the participant in round one and the second split proposed by the participant in round three were the response variables and participant height was a covariate. A Pearson's Chi-squared test was used to determine any effects of height or team role on participants accepting the unfair (75/25) proposal by the confederate. Post-hoc comparisons in all tests used the Bonferroni correction.

Subjective Measures

Our analysis of participant responses to the questionnaire included tests of internal consistency along the dimensions defined by the Interpersonal Dominance [19] and the Subjective Value in Negotiation Tasks [33] scales, described earlier in Section 4.3.3. Because these measures were adapted from research in human communication, we conducted a confirmatory factor analysis to ensure their reliability in the context of robot-mediated communication. This analysis showed that the items did not reliably compose the sub-scales suggested in the literature. Therefore, we followed up with an exploratory factor analysis to construct new sub-scales from the set of items. Our analysis resulted in two new sub-scales, which we identified as *conversational control* (two items; $Cronbach's\ \alpha = .78$) and *feelings about the negotiation* (11 items; $Cronbach's\ \alpha = .91$). The analysis of data from these sub-scales and of the individual questionnaire items involved ANCOVA tests that used participant height as a covariate. Data from the manipulation check questions were analyzed using Pearson's Chi-squared tests.

Behavioral Measures

Analysis of the data resulting from our qualitative coding of the videos involved ANCOVA tests, using participant height as a covariate for time-based measures and Pearson's Chi-squared tests for frequency-based behaviors.

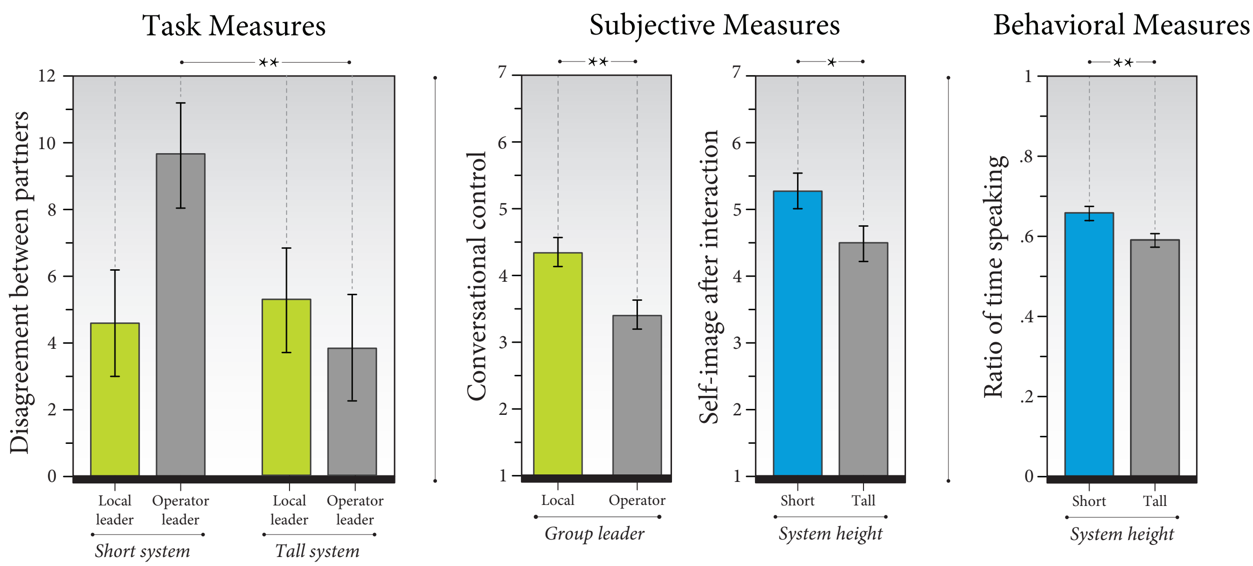

Figure 4.3: Results showing significant effects of the relative height of the telepresence robot and assigned role on task (left), subjective (middle), and behavioral (right) outcomes. (*) and (**) denotes $p < .05$ and $p < .01$, respectively.

4.4 Results

The analysis of data from manipulation check questions showed that participants were able to distinguish between the different heights of the telepresence robot, $\chi^2(3, \text{N=36}) = 37.0, p < .001$, and assigned roles, $\chi^2(2, \text{N=38}) = 20.8, p < .001$, across conditions.

Hypothesis 1 posited that when interacting with a remote that was using a shorter telepresence robot, local participants who were assigned leadership would exhibit the most dominance. Our results showed partial support for this hypothesis. We found that locals who interacted with an remote that was using a shorter telepresence robot felt that the negotiation had a more positive impact on their self image $M = 5.29$, $SD = 1.68$ than those who interacted with a remote that was using a taller telepresence robot $M = 4.50$, $SD = 1.64$, $F(1, 34) = 4.41$, $p = .043$, $\eta_p{}^2 = .115$ as shown in Figure 4.3. Locals that interacted with a remote that was using a shorter telepresence robot also showed a tendency toward feeling more satisfied with their relationship with the remote $M = 6.05$, $SD = 1.65$, than those who interacted with a remote that was using a taller telepresence robot $M = 5.35$, $SD = 1.65$, $F(1, 35) = 3.54$, $p = .068$, $\eta_p{}^2 = .092$. We also found that locals who interacted with a remote that was using a shorter telepresence robot spent a greater ratio of the total interaction time speaking $M = .656$, $SD = .070$ than those that interacted with a remote that was using a taller telepresence robot $M = .589$, $SD = .081$, $F(1, 33) = 8.07$, $p = .008$, $\eta_p{}^2 = .196$. There was a marginal effect of the relative height of the telepresence robot on the total amount of time spent in discussion. Locals who interacted with a remote that was using a shorter telepresence robot spent more time in discussion $M = 536.63$, $SD = 126.82$ than those that interacted with a remote that was using a taller telepresence robot $M = 479.74$, $SD = 90.21$, $F = (1, 33) = 2.98$, $p = .094$, $\eta_p{}^2 = .083$.

We found no support for Hypothesis 2, that when interacting with a remote that was using a taller telepresence robot, local participants who were assigned a follower role would exhibit the least dominance. We found that when the local was assigned leadership, locals felt that they were significantly more in control of the conversation, $M = 4.33$, $SD = 1.34$ than when the remote user was assigned leadership, $M = 3.40$, $SD = 1.31$, $F(1, 34) = 9.81$, $p = .004$, $\eta_p{}^2 = .224$, regardless of the relative height of the telepresence robot. Locals who were assigned leadership felt marginally more relaxed $M = 5.78$, $SE = .289$ than those that interacted with a remote who was assigned a leadership $M = 4.97$, $SE = .297$, $F(1, 34) = 3.70$, $p = .063$, $\eta_p{}^2 = .098$. We found no significant effects of the relative height of the telepresence robot or of assigned role on the participant's feelings about the negotiation. We found no main effects for the relative height of the telepresence robot or for assigned role on the measures for agreement in the Desert Survival Task. We also found no significant effects of the relative height of the robot or assigned role in the Ultimatum Task on what the participant chose as a split in their first or second proposals or on whether or not the participant chose to accept the unfair split in the last round of the task. In contrast, we found a marginal effect of assigned role on the ratio of time spent looking at the other person while speaking. When the remote user was assigned leadership, locals spent more time looking at the remote user when speaking $M = .252$, $SD = .149$ than when the local was assigned leadership $M = .181$, $SD = .096$, $F(1, 33) = 2.98$, $p = .094$, $\eta_p{}^2 = .083$. There were no significant effects for the relative height of telepresence robot or for assigned role in the amount of time spent listening, the ratio of looking at the other person while listening, or the number of times that locals attempted to interrupt the remote user.

Hypothesis 3 predicted that local participants interacting with a remote that was using a shorter telepresence robot would exhibit more dominance, regardless of their assigned role, than those who interacted with a remote that was using a taller telepresence robot. Our results showed support for this hypothesis. We found a significant interaction effect between the relative height of the telepresence robot and assigned role, $F(1, 35) = 4.17$, $p = .049$, $\eta_p^2 = .107$ in the Desert Survival Task. Post-hoc analyses revealed that height only had an effect when the remote user was assigned the leadership role, $F(1, 35) = 6.68$, $p = .014$, $\eta_p^2 = .160$; locals were more persuaded by remote users who were assigned leadership and who were using a taller telepresence robot, $M = 4.80$, $SD = 3.29$, than locals who interacted with remote users who were assigned leadership and who were using a shorter telepresence robot, $M = 9.60$, $SD = 7.65$ (Figure 4.3). When the local was assigned leadership, the relative height of the robot did not have a significant effect, $F(1, 35) = 0.094$, $p = .762$, $\eta_p^2 = .003$.

In addition, we also found a marginal interaction effect between the relative height of the telepresence robot and assigned role on how well the interaction built a foundation for a future relationship with the remote user, $F(1, 35) = 6.86$, $p = .062$, $\eta_p^2 = .096$. Post-hoc analyses (using the Bonferroni correction) revealed that height only had an effect when the participant was leader, $F(1, 35) = 3.73$, $p = .061$, $\eta_p^2 = .096$. Local leaders tended to feel that the interaction built a better foundation for a future relationship when the remote user was using a shorter telepresence robot $M = 5.66$, $SD = 3.85$, than when the remote was using a taller telepresence robot $M = 4.84$, $SD = 3.85$. When the remote was leader, height did not have a significant effect, $F(1, 35) = .63$, $p = .433$, $\eta_p^2 = .018$.

4.5 Discussion

The results provided limited support for Hypothesis 1; when using a shorter telepresence robot, local participants in leadership roles would exhibit the most dominance. We found no support for Hypothesis 2; when using a taller telepresence robot, local participants in follower roles would show the least dominance. However, when using a shorter telepresence robot, local participants exhibited more dominance, regardless of their assigned role, than those who used a taller telepresence robot, providing support for Hypothesis 3.

We found that locals felt better about themselves and showed more dominance by taking more speaking time (as opposed to listening time) when the remote used a shorter telepresence robot and felt more in control of the conversation when assigned leadership, regardless of the robot's height. However, locals who were assigned a follower role exhibited more dominant behavior in the form of higher ratios of gaze while speaking. Our results also highlight that locals found the remote to be the least persuasive when the remote used a shorter telepresence robot while being in a leadership role. Further analysis may provide insight into why locals had such an adverse reaction to the remote in this condition.

Based on our results, we speculate that when locals were assigned leadership and interacted with a remote who used a shorter telepresence robot, the local's role was reinforced by his or her superior height. Conversely, when assigned a follower role and interacting with a remote who used a taller telepresence robot, the local's role was reinforced by his or her inferior height. However, when interacting with a remote who was assigned leadership while using a shorter telepresence robot, the disparity between the local's assigned role and his or her greater height may have created cognitive dissonance. This dissonance may have triggered more aggressive behaviors in participants, which may explain why locals exhibited more dominance by spending more time speaking than listening to the remote when they were assigned a follower role. Additionally, in our qualitative observations, we noted that locals who interacted with a remote in a leadership role using a shorter telepresence robot spent more time leaning toward the robot in an open and aggressive posture than in any other condition. In taking this type of posture, participants may have triggered short-term physiological changes, making them less agreeable to negotiation [22].

An alternative explanation may be that adults are accustomed to interacting with shorter people, such as children, using an authoritative stance. Communicating via a shorter system, similar in height to that of a child, may have triggered behavior or strategies for interacting with children, who may be aggressive in trying to persuade others.

4.5.1 Design Implications

Although our results found that interacting with a taller telepresence robot had no effect in either assigned role, they highlighted the potential negative effects that height might play on a remote user's influence when he or she is in a position of power. These effects are of particular importance in contexts where the remote's ability to exert authority are critical to the success of the interaction, such as in businesses where employers are using telepresence robots to stay in contact with their employees, in interactions where negotiation is a key factor, in educational settings where the teacher is using a telepresence robot to teach while maintaining control of the classroom, and in medical settings where doctors are prescribing treatment plans for patients. As a result, those designing robotic telepresence systems should be aware of who the potential users of the system are and what their roles may be. For example, if a system is intended for use by remote team members in collaborative tasks, designers may choose to create a shorter system to increase how positive the local users feel about interactions with the remote user. However, if systems are expensive and will be reserved for use by company executives in negotiations or by specialists such as doctors, designers may prefer to create taller systems that can aid remote users in persuading locals to follow their lead.

4.5.2 Limitations

The study presented here has several limitations that may decrease the generalizability of our results. First, the lack of support for our hypotheses in the Ultimatum Task may have stemmed from positioning it after the Desert Survival Task. In previous studies [46, 183], the Ultimatum Task was an independent exercise. Asking the participant to interact with the confederate in a negotiation that requires consensus prior to engaging in the Ultimatum Task might have established a cooperative relationship between the local and the remote, leading to a tendency toward fairness and compromise.

In addition, our inability to match our questionnaire items with the dimensions defined by previous work and the results of our confirmatory factor analysis indicate that these measures may not translate directly from human communication research to robot-mediated communication. More work should be done to further disentangle the subjective effects that the height of the telepresence robot has on the local-remote relationship.

Last, the system that we used for the study forced some physical limitations on how much we were able to adjust for height. For example, during the study, several participants commented on the inability to tilt the screen to an angle appropriate to the system's height. Due to physical stability issues associated with increasing the center of mass, we were unable to increase the height of the robot to investigate differences in the perceptions of the local between seated and standing positions. We were also unable to move the camera on the robot closer to where the confederate appeared on the screen, making it difficult for participants to feel that they were able to maintain eye contact.

4.5.3 Future Work

Further studies in this domain may increase the generalizability of our results by examining how the short-term effects of height may evolve over time, how previous contact with the remote may mediate the local's reaction to the height of the system, and how allowing the remote to adjust his or her height may change local user perceptions. Additionally, modifying the angle of the screen may increase the impact that the height of the system has on the relationship between users. Examining the interaction between two non-confederate users in a dyadic study may offer other insights into the repercussions that the height of the system and thus the physical representation of the remote might have in working relationships.

Additional work must also be done to further untangle how other aspects of system appearance might change the dynamics between collaborators. Further work in the proportions of the system, the dimensionality of the remote's representation (e.g., a flat screen, multiple screens oriented in different directions, projected onto a sphere), and the fluidity of the system's movements may reveal additional factors that will influence the design and use of future systems.

4.6 Conclusion

Many aspects of physical appearance have been shown to change how an individual is perceived, judged, and treated by others. One of these characteristics shown to have a prominent effect is height. Robotic telepresence systems that extend a remote user's presence through a robotic representation are unique in that designers are able to choose the height and appearance of the system. However, many of the systems that are currently being used have been designed to place remote users at an arbitrary height relative to that of the local users with minimal consideration of how the local-remote relationship might be affected.

In our study, we assigned the role of either a leader or a follower to participants and explored how manipulating the relative height of the telepresence robot to be shorter or taller than the participant reinforced or undermined his or her authority. We found that locals felt that the remote was less persuasive when using a shorter telepresence robot and playing a leadership role. Locals also exhibited more dominance in terms of how much time they spent speaking (vs. listening) and experienced an increase in self-esteem when interacting with a remote using a shorter telepresence robot. In addition, locals in leadership roles felt that they had greater control over the conversation. However, locals in follower roles exhibited greater dominance by looking at the other person more while speaking. While the results presented in this paper are limited to short-term interactions, they provide evidence that the height of robotic telepresence systems may shape interactions between remote and local users. These results inform the design of current and future systems and reinforce the importance of considering not just the feature of embodiment, but also the variables that compose it when designing robotic communication systems.

5 | Visual and Verbal Framing

As geographically distributed collaboration becomes more commonplace, workplaces have been challenged to find ways of coordinating communication to ensure effective team outcomes. The productivity of group activity has been attributed to factors such as access to the communication behaviors of participants [178], knowledge of the environment and context of the situation [116], and a sense of membership within the organization [11]. Past approaches to facilitating geographically distributed teamwork have ranged from text-based communication to high-fidelity group videoconferencing.

While the physical embodiment of telepresence robots provide a physical representation of the remote user, opening up new design opportunities, it also has the potential to interpose barriers between users.

In this section, we studied how the physical presence of the telepresence robot affected the team dynamic between the local and remote users, as well as the impact this may have on collaborative work outcomes. In particular, we explored how the relationship between remote and local users might be manipulated to increase the local user's feelings of in-group membership with the remote. To do this, we applied two different theoretical methods. In the first method, we used the physical embodiment of the system to improve the local user's perceptions of the remote through the use of visual framing and self-extension [12, 55, 106, 149]. The second method focused on the relationship between the local and the remote as group members, verbally manipulating the framing of the remote user within the context of the team [164].

The next section outlines related work to provide background on how the creation and development of in-group identity in other media informed our efforts toward achieving similar outcomes

Figure 5.1: The telepresence robot used in our study shown with a participant.

with robotic telepresence systems.

5.1 Related Work

In organizations, the dynamics of group effectiveness are complex and influenced by a number of factors including access to communication behaviors of participants [178], awareness of the environment or context of the situation [116], and sense of membership within the organization [11].

Group cohesion is associated with promoting cooperation between group members, increased instances of people helping and training each other within the team, and improved productivity [11, 116]. In addition, groups with strong feelings of identity and membership tend to self-regulate, lessening the need for direct supervision and working more flexibly to resolve problems [11]. Conversely, the lack of group cohesion can sabotage organizational and team dynamics. People have been shown to be less cooperative and less trusting of those that they feel are out-group, and to deprive people that they do not identify with of positive consequences, acting against them [165].

Video-mediated communication systems support geographically distributed collaboration by enabling communicative behaviors through audio and video channels. Recent forms of these systems include movable [109] or multi-viewpoint directional displays [114]. Other systems improve knowledge of the environment and situational context through the use of immersive media spaces [91]. Each of these systems has treated the medium as a tool, using advances in technology to improve communication bandwidth. However, these studies have not considered leveraging the medium to promote a sense of membership between remote team members, shown to be integral to the success of collaborative work outcomes.

Robot-mediated communication offer the potential for designers or users to promote feelings of group membership by modifying variables in the physical embodiment of the system or the interface. These promotions of group membership are particularly important in geographically distributed teams, where remote members often have difficulty with participating in work and social settings [155, 166].

Work on both human–human and human–computer interaction has shown *framing*—the presentation of information to encourage particular interpretations—to be effective in changing people's decisions [164] and their perceptions of others. For example, in studies where an opponent was *verbally framed* as a human as opposed to a computer [118], where a robot was presented as autonomous versus as being remote controlled [181], or where participants were told before the interaction that their performance would be evaluated as a team (*interdependently*) or independently [112], the choice of framing had a significant effect on attitudes and behaviors toward the entity being framed.

In other examples, research in personality has shown that the use of *visual framing*, such as through the design and customization of objects, can increase group identity, improve judgments of the ease-of-use of an item, and promote *self-extension*—the feeling that a possession has meaning associated with a person's self-identity [12, 106]. These effects extend to objects or machines that have the ability to move autonomously or without the control of the person customizing them [55,

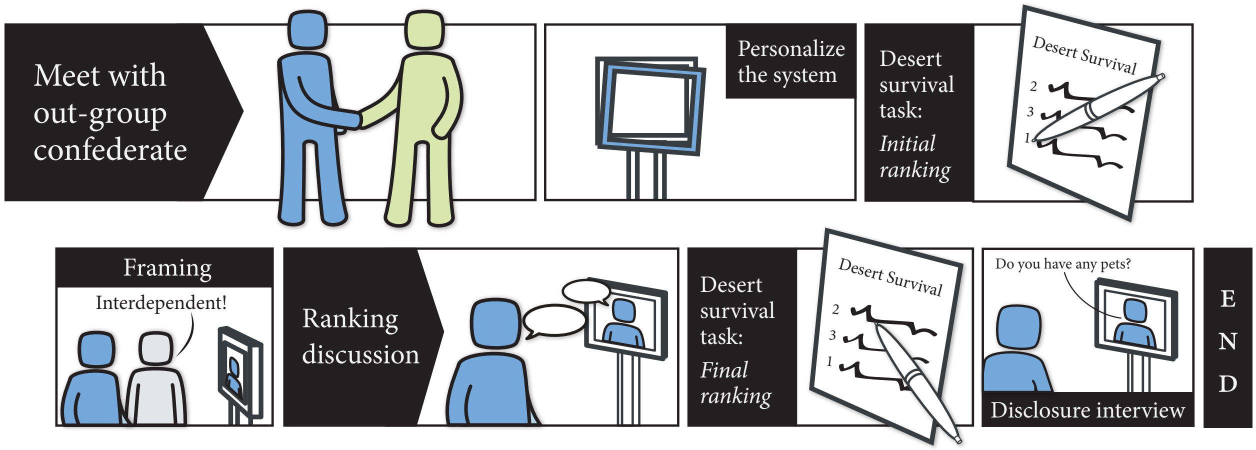

Figure 5.2: Storyboard of study procedure, depicting a participant's experience in the personalize and interdependent condition.

149].

In this section, we build on the concept that verbal and visual framing can be effective ways to manipulate perceptions by examining the effect framing has on the relationship between local and remote users of telepresence robots. In our study, we employed a *verbal framing* variable and a *visual framing* variable to cultivate feelings of in-group identity and improve group cohesion with the goal of optimizing collaborative task outcomes.

In the next section, we present our research hypotheses and methodology, including both a pilot test and full laboratory experiment.

5.2 Hypotheses

We formulated our hypotheses based on previous work that focused on creating a sense of in-group identity between humans and computers [112]:

Hypothesis 1. Participants will perceive the remote user as more similar to themselves and as more trustworthy, exhibiting more signs of group identity through greater disclosure and more agreement when the remote is introduced with interdependent verbal framing as opposed to individual verbal framing.

Hypothesis 2. Participants will perceive the remote user as more similar to themselves and as more trustworthy, exhibiting more signs of group identity through greater disclosure and more agreement when the system has been visually framed (decorated) by the participant than they will if the system is not visually framed.

5.3 Method

We conducted a laboratory experiment to test these hypotheses and, due to the lack of previous work on robotic telepresence systems, we performed an extended pilot test to form a methodological basis for our experiment. This pilot test was based on related research in the fields of human–computer interaction, computer-mediated communication, and human–robot interaction. We used our observations from the pilot test as a guide for our final experimental design. Below we describe how the pilot test influenced each aspect of our study procedure.

5.3.1 Experiment Procedure

Participants were met at the lobby of Willow Garage by the experimenter and led to the room in which the study took place. There, the participant was introduced to an *out-group confederate*, who identified himself by name and stated that he was also participating in the study. This confederate's role was to provide an out-group member to compare against for an infrahumanization test in the experiment questionnaire. The experimenter explained to both the participant and the out-group confederate that there were two teams, a "blue team" and a "green team". The experimenter then told the participant that he/she was on the blue team, that the out-group confederate was on the green team, and that the teams would be separated. At that point, the experimenter led the out-group confederate out of the room. When the experimenter returned to the room, she had the participant complete a consent form.

After filling out the consent form, the experimenter instructed the participant on the Desert Survival Task (described in greater detail in our study measures) and asked the participant to perform an initial ranking of items in three minutes. Once completed, the experimenter introduced the participant to an *in-group confederate* who was logged in as the remote user of the telepresence robot. The participant and the in-group confederate then engaged in a ten minute discussion of their individual rankings of the Desert Survival Task items. After the participant and the confederate had concluded their discussion, the in-group remote confederate exited the room and the experimenter asked the participant to do a second, three minute, final ranking of the task items. The participant then filled out a questionnaire, described in greater detail in our study measures. Following the questionnaire, the experimenter re-introduced the confederate (still logged into the telepresence robot) to the room and gave the participant a list of questions. The experimenter told both the confederate and the participant that they would be engaging in an untimed "getting to know you" (disclosure) task and that they had each received a list of questions, one odd numbered, one even numbered. They were instructed to alternate asking each other these questions after the experimenter left the room and to inform her when finished. After the disclosure task was complete, the confederate drove the telepresence robot out of the room and the participant was debriefed.

A full list of the disclosure task questions is available in Appendix A.2 and a diagram of the full procedure is shown in Figure 5.2.

Modifications From Pilot Test. In pilot tests, two participants guessed that the pilot was a confederate. To counter this, we added a white backdrop to remove environmental cues. In addition, we found during the pilot test that some participants had taken an inordinately long time to rank the desert survival items and to discuss their rankings with the confederate; therefore, we found it necessary to add time limits to both the ranking and discussion portions of the Desert Survival Task.

5.3.2 Experiment Design

We used a telepresence robot with a touch screen mounted on a mobile platform, standing at approximately 1.58 meters or 5′ 2″ tall, as shown in Figure 5.1. If the participant was in the visual framing manipulation, immediately after completion of the consent form the experimenter gave the participant three items in the blue team's colors to use as decorations on the telepresence robot:

a rectangular frame to be placed on the screen, a chest shaped body piece, and a magnetic name tag (see Figure 5.3). We positioned the telepresence robot in the hallway outside of the experiment room, asked the participant to write the *in-group remote confederate's* name on the name tag and had him/her personalize the placement of the decorative pieces on the telepresence robot. After the participant finished placing the decorations, we asked him/her to return to the experiment room and continued by instructing him/her on the Desert Survival Task.

If the participant was in the interdependent framing condition, the experimenter explained that performance on the Desert Survival Task would be evaluated as a team. If the participant was in the independent framing condition, the experimenter explained that performance on the Desert Survival Task would be evaluated independently. During the study, participants interacted with two separate confederates, the *in-group remote confederate* who was on their team and an *out-group confederate* who they were told was on the opposite team.

Modifications From Pilot Test. Because of the lack of related work in the field of robot-mediated communication, we conducted a pilot test based on six different methods, each of which was informed by the manipulations used in previous studies on feelings of group identity or self-extension. Three of these methods sought to foster a sense of self-extension toward the embodied system through the use of visual framing or design elements and three attempted to build a stronger sense of group identity through the use of verbal framing. A total of 17 participants were pilot tested and three were eliminated, two due to a technical failure and one after guessing that the pilot was a confederate, leaving a total of two participants per condition ($n = 14$).

- **Visual framing.** In Nass et al.'s study on creating a sense of team identity with a computer, people were found to act more collaboratively toward a computer visually framed with colored bands that matched the participant's group color [112]. We sought to create a similar manipulation by pre-decorating the telepresence robot in colors matching the participant's group, illustrated in Figure 5.3b. In this condition the procedure was the same as that of the full experiment and the telepresence robot was pre-decorated in blue.

- **Visual framing through self-extension.** Blom & Monk [12] found that the personalization of mobile phones and web portals led to a feeling of self-extension among participants. In this condition, we strengthened the visual framing manipulation by allowing people to choose where to place the colored markers, "personalizing" the system. Our goal was to create a sense of self-extension while limiting the level of customization to avoid possible confounds. In this condition, prior to being instructed on the Desert Survival Task, we gave participants the blue decorations and asked them to place them on the system, as shown in Figure 5.3a.

- **Mimicry.** This condition was based on studies on mimicry [6] and the person-positivity bias [135] that concluded that similarity to an individual produces more trust and liking. In the case of the telepresence robot, creating human-like movement was an attempt to de-mechanize the appearance of the system, making it more similar to the participant. In this condition, the procedure was identical to that of the full experiment, but during both the desert survival and the disclosure tasks the remote confederate rotated the telepresence to the right and left by a small degree when stationary.

- **Choice.** Demoulin et al. found that participants given a choice of what team they were on had a greater sense of team identity and favored their team members more than those who were assigned a team [35]. To reproduce this manipulation, we allowed the participant to choose his/her team color. In this condition, we asked participants which team they wanted to be on after informing them of the two team colors. We assigned the out-group confederate to the opposite group.

- **Individuality.** In his work on the person-positivity bias, Sears found that verbal framing of professors and politicians resulted in more positive or negative evaluations. When presented as individuals, professors and politicians received more positive evaluations than when presented as an aggregate. This result supported Sears's hypothesis that the more an entity resembles an individual person, the more positively people are inclined to judge it [135]. We similarly attempted to verbally frame the remote confederate as an individual by providing details on her interests. In this condition, when the confederate was introduced, we told the participant "Your teammate will be [name], and she enjoys reading fiction novels, baking, and swimming. She said that she would one day like to bake the perfect cake."

- **Interdependency.** Nass et al.'s study on creating a sense of team identity with a computer found that when participants were told that their performance would be dependent on how well they did as a team, their levels of cooperation and trust increased [112]. We replicated this by telling participants that they would be evaluated as a team. In this condition, when we instructed the participant on the Desert Survival Task the experimenter told the participant that their evaluation would be interdependent with that of the pilot.

- **Neutral.** No manipulation of design or framing were used in this condition to serve as a control.

Using our observations of this pilot test, we determined that the visual framing through self-extension and the verbal framing manipulations were the most promising, as they nominally demonstrated the largest effects. The similarity of our pilot test results to Nass et al.'s experiment in building team identity between participants and computers [112] was also a factor in our choice of manipulations. The final experiment design involved a 2 (visual framing: no personalization vs. personalization) $\times 2$ (verbal framing: individual vs. interdependent) between-participants manipulation, as illustrated in Figure 5.4.

5.3.3 Participants

Forty adults $n = 40$, gender balanced, whose ages ranged between 18 and 82 years, $M = 34.8$, $SD = 15.8$, volunteered to participate. They were recruited via a local university's online bulletin board, postings at two local newspapers, word of mouth from participants of previous studies, and posters placed around the neighborhood. Participants reported that on average they were somewhat familiar with robots, $M = 3.05$, $SD = 1.77$ (1 = not very familiar; 7 = very familiar), and were compensated $20 for each hour of their participation.

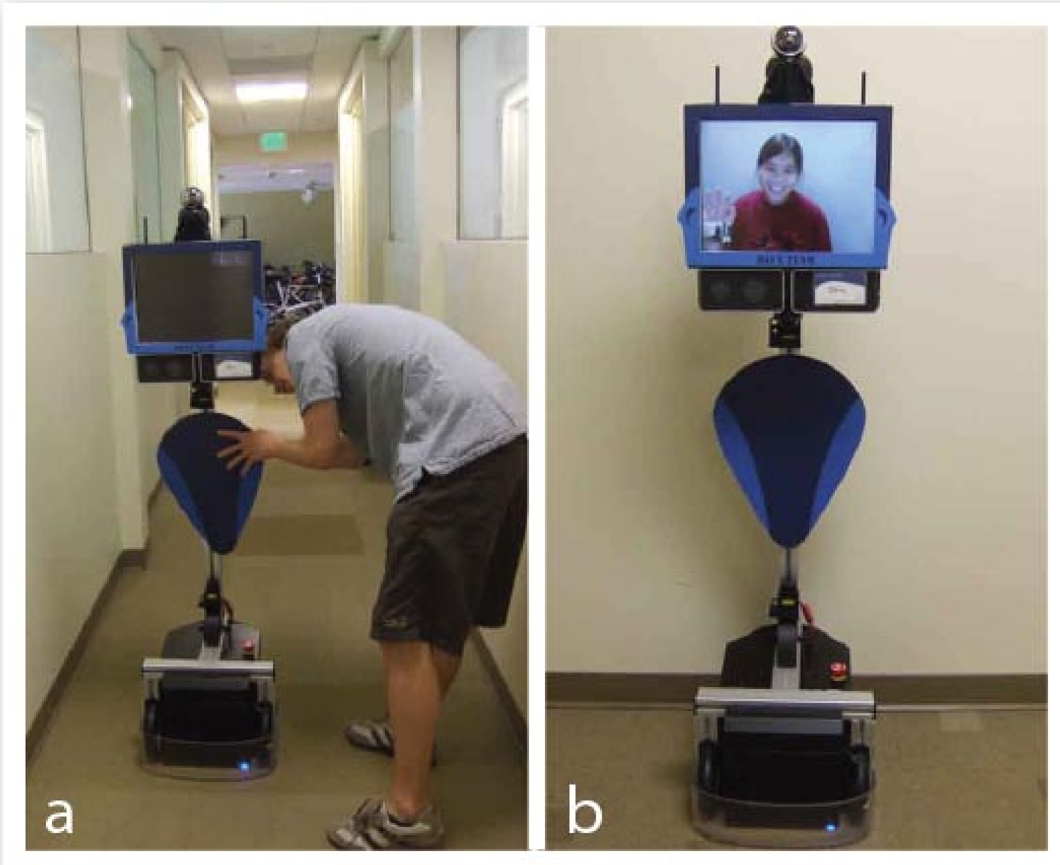

Figure 5.3: The telepresence robot (a) being decorated and (b) with decorations on.

5.3.4 Measures

The measures we used for the study included video footage taken with a single camera of the personalization session, the Desert Survival Task, and the disclosure interview. We also collected attitudinal data using a three-part questionnaire and included a demographic information survey.

Desert Survival Task Rankings

The Desert Survival Task [84] is a collaborative decision-making task, modified from the original design to include items that would be relevant to a present-day survival situation. Participants were provided with a written scenario of a bus crash in the desert and were asked to do an initial ranking of nine items in order of their importance for survival. The list of items included (1) a map of New

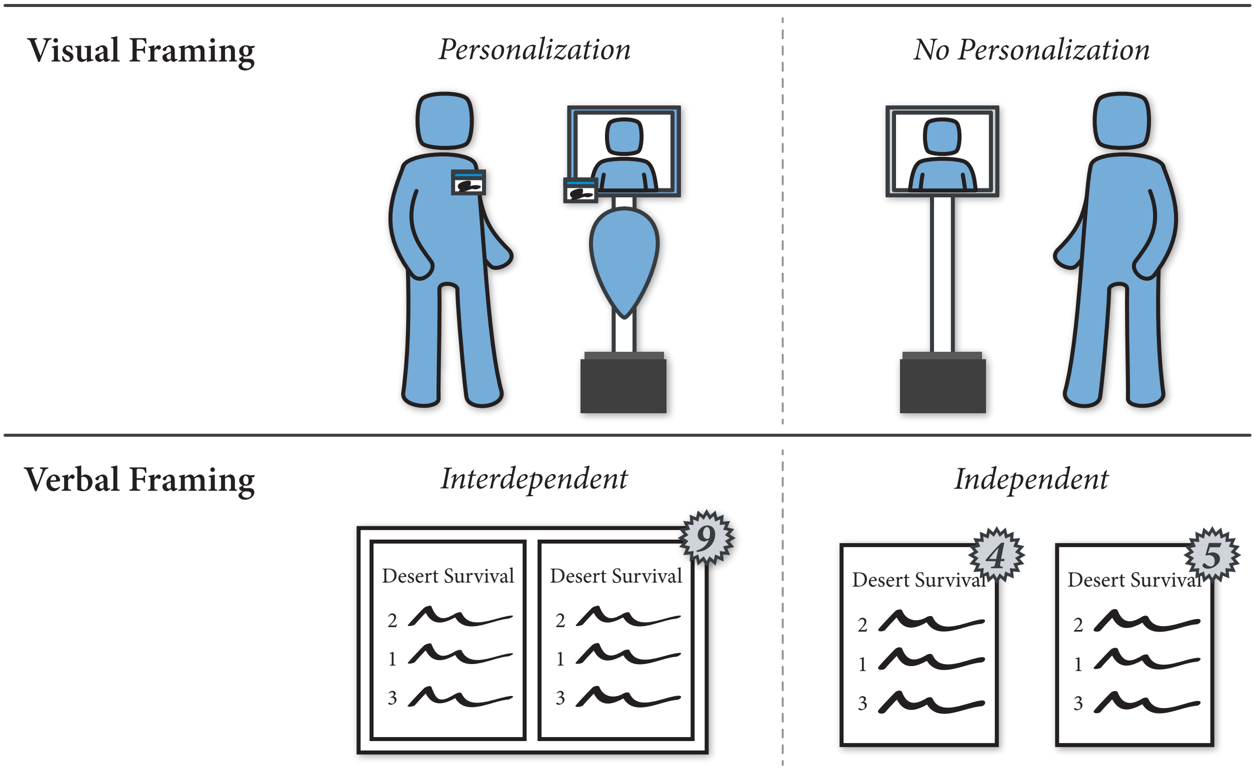

Figure 5.4: Diagram of study design conditions.

Mexico, (2) the book "Edible Animals of the Desert," (3) duct tape, (4) first aid kit, (5) cosmetic mirror, (6) flashlight (four-battery size), (7) magnetic compass, (8) one 2-quart flask per person that is full of 180 proof vodka, and (9) one plastic raincoat per person.

We chose the Desert Survival Task primarily because it was used in Nass et al.'s study on creating a sense of team identity between a participant and a computer [112] and because it has been validated and tested for reliability. Related work has also used the Desert Survival Task as a measure of team alignment and agreement, both because participants are inclined to believe that they should be good at the task and because a large amount of variance is regularly found in the ratings. After the initial ranking, the confederate and the participant discussed the differences in their orderings. For this discussion, we created a set of rankings for the confederate that would be consistently different across participants using an algorithm based on previous work [84], (see Appendix A.2). After the discussion, we asked participants to re-rank the nine items to create a final ranking.

Modifications From Pilot Test. In the pilot test, we used 12 items in the Desert Survival Task; however, we found that participants were spending a great deal of time ranking the items and there was confusion on what some of the items were, so we removed three from the task, resulting in a total of nine. In addition, we added a time limit of three minutes to perform rankings and of ten minutes for the discussion.

Questionnaires

Our questionnaire was split into three sections. In the first section we used the assessment of perceived homophily, developed and validated by McCroskey et al. [94], to measure how similar the participant felt that the confederate was to himself or herself. This test consisted of nine adjective pairs (e.g., "similar to me vs. different from me" and "from a social class similar to mine vs. from a social class different from mine"), each in a seven-point semantic differential scale.

In the second section of the questionnaire we used the interpersonal solidarity measure, developed and validated by Wheeless [177], to measure how trustworthy the participant felt that the confederate was. This consisted of 23 statements (e.g., "This person has a great deal of influence over my behavior." and "We share a lot in common."), each paired with a seven-point ranking scale to indicate level of agreement ranging from 1 (strongly disagree) to 7 (strongly agree).

We based the third section of the questionnaire on measures used in studies of infrahumanization—the belief that members of one's group are more human than those outside of it [31, 35, 135, 165, 169]. This section consisted of two pages and was informed by the tests used in related infrahumanization work [31, 35, 165, 169]. Both pages included the following directions: "For the person listed on the left, draw lines connecting him/her with 8–10 words on the right that you think he/she may experience in a given day." Each page had sixteen words listed on the right side. These words were chosen from prior work that categorized and validated them as either primary (non-uniquely human) emotions (e.g., attraction, desire, excitement, pleasure, agitation, anger, fear, rage), or secondary (uniquely human) emotions (e.g., regret, disappointment, compassion, love, hope, admiration, bitterness, enthusiasm). The left side of the first page showed the name of the in-group remote confederate and their team identification (*blue* team). The left side of the second page showed the name of the out-group confederate and their team identification (*green* team).

Modifications From Pilot Test. During our initial observations of these measures in the pilot test we found that the response to all three sections was promising, thus we kept all three sections. In our final questionnaire we added questions about the name of the in-group confederate and the team color as manipulation checks.

Disclosure Interview

The disclosure questions were developed and selected from related work that employed the disclosure task to test trust and group identity [30, 102, 156]. Similar to these previous studies, questions were asked on a gradually increasing scale of intimacy and the participant and in-group remote confederate alternated asking questions. The confederate's responses to the questions were scripted (see Appendix A.1 for the questions used in the study).

Modifications From Pilot Test. In our initial pilot test the disclosure task was a one-sided interview in which the confederate asked the participant questions and the participant responded. Feedback from the participants and our observations led to our changing the disclosure task to be two-sided, with the participant and confederate taking turns to ask questions.

5.3.5 Analyses

For the Desert Survival Task, we calculated Spearman's ρ—a rank-order correlation—to assess the similarity between the participant's final rankings and the confederate's rankings. This measure captured how much the participant changed his/her rankings to align more closely with those of the confederate. The distribution for our data from this measure showed a positive skew; therefore, we used Tukey's ladder of powers to take a $\log_{10}$ transformation of the dependent variable. Finally, we used an analysis of variance (ANOVA) to analyze the effects of personalization and framing (independent variables) on how much the participant aligned his or her final rankings to match the confederate's rankings (dependent variable).

The video data from the disclosure interview was transcribed and analyzed for the degree of self-disclosure, consistent with previous self-disclosure studies [30, 102, 156]. The breadth of disclosure was measured by the length of responses through word count and compared using an ANOVA.

We used an analysis of covariance (ANCOVA) to identify differences across conditions in each of the three sections of the questionnaire data.

5.4 Results

The results of our data analyses showed that verbal framing of the situation as interdependent had a positive effect on performance ratings and group cohesion, which was consistent with the first hypothesis. However, we also found that visual framing of the telepresence robot had a negative effect, going in the opposite direction of our second hypothesis. All of the statistically significant results are shown in Figure 5.5.

5.4.1 Behavioral Measures

Decision making

In the collaborative decision making task, we found a trend of participants aligning to the confederate's scores less when the system was visually framed, but this effect was not significant at $p < .05$. Participants who did not have a visually framed telepresence robot tended to move their final decisions closer to the in-group confederate's, $M = \log(0.75)$, $SE = 0.12$, than participants in the visual framing through self-extension condition, $M = \log(0.65)$, $SE = 0.12$, $F(1, 36) = 2.83$, $p = .10$, $\eta_p{}^2 = .073$.

Disclosure

In the disclosure interview, participants who were told that performance would be interdependent with their teammate's performance disclosed more to the confederate, providing longer responses—

measured by word count ($M = 530$, $SD = 284$)—than participants who were told that their performance would be judged independently ($M = 357$, $SD = 184$, $F(1, 35) = 4.85$, $p = .034$, $\eta_p^2 = .12$).

5.4.2 Attitudinal Measures

Perceived Homophily

Our analysis of the first section of questionnaire data, which controlled for video-game experience[1] in all tests, showed several main effects that approached, but did not reach significance. Participants who did not participate in the visual framing condition seemed more likely to report that they and the confederate worked well together, $M = 6.05$, $SD = 1.15$, than those who adorned the robot with team colors in the visual framing through self-extension condition, $M = 5.30$, $SD = 1.42$, $F(1, 35) = 3.80$, $p = .059$, $\eta_p^2 = 0.098$. Participants who did not participate in the visual framing condition also seemed to show a tendency toward feeling that the confederate was more similar to them, $M = 5.05$, $SD = 1.23$, than participants in the visual framing through self-extension condition, $M = 4.35$, $SD = 1.46$, $F(1, 35) = 3.48$, $p = .070$, $\eta_p^2 = .091$.

Interpersonal Solidarity

In the second section of the questionnaire, controlling for video game experience, we found that participants who did not participate in the visual framing condition were more interested in interacting with the confederate outside of the study, $M = 5.35$, $SD = 0.88$, than those who decorated the system in the visual framing through self-extension condition, $M = 4.65$, $SD = 1.14$, $F(1, 35) = 4.65$, $p = .038$, $\eta_p^2 = .12$. Participants using a system that was not visually framed also made more of an effort to cooperate with the confederate, $M = 6.45$, $SD = 0.61$, than participants who personalized the system did, $M = 6.05$, $SD = 0.39$, $F(1, 35) = 5.68$, $p = .023$, $\eta_p^2 = .14$.

[1]Video-game experience significantly correlates with people's perceptions of robots, as suggested by our previous research [108].

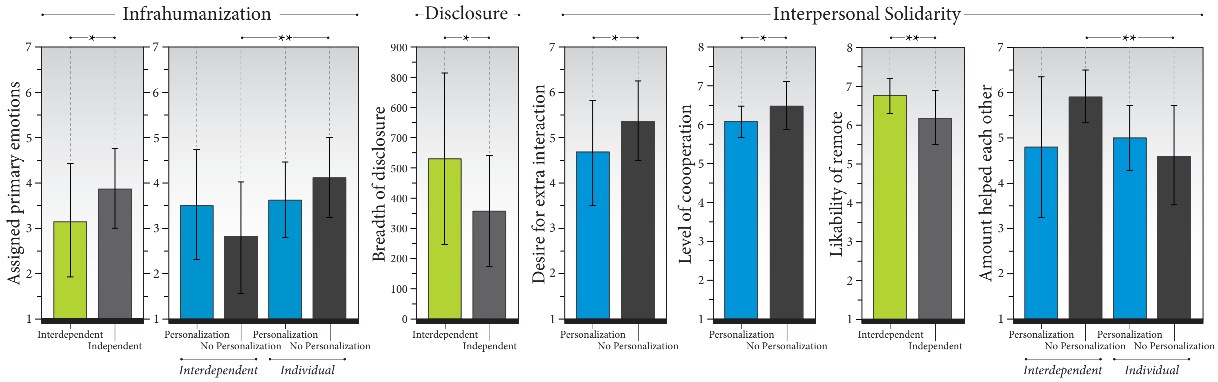

Figure 5.5: Results from the infrahumanization, disclosure, and interpersonal solidarity measures. (*) and (**) denotes $p < .05$ and $p < .01$, respectively.

In contrast, participants who were told that evaluation of their performance was interdependent with that of the confederate's liked their teammate more, $M = 6.75$, $SD = 0.44$, than those who were told that their performance would be evaluated individually, $M = 6.20$, $SD = 0.70$, $F(1, 35) = 8.10$, $p = .007$, $\eta_p{}^2 = .19$.

Controlling for videogame experience, there was also an interaction effect between visual framing through self-extension and interdependence, $F(1, 34) = 4.40$, $p = .043$, $\eta_p{}^2 = .12$. For participants who did not decorate the telepresence robot in the visual framing condition, having interdependent scores made them feel more like they and the confederate did helpful things for each other, $M = 5.90$, $SD = 0.57$, than when their scores were verbally framed as being evaluated individually, $M = 4.60$, $SD = 1.08$, $F(1, 17) = 11.05$, $p = .004$, $\eta_p{}^2 = .39$. For participants who decorated the system in the visual framing condition, having interdependent vs. individual scores did not significantly influence how much they felt that they and the confederate did helpful things for each other, $F(1, 16) = 0.16$, $p = .69$, $\eta_p{}^2 = .010$.

We also found several other marginal main effects, which approached, but did not reach significance at the $p < .05$ level. Participants with scores verbally framed as being judged interdependently with their teammate's scores appeared to cooperate more, $M = 6.40$, $SD = 0.50$, than those with individually framed scores, $M = 6.10$, $SD = 0.55$, $F(1, 35) = 3.63$, $p = .065$, $\eta_p{}^2 = .094$. Those who did not decorate the system in the visual framing through self-extension condition seemed to feel that they and the confederate understood each other more, $M = 5.75$, $SD = 0.97$, than those who did, $M = 5.05$, $SD = 1.36$, $F(1, 35) = 3.82$, $p = .059$, $\eta_p^2 = .098$. In addition, those who did not participate in the visual framing through self-extension condition seemed to feel that they had more in common with the confederate, $M = 4.90$, $SD = 0.91$, than those who did participate in the visual framing through self-extension, $M = 4.22$, $SD = 1.22$, $F(1, 33) = 3.79$, $p = .060$, $\eta_p^2 = .10$.

Infrahumanization

In the test for infrahumanization, controlling for video game experience across conditions, we found a main effect for verbal framing. Participants assigned more primary, non-uniquely human emotions to the confederate when told that performance was judged individually $M = 3.85$, $SD = 0.88$, than participants who were told that they would be judged interdependently, $M = 3.15$, $SD = 1.23$, $F(1, 35) = 4.32$, $p = .045$, $\eta_p^2 = .11$. This indicates that participants who believed that performance would be judged individually felt that the confederate was less human than those who believed that judgment of performance would be evaluated interdependently with their teammate's performance.

We also found an interaction effect between visual framing and verbal framing conditions. For participants not in the visual framing through self-extension condition, having individual scores caused them to assign more primary or non-uniquely human emotions to the confederate on average, $M = 4.10$, $SD = 0.88$, than having interdependent scores, $M = 2.80$, $SD = 1.23$, $F(1, 17) = 16.1$, $p = .001$, $\eta_p^2 = .49$. For participants for whom the system was visually framed through self-extension, having interdependent vs. individual scores did not significantly influence how many primary or non-uniquely human emotions they assigned to the confederate, $F(1, 17) = 0.07$, $p = .79$, $\eta_p^2 = .004$.

5.5 Discussion

When the confederate's presence was verbally framed by instructing the participants that their performance would be interdependent with their teammate's, participants liked the confederate more and offered greater breadth of disclosure, showing more willingness to talk to the confederate. They also seemed to feel more cooperative and experienced weaker feelings of infrahumanization toward the confederate, meaning that they thought of the confederate as more human. These results support our first hypothesis.

Our results showed that participants who decorated the telepresence robot in the visual framing through self-extension condition were less inclined to interact with the confederate outside of the study and cooperated less with their teammate. They also tended to be less affected by the confederate's arguments in the Desert Survival Task and seemed to feel that they worked less well together, were less similar, understood each other less, and had less in common, than they did when the telepresence robot was not visually framed. This negative bias toward the confederate using the visually framed telepresence robot is inconsistent with our second hypothesis.

The results also showed that when participants did not personalize the telepresence robot in the visual framing condition and were told that their performance would be interdependent with the out-group confederate's, they felt greater group identity with the confederate and believed that they had helped each other more as a team.

These results are consistent with some aspects of prior work (e.g., [112]); we found that interdependence between the task performances of the locals and the confederates increased in-group behaviors and attitudes. However, some of our results are also inconsistent with previous findings. Visually framing the telepresence robot by decorating it with the team's colors did not encourage the development of in-group behaviors and attitudes and decreased group cohesion and feelings of team identity. This inconsistency with previous research on building group membership with machines [112] and creating a sense of self-extension through personalization [55] suggests a potential disparity between the local user's perception of the telepresence robot as a communication medium and the local's awareness of the system as its own entity.

The negative feelings that people expressed toward the confederate of the visually framed telepresence robot suggests that unlike communication facilitated by computer-mediated communication, robot-mediated platforms, such as telepresence robots, may be perceived as independent entities (see Figure 5.6). In previous work on personalization, people who put a face on an item in the process of customizing it experienced negative feelings of self-extension toward the item; in contrast, those who did not put a face on the item attributed a more positive bias toward it [78]. This negative reaction was attributed to the addition of the face, which was believed to have given the object a new identity as an individual in its own right. In the case of our study, the addition of the decoration step with the visual framing may have created a sense of self-extension or feelings of group identity between the local and the robotic telepresence system. The subsequent materialization of a face on the screen when the remote confederate logged on may have been perceived by the local as the intrusion of an out-group member on the in-group local-system team, thereby soliciting a hostile reaction. This creation of a relationship between the local and the robotic telepresence platform is a factor unique to robot-mediated communication.

In this study, we found that the physical presence of a robot-mediated communication system created a communication dynamic unlike that found in human-computer and computer-mediated communication. While the intricacies of this dynamic have yet to be fully explored, we have taken a first step toward understanding how both visual and verbal framing may impact the perceptions that local users have of the system, thus affecting their subsequent treatment of the remote user. Although we have not yet untangled the full consequences of highlighting or de-emphasizing the physical presence of the robotic telepresence system for the local, it is clear that this unique aspect of robot-mediated communication has a number of implications for future design and research.

5.5.1 Design Implications

For designers of current and future robotic telepresence systems, there is a need to be aware that locals may perceive the telepresence robot as an independent entity and that this may alter their

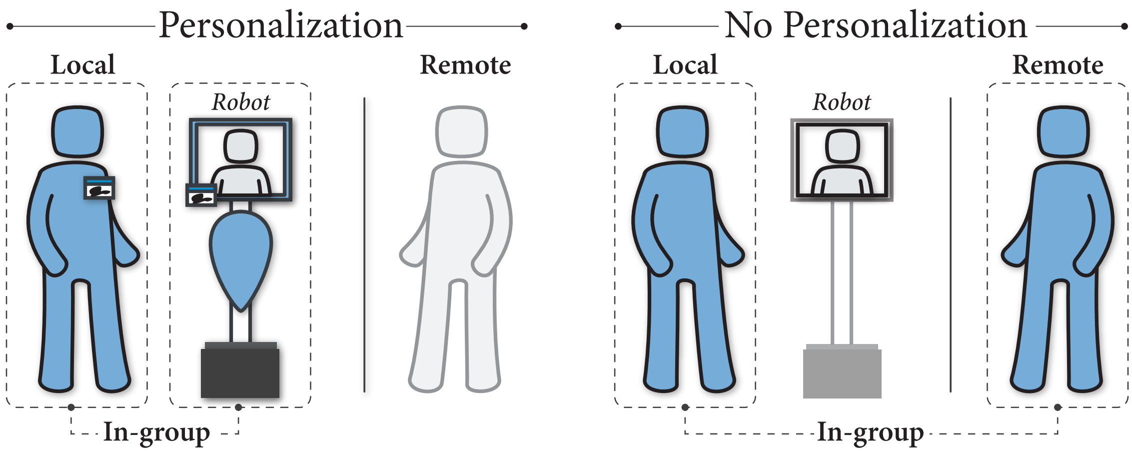

Figure 5.6: Our results suggest that personalization led participants to perceive the telepresence robot as an independent entity, diminishing collaborative outcomes between the local and the remote user.

perceptions of remote users of the system. In fact, although people often customize and personalize their domestic robots [149], this paradigm is not necessarily ideal for mobile mediums that are inhabited and controlled by remote users. A possible solution may be to design the system to be less obtrusive and to highlight the presence of the remote user, de-emphasizing the physicality of the system. Ways of accomplishing this may be to create systems that bear less of a resemblance to humans and are more generic in appearance. Other design heuristics for future robot-mediated communication systems may include avoiding unique markers, actively discouraging decoration of the system by locals, or creating more mechanical physical interfaces; however, these approaches would require further study before implementation to ensure full understanding of their impact.

5.5.2 Organizational Implications

For businesses that use these systems, the importance of verbally framing the remote member as part of the team by reminding locals about the need to work together should not be underestimated. Managers of geographically distributed teams would benefit from communicating to the teams that their job performance will be judged in terms of team performance rather than being based solely on individual contributions. Designers of these systems may also leverage this verbal framing by setting a text reminder of the remote's team identity before or during use.

5.5.3 Research Implications

For research in the field of robot-mediated communication, our study has highlighted one of the critical key differences between other technological solutions and telepresence robots. We have illustrated the importance of considering how the physical presence of telepresence robots may significantly affect collaborative outcomes, ultimately leading to the success or failure of such systems in the future. We have also demonstrated that cultivating in-group identification can be a powerful tool for building successful teams across distances. Because of the unique dynamics between local users, remote users, and the telepresence robot itself, a great deal of further research is required to understand where the boundaries of the relationship between communicative actors lie. We outline a number of these new research questions in the following section.

5.6 Future Work

The nascency of work in the field of robot-mediated communication and robotic telepresence offers potential for further research on the topic and deeper investigations into the interaction between the remote user, the local user, and the local system. The use of a more realistic task, longer exposure to the remote, or repeated exposure to the remote to simulate a real-world work environment may illuminate further differences or uncover changes in behavior toward the remote or the telepresence robot over time. Our findings may also inform the development and use of telepresence robots outside of business environments, such as in remote education or medical settings. Understanding the role of verbal framing may contribute to increased motivation and rapport in such settings, leading to better learning outcomes or increased follow-up by patients in treatment plans.

Further studies into how perceptions of the remote user or of the telepresence robot may be affected by the number of locals present during the interaction, the number of telepresence robots in use, or the number of different remote users that share a system would provide a better understanding of the local user's view. From the remote user's perspective, opportunities for future research include improving the user interfaces of telepresence robots, investigating how the perception of the locals by the remote user might change interaction dynamics, and exploring what the impact might be if the remote user personalized the telepresence robot instead of the locals.

Future work must also strive to untangle how the physicality of the robotic telepresence changes the local-system and local-remote dynamic. For example, would visual framing without self-extension have facilitated more trust and cooperation on the local's side toward the remote user? Would visual framing of the system as more human-like or machine-like have created a different relationship between the local and the system, thus affecting the local's perception and attitude toward the remote user? From the remote user's perspective, the telepresence robot interface is similar to that of a videoconferencing system. How would the dynamic change if both parties were aware of the physical presence of the system? How do other physical characteristics of the telepresence robot such as speed, volume, width, and proportion change behavior toward the system and affect collaborative outcomes? These and many other questions remain to be resolved in future studies and have the potential to not only affect remote collaborators but also to provide mobility challenged individuals with a way to establish spontaneous communication while giving them control over the way that they are perceived.

5.7 Limitations

The relationship between the local and remote users, and the relationship between the local user and the telepresence robot, has proven to be complex, imposing limitations on the depth at which these relationships could be examined in our study. We chose to use a remote confederate to limit the amount of noise in our data that would have been caused by using two naïve participants. However, future work could explore truly dyadic interactions without the use of a confederate.

In the field, we observed that locals decorated the telepresence robot with company-specific items (e.g., stickers, hats, expressions of inside jokes), but the current study used a fabricated identity of "the blue team." While limiting participants to pre-supplied decorations was necessary for the purposes of this study, allowing locals to decorate the telepresence robot with items that have more personal significance might generate a more externally valid understanding of the effects of visual framing through self-extension.

In light of our findings, we have learned that measuring the participant's sense of self-extension toward the telepresence robot *before* the remote logged in would have allowed us to better detect whether or not the decoration of the system was the root cause of the negative bias that the locals expressed. In addition, the tasks used for detecting objective differences in team decision-making performance may not have been sensitive enough or of the correct design to successfully measure the manipulation effects.

Other possible limitations include imperfect capture of some of the disclosure tasks due to hardware errors (e.g., pauses in network connectivity), lack of rigorous qualitative analysis, and the difficulty in creating a convincing remote environment for the remote to be situated in. Field observations suggest that some differences in behavior might occur if the local believes that the remote is logged into the telepresence robot from a physically accessible location. A small number of participants voiced suspicions at some point in the interaction that the confederate may have been on-site and had to be reassured otherwise.

5.8 Conclusion

Research toward facilitating geographically distributed work teams is constantly evolving. As an emerging technology, telepresence robots offer new opportunities for improving social and task outcomes in collaborative work. In this section, we explored how the physical presence of the system affected group identity and collaborative outcomes using two different approaches: visual framing of the system using the placement of decorations on the system to create a sense of self-extension and verbal framing of the remote user with particular emphasis on the interdependence of evaluation. We found that verbal framing was successful in producing more in-group oriented behaviors such as willingness to work together and identification with the remote user and, contrary to our predictions, visual framing of the telepresence robot had a negative impact on levels of cooperation and feelings of team connectivity. Our results highlight the need for designers to carefully consider not just the choices that they make in creating the appearance of robotic telepresence systems, but also to account for the effects that local user behaviors and design choices may have.

6 | Distance

Robot-mediated communication promises us the ability to seamlessly interact with others that are far away. These systems are envisioned as catalysts for closing distance, lowering travel costs [38, 146], enabling those who are physically unable to travel [176], and granting access to services or expertise that may otherwise be unreachable [85, 167]. While these systems often provide us with a way to communicate across any number of miles, past work has shown that physical distance still affects our behaviors, with greater levels of separation resulting in less honesty and cooperation [16, 103].

Telepresence robots seek to alleviate this effect by providing a physical embodiment of the remote in the environment of the local user. By providing a strongly embodied proxy that is situated in the local user's space, these systems have the potential to simulate cues found in face-to-face interaction, such as position, orientation, or spatial and temporal history, that aid us in maintaining common ground and mutual understanding. These systems also hold the promise if creating a more embodied interaction, facilitating user perceptions and actions within the space to enhance feelings of presence, and thus improve collaborative outcomes. This, however, leads us to the question of whether the physical embodiment of the system provides sufficient spatial cues for the local user to view the system as being a proxy for the remote user's presence. Or to paraphrase seminal work in computer-mediated communication, if you have a body, does (geographic) distance still matter?

In the next section, we first outline work that has informed our investigation of this question. We then describe the competing hypotheses that are suggested by this prior work and explain our study methodology. Finally, we outline our results and discuss their implications for theory and for design.

Figure 6.1: "Local" participant interacting with a "remote" confederate via a Beam telepresence robot.

6.1 Related Work

The embodiment of robot-mediated communication systems offers a unique opportunity to examine the effects that distance has on user behaviors. In these interactions, although the remote user may physically be distant, their proxy or embodied representation exists and acts in the local user's space. This dichotomy of where the remote user is "present" reveals an opportunity to clarify what is most important to the local user: the remote user's physical distance or the location of their proxy embodiment.

6.1.1 Distance in Computer-Mediated Communication

Although geographic distance has occasionally been proposed in computer-mediated communication theory as a factor in shaping user interactions, it has not been extensively studied. Prior work has examined this question from the perspective of interacting with a computer, finding that participants exhibited more self-deception and impression-management, as well as being less persuaded by the computer, when they believed it to be across the country rather than on-campus with them [103]. A replication and extension of this work found that when interacting with a human, participants again exhibited greater self-deception and impression-management, as well as being less persuaded, when they believed the other person to be across the country rather than on-campus with them [16].

Within the sphere of computer-mediated communication theory, it is possible that these prior results may relate to the Social Identification/De-individuation Model (SIDE) [86]. This model suggests that people make cognitive adjustments to form impressions of others based on attributions of group membership [86]. Users utilize this strategy to reduce uncertainty as well as modifying their levels of disclosure when compared to face-to-face interactions. In prior findings on distance, participants may have identified remote users that were perceived to be on-campus with them as being part of their group, with greater similarity and shared culture. In contrast, when the remote user was perceived as being across the country, participants may have classified them as out-group members. This shared group membership and perceived similarity to on-campus remote users may have had a positive effect, encouraging cooperation and greater disclosure [135, 178], while perceiving the remote user as an out-group member may have led to more negative consequences [11].

Perceptions of the remote user may also have been influenced by Social Information Processing Theory (SIPT). This theory suggests that in reaction to the relative sparsity of information in technology-mediated communication, people will draw on other available cues to imbue messages with additional meaning. Past work has shown support for a number of cues being adapted and incorporated into the interpretation of messages in mediated communication, such as using chronemics—response latencies and silences [72]—or voice gender [142] to alter perceptions and behaviors toward the other user. These results suggest that users may attribute meaning to a wide variety of cues, such as perceived geographic distance.

6.1.2 Embodiment in Robotic Telepresence

Research in the area of telepresence has begun to explore how the physical embodiment of the system affects distant interactions in collaborative contexts. For example, in-situ studies have revealed that using a telepresence system with a physical embodiment aids in increasing the saliency of the remote user's presence, leading to greater participation for the remote user and more opportunistic interactions [88, 166]. Contrasting field work has examined breakdowns between users, showing how perceptions of the system embodiment evoke specific metaphors, creating conflict when such metaphors are mixed between users [150]. In controlled laboratory settings, work has shown that using a physically embodied telepresence robot increased the remote user's presence [123, 132] and enhanced the development of trust between users [124]. Additional work has also shown that other aspects of the physical appearance, such as height, visual framing, or even a partial level of embodiment (e.g., an orientation-capable but non-mobile system) are enough to affect the remote user's involvement, authority, or feelings of "groupness" with the local user [9, 125, 126].

While these studies have shown that the physical embodiment of the system presents additional cues that affect the local user's perceptions, the extent to which the local users consider the embodiment to be an extension or proxy for the remote user has yet to be explored. By seeking a more nuanced understanding of the role that the system embodiment plays, particularly in relation to the remote user's physical location, we may not only inform design decisions about the appearance of these systems, but may also extend prior computer-mediated communication theory into the realm of robot-mediated communication.

6.2 Hypotheses

Based on a comparison between studies examining the effects of distance in computer- and video-mediated contexts and work on embodiment in the area of robot-mediated communication, we formulated two competing hypotheses.

6.2.1 Distance Matters

Informed by previous results indicating that, in both computer- and video-mediated communication, the perceived physical location of the remote user or computer affected impression-management and persuasion, we posit the hypothesis below:

H1. Participants using a telepresence robot will exhibit more self-deception, greater impression-management, and less cooperation toward a remote user that is perceived to be across the country than they will toward a remote user that is perceived to be on the same campus.

6.2.2 Embodiment Matters

Due to the physical aspect of the telepresence robot and the embodiment that they represent the user as, we suggest that the local will perceive the remote user as being located where the embodied system is, rather than where their physical body is. We therefore hypothesize that the physical embodiment of the system will neutralize the negative effects of distance found in prior literature, while videoconferencing users will remain affected.

H2. Participants using a telepresence robot will exhibit similar amounts of self-deception, impression-management, and cooperation toward a remote user perceived to be across the country and one perceived to be on the same campus.

H3. We also predict an interaction effect, where the greater perceived distance of the remote user will increase the local user's self-deception, impression-management, and lack of cooperation when using a videoconferencing system, but will not affect participants using a telepresence robot.

Figure 6.2: Example of one of the eight stations placed around the room for the Balanced Inventory of Desirable Responding task in the telepresence robot condition.

6.3 Method

To test these hypotheses, we conducted a two (system embodiment: low or video-mediated vs. high or robot-mediated) by two (perceived distance: on-campus vs. across the country) between-subjects controlled laboratory study. As we were interested in perceptions of the remote user's location, participants acted as the local user and a confederate acted as the remote user. In the system condition, participants interacted with the remote user via either the Beam Pro telepresence robot or using Skype in full screen mode on an iMac. To manipulate distance, participants were informed that the remote confederate was participating in the study from either a building on-campus or from across the country. The confederate was a 37-year-old female logged into the telepresence robot from a nearby meeting room and using semi-scripted responses throughout the study. To maintain consistency across participants, the same confederate operated the robot and appeared in the videoconferencing condition across all trials.

6.4 System

We used an unmodified Beam Pro, shown in Figure 6.1 in the telepresence robot condition and an iMac running Skype in the videoconferencing condition. The Beam Pro stands at 62-inches tall, with a 17-inch LCD screen, two wide-angle cameras with pan and zoom capabilities across a 105 degree field of view, and a top speed of two miles per hour. The iMac had a 27-inch LED-backlit display and was running Skype v7.1 in full screen mode.

6.4.1 Tasks and Measures

Following examples in prior work [16, 103], participants engaged in a total of three tasks with the remote confederate to measure self-deception, impression-management and cooperation. We also added a job negotiation task to increase the validity of the interaction, as this is one of the scenarios that these systems are envisioned for use in [128].

Balanced Inventory of Desirable Responding

We chose the Balanced Inventory of Desirable Responding (BIDR) for its use in prior literature examining the effects of distance [16, 103] and as a measure that has been previously tested and validated [120]. The scale is composed of two separate measures, self-deception and impression-management, that combine to provide a total score representing self-presentation. Each of the sub-measures consists of 20 statements (e.g., "When I was young I sometimes stole things."; "I always know why I like things.") that the participant rated on a seven-point scale (1 = "Not true," 7 = "Very true."). The full scale consists of the sum of the responses in the sub-measures for a total of 40 statements.

To make this task cooperative we had eight stations, each with a random ordering of five questions from the BIDR. In the telepresence robot condition, these stations were placed around the room in a random order, as shown in Figure 6.2. In the videoconferencing condition, these stations were placed in a packet in a random order and provided to the participant. Participants were instructed to go to each station in order and to read the numbers provided at each station to the confederate. The remote confederate would ask the question corresponding to the number read and would record the participant's response, repeating the process for all eight stations.

Desert Survival Task

Using prior literature as an example, we used an adapted version of the Desert Survival Task [125], developed and validated by Lafferty et al. [84], to measure the participant's levels of cooperation. In this task, the participant was given a scenario of a bus crash in the desert and a list of nine items. The participant was given up to five minutes to rank the nine items on their own, in order of their importance for survival. Following the five minutes, the local participant and the remote confederate engaged in a discussion of up to ten minutes to compare their initial rankings and decide on a final ranking for the items. The confederate's rankings were algorithmically generated to be consistently different across participants. Using semi-scripted responses, the confederate would discuss each item in turn, offering one argument for why the item should be at a higher or lower ranking than the participant's. Following each argument, the confederate would allow the participant to make the decision on the final ranking of each item.

Participants in the videoconferencing condition were given pictures of each of the nine items to place on a sheet with nine ranked spots, as shown on the left side of Figure 6.3. Participants in the telepresence robot condition were given pictures of each of the nine items to place on a wall with nine ranked spots, as shown on the right side of Figure 6.3.

Final rankings were recorded by the experimenter and cooperation was measured as the distance

Figure 6.3: Desert Survival Task pictures. On the left, the nine pictures and sheet provided in the videoconferencing condition. On the right, the nine pictures and wall placements provided for the telepresence robot condition.

from the confederate's generated ranking to the final ranking for each item.

Negotiation Task

Taken from Curhan et al. [32]'s multi-round negotiation study, the participant was told that in this task, they would be acting as the hiring manager and the confederate would be the job applicant. The participant and the confederate each received a sheet of eight issues for negotiation with differing scoring matrices for each, as shown in Appendix A.3.

Each issue was divided into five potential items of agreement (e.g., Salary: $90,000, $88,000, $86,000, $84,000, and $82,000). Of the eight issues, two were always fixed sum, so that a gain to one party came at an equal loss to the other, two were compatible so that interests were aligned, and four were integrative so that point values were disparately proportioned. Participants received a short instructional sheet explaining the hiring situation and were told to stay in role during the task. The experimenter also instructed the participant that they should consider it to be worth hiring the confederate if their score was above zero, but that higher scores were better.

To maintain consistency across participants, the confederate followed a semi-scripted negotiation strategy in this task with the following rules: (1) At the beginning of the interaction, name the two issues with the highest point values as most important and name the two issues with the lowest point values as areas where she could be flexible; (2) When asked to make a first offer, propose the most advantageous value for that issue; (3) When negotiating an item that was worth a negative number of points, propose an item in another issue that was worth a corresponding positive value in points; (4) When the participant gave an initial offer on any issue, propose the second highest value item in that issue; (5) Agree with the second proposal by the participant on any issue.

Participants were given up to ten minutes to complete the negotiation and at the end the confederate confirmed each item of agreement.

Subjective Questionnaires

Participants filled out two questionnaires and a sheet of demographic information during this study. The first questionnaire consisted of 25 items measuring along six dimensions: participant engagement (four items; $\alpha = .85$), engagement with the local environment (four items; $\alpha = .52$), awareness of using the technology during the interaction (three items; $\alpha = .51$), ease of working via the technology (seven items; $\alpha = .75$), ability to monitor and track the situation (four items; $\alpha = .76$), and dominance (three items; $\alpha = .68$).

The second questionnaire was the Subjective Value in Negotiation scale that has been validated in prior work [33]. This survey consists of 16 items measuring four dimensions of negotiation: feelings about the instrumental outcome (four items; $\alpha = .71$), feelings about the self (four items; $\alpha = .69$), feelings about the process (four items; $\alpha = .81$), and feelings about the relationship (four items; $\alpha = .87$). Additionally, following prior literature [16], we also asked participants to draw where they felt that the remote confederate was in relation to them.

6.4.2 Analyses

We analyzed the BIDR in three parts and following prior literature [16, 103, 120], only items with extreme responses (a 6 or a 7) were counted. We used an analysis of variance (ANOVA) with scale responses as the dependent variable, using system embodiment and confederate location as independent variables. Post-hoc comparisons were carried out using a Bonferroni correction.

Measures of cooperation in the Desert Survival Task were analyzed using an ANOVA with the difference between the confederate and final rankings as the dependent variable and independent variables of system embodiment and confederate location. We also used an ANOVA to analyze the results of the Negotiation Task, testing the participant's point total, the confederate's point total, the sum of the totals, and the difference between totals as dependent variables and independent variables of system and confederate location.

Questionnaire items in both the first and second surveys were tested for reliability and then used as dependent variables in an ANOVA, with independent variables of system embodiment and confederate location. The drawings from the second questionnaire were free form and were coded by two independent raters, blind to condition, as "room" if they depicted the confederate as in the room with them, "close" if they depicted the confederate as on the same campus, and "far" if they depicted the confederate as across the country. Nine participants were excluded from the dataset of drawings because they did not follow instructions to depict both themselves and the confederate. An inter-rater reliability analysis for these drawings indicated almost perfect agreement (Cohen's $\kappa = .82$, $p < .001$).

A Pearson's Chi-squared test was used to determine the effects of system embodiment and perceived distance on drawing code as well as for manipulation checks.

6.4.3 Procedure

Upon arrival at the laboratory, participants were greeted and asked to read and sign a consent form. Following consent, the experimenter provided a high-level overview of the tasks. The experimenter then told the participant that there would be a short delay until the experimenter, either on-campus or across the country (dependent on the condition), indicated readiness. During this time, the confederate logged in to either the videoconferencing or the telepresence robot system.

Following confirmation of the confederate's login, the experimenter led the participant into the experiment room and introduced the confederate as another participant. The experimenter then stated that they would be providing all of the instruction on the tasks and told the confederate that the experimenter on-campus or across the country should have provided a manila envelope marked "one" containing the questions for the first task. The confederate confirmed that they had received the questions for the first task and the experimenter instructed the participant to go to each station in order, reading the question numbers to the confederate. After instructing the confederate to ask the question corresponding to the number, the experimenter then said to open the door when the task was completed and left the room.

When all eight stations had been completed, the experimenter returned to the room and asked both the participant and confederate to read the instructions for the Desert Survival Task, explicitly stating that the confederate's experimenter on-campus or across the country should have provided them in a second manila envelope. After the participant indicated that they were done, the experimenter set a timer for five minutes, told them not to talk during initial rankings, that they could get started, and then left the room. If the timer went off or the participant indicated that the rankings were complete, the experimenter came back into the room and turned off the timer.

During the next instruction period, the experimenter told the participant and the confederate that they would be discussing their initial rankings to come up with a final ranking for the nine items in the task. The experimenter provided the participant with nine pictures of the items and showed them the board or the wall with spaces for them. Next, the experimenter told them that they would have up to ten minutes to rank the items in order of importance, from one to nine, and that once an item was placed in a ranking spot it could not be moved. The experimenter then set the timer for ten minutes and left the room.

Following completion of the final rankings, the experimenter came back into the room and administered the first questionnaire, asking the participant and confederate not to speak while they were filling it out. The experimenter left the room again until the questionnaire had been completed. After re-entering, the experimenter asked the confederate to open the third manila envelope provided by their experimenter on-campus or across the country. The experimenter provided the participant with a copy of the instructions for the Negotiation Task and asked that they both read them.

When the participant had finished reading and indicated that there were no questions, the experimenter gave the participant a sheet of eight issues with accompanying point values. The experimenter told the confederate to flip to the next page in their packet for their point values, set the timer for ten minutes, and left the room. Following the negotiation, the experimenter returned and told the participant and confederate to say goodbye to each other, then took the participant into the hall to complete the last questionnaire.

The time to complete the instruction and three tasks ranged from approximately 40 to 60 minutes.

6.4.4 Participants

A total of 48 participants, gender balanced, participated in our study. They were recruited in-person from a college campus and from online job postings. Ages ranged between 18 and 30, $M = 21.04$, $SD = 2.20$, with participants reporting low familiarity with robots (1 = "Not at all familiar," 7 = "Very familiar"), $M = 2.98$, $SD = 1.45$ and high levels of comfort with videoconferencing (1 = "Not at all comfortable," 7 = "Very comfortable"), $M = 5.46$, $SD = 1.35$. Participants were compensated at a rate of $10 per hour for their participation.

6.5 Results

We first conducted manipulation checks, showing that participants were able to distinguish between the videoconferencing and telepresence robot conditions, $\chi^2(1, n = 39) = 33.57$, $p < .001$. Based on the drawings from the second questionnaire, manipulations of perceived distance were also successful, with no participants in the on-campus condition reporting the remote user to be "far" (e.g., across the country), and no participants in the across the country condition reporting the remote user to be "close" (e.g., on campus). As a result, we collapsed the codes into "room" if participants indicated that the remote user was in the room with them, or "away" if participants indicated that the remote user was not in the room with them.

To resolve the question of whether the local user would orient on the remote user based on their perceived physical location or based on their proxy embodiment, we posited two competing hypotheses.

6.5.1 Hypothesis 1

Our first competing hypothesis was that the local user would orient on the remote user's perceived physical location, regardless of system, showing greater self-deception and impression-management, with lower levels of cooperation, when they perceived the remote user to be across the country rather than on-campus. We found no support for this hypothesis and marginal support for the opposite effect. Using the perceived location in the drawings from the second questionnaire as a covariate, $F(1, 34) = 4.39$, $p = .044$, ${\eta_\text{p}}^2 = .11$, we found a marginal main effect of perceived location on levels of self-deception. Participants who perceived the remote confederate as being on-campus with them exhibited greater levels of self-deception, $M = 5.70$, $SD = 2.85$, than those that perceived the remote confederate as being across the country, $M = 4.00$, $SD = 2.67$, $F(1, 34) = 3.68$, $p = .063$, ${\eta_\text{p}}^2 = .098$, as shown in Figure 6.4.

6.5.2 Hypotheses 2 & 3

Our second competing hypothesis was that local users would orient on the proxy embodiment of the remote user in the telepresence robot condition (high embodiment), showing the same levels of self-deception, impression-management, and cooperation regardless of distance. We also posited a related interaction effect in our third hypothesis, suggesting that while distance would have no effect in the telepresence robot condition, participants using videoconferencing would exhibit higher self-deception and impression-management, with lower levels of cooperation toward a remote user that they perceived to be across the country as opposed to on-campus with them. We found partial support for these hypotheses, as shown in Figure 6.4.

There was a significant interaction effect between system embodiment and perceived distance on the gap between confederate and participants scores, $F(1, 44) = 9.83$, $p = .003$, ${\eta_\text{p}}^2 = .183$.

Score differences were recorded between the videoconferencing system, on-campus condition, $M = 1891.7$, $SD = 1229.5$, telepresence robot, on-campus condition, $M = 3383.3$, $SD = 1750.8$, videoconferencing system, across the country condition, $M = 3541.7$, $SD = 2744.4$, and the telepresence robot, across the country condition, $M = 1641.67$, $SD = 1389.2$. Post-hoc analyses revealed a marginal difference in score gap in participants using a telepresence robot between those perceiving the remote user to be on-campus and those perceiving the remote user as being across the country $F(1, 22) = 7.29$, $p = .052$, ${\eta_p}^2 = .249$. A marginal difference in score gap also existed when participants perceived the remote user to be on-campus with them, between videoconferencing and telepresence robot use, $F(1, 22) = 5.83$, $p = .096$, ${\eta_p}^2 = .210$.

There was a marginal effect of system embodiment on where participants depicted the remote user in questionnaire drawings, with more users of the telepresence robot depicting the confederate as in the room with them than in the videoconferencing condition, $\chi^2(1, n = 39) = 3.08$, $p = .077$ There was also a main effect of the system used on participant perceptions of how engaged the remote user was with the local environment. Participants that interacted with the remote confederate using a telepresence robot rated the remote as more significantly more engaged with the local environment, $M = 5.61$, $SD = .97$, than remote users in the videoconferencing condition, $M = 4.79$, $SD = .86$, $F(1, 44) = 10.54$, $p = .002$, ${\eta_p}^2 = .193$. There was also a main effect of the system on participant awareness of using the technology. Participants that interacted with the remote confederate using a telepresence robot were significantly more aware of the technology during the interaction, $M = 5.13$, $SD = 1.03$, than remote users in the videoconferencing condition, $M = 4.38$, $SD = 1.37$, $F(1, 44) = 6.75$, $p = .038$, ${\eta_p}^2 = .094$.

We found no main effects of system embodiment or perceived distance on participant levels of impression-management, overall scores in negotiation, how persuaded participants were in the Desert Survival Task, or the Subjective Value in Negotiation questionnaire.

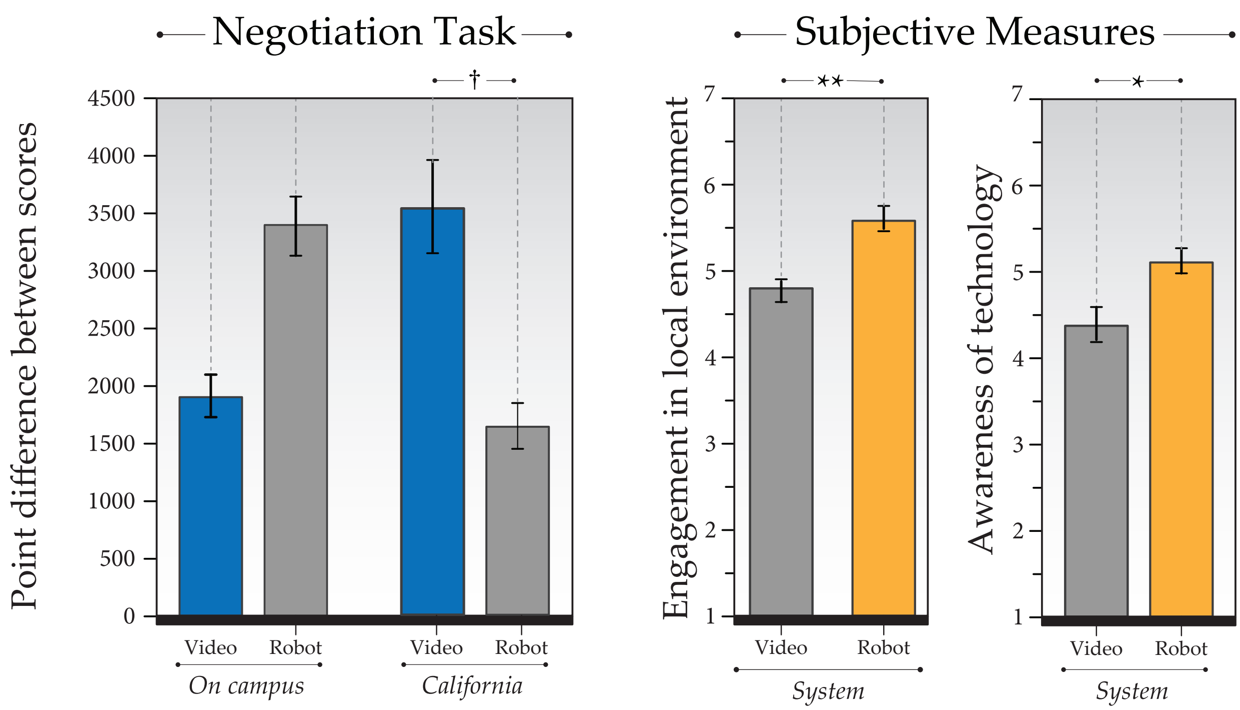

Figure 6.4: Significant results from the negotiation task and the first questionnaire. (†), (*) and (**) denotes $p < .10$, $p < .05$ and $p < .01$, respectively.

6.6 Discussion

In summary, our main findings were that participants showed a trend toward being more self-deceptive when they thought the remote user was on-campus with them than when they thought the remote user was across the country. There was also a significant interaction effect of system embodiment and perceived distance on negotiation outcomes. When participants thought the remote user was on-campus, negotiation performance was more even when using videoconferencing and showed more skew when using a telepresence robot. In contrast, participants using a robot showed more even performance when they perceived the remote user as being across the country, and showed more skew when they believed the remote user to be on-campus. Last, participants using a telepresence robot tended to feel that the remote user was more present in the room with them than when they used videoconferencing.

These results showed no support for our first hypothesis that participants would orient on the remote user's physical location, exhibiting greater self-deception and impression-management, with less cooperation, toward a participant perceived as being across the country than a participant perceived to be on-campus. Our results actually showed a marginal effect in the opposite direction of prior work, with greater levels of self-deception when the confederate was perceived to be geographically *closer* to the participant. This reversal in trends may be related to expectations of future interaction, where prior work has shown that when expecting to interact with someone again in the future, participants had greater self-presentation concerns than if they thought the interaction to be singular [138]. In the case of the remote user being perceived as being on-campus, participants may have factored in the chances that they might run into the confederate again in the future when responding to the BIDR self-presentation scale.

We found partial support for our second and third hypotheses that participants would orient on the proxy embodiment of the remote user in the telepresence robot condition, but remain affected by distance in the videoconferencing condition. Participants tended to depict the remote confederate as present in the room with them more often when using a telepresence robot than when using a videoconferencing system. In addition, we found a significant interaction effect in the negotiation task showing that when perceived to be on campus, negotiation results were marginally more skewed when using the telepresence robot, whereas use of the telepresence robot tended to generate more equal results when the remote user was believed to be across the country. These higher differences in score suggest that the physical embodiment of the system did affect the local user's perceptions of the remote user's distance, equalizing the negotiation advantages or potentially creating greater empathy [113] between negotiators when the remote user was perceived to be distant, but not when they were perceived to be on-campus.

Our most surprising findings were our failure to replicate the effects of perceived distance when using videoconferencing and in the opposing effects of distance and embodiment in negotiation outcomes. We suggest two main reasons for this: (1) as users become more experienced with using a technology, they develop strategies that diminish the mediating effects of the technology; and (2) cognitive conflicts between the necessity for the technology and its use.

6.6.1 User Experience With Technology

When people are first exposed to a technology, their impressions and attitudes are affected by the newness of the system and their inexperience with it. As people gain experience and become more comfortable with the system, their perspectives shift; this is called the *novelty effect* [81]. When Moon [103] first examined the effects of distance on behaviors toward a remote computer in 1998, texting was not as commonplace as it is today. Additionally, work by Bradner & Mark [16] on the effects of distance in human interactions took place in 2002, when videoconferencing was also less ubiquitous than in the present day. While neither of these studies reported user comfort with the technology used, demographic data showed that our participants had high levels of experience with videoconferencing. In the context of computer-mediated communication theory, work investigating the SIDE model has shown support for the effects of technology diminishing over time [174], and literature on SIPT theory has highlighted the gradual repurposing of available information to use as cues for meaning in mediated systems [72]. Based on these factors, we suggest that the increased comfort and experience with and adaptations to videoconferencing among our participants may have diminished the effects of perceived distance.

6.6.2 Match Between Need and Use

As a technology becomes ubiquitous, people's mental models of how the technology works, the skills required to engage with them, and when it is socially appropriate to use them, also develop. Once these mental models reach maturity, they may be applied to new technologies to provide guidance in their use as well as aiding in their cultural acceptance. For example, videoconferencing has benefited from the metaphor created by the telephone, of the technology being used as a communication medium. In this metaphor, for example, people understand that one side initiates a call, a notification is received, and the other party has the option of accepting or ignoring the contact. By considering videoconferencing to be an extension of the communication medium metaphor, the technology was easily integrated into people's use of smartphones and tablets.

The complexity of robotic telepresence systems, however, may result in a number of conflicting metaphors that users employ to understand the system [150]. While these metaphors can guide our understanding of when it is socially acceptable to use these platforms, conflicts between metaphors and observed use can result in negative consequences, such as hostility toward the technology, anger at the users of the system, or outright rejection of the value of the system [2, 64, 71, 150].

In our results, we believe that the participant's lack of experience with robots led them to choose their own metaphors, developing individual mental models as to the necessity of their use. When perceiving the remote user to be across the country, the use of the telepresence robot matched their expectations for when these systems should be used. However, when told that the remote user was on-campus, the cognitive dissonance between when users expected the technology to be used, the perceived need, and the ease with which the remote user could have just met them face-to-face to complete tasks may have resulted in reactions of hostility and decreased cooperation.

6.6.3 Theoretical Implications

Our findings provide a first look into how local users use the physical embodiment of a robot-mediated communication system to affect their perceptions of the remote user's location. We show evidence that use of a highly embodied system, a telepresence robot, may increase the local user's perceptions of the remote user's presence in their space and highlight that the embodiment of the system may also aid in equalizing roles in negotiation when the remote user is sufficiently distant to merit use of the technology. Additionally, we reveal a potential diminishing effect of the mediating role that technology plays in user interactions as users become accustomed to the ubiquity of available systems.

These findings have three key theoretical implications. First, our findings extend the library of cues that SIPT proposes as affecting user interpretations of received messages. We showed that local users tend to depict the remote user as present in their space when using a highly embodied system, showing that the physical embodiment of the system provides additional cues that are incorporated into the local user's mental model of the remote user's location. Second, by providing contrasting results to prior research, our findings show support for the SIDE model's suggestion that the mediating effects of technology diminish over time. In SIDE theory, this decreasing effect is applied to the length of the relationship between users. Our findings, however, highlight that this lessening of effect may also apply to user relationships and comfort with specific mediating technologies. Third, while prior research has examined how using technology affects the interactions that take place during them, very few have explored how existing perceptions, mental models, and metaphors of the technology shapes its acceptance. Our results illuminate a rich new space for future explorations into these effects, particularly in their application to prior theory.

6.6.4 Design Implications

Our findings suggest that the physical embodiment of the remote user may serve to eliminate the negative effects of perceived distance in computer- and video-mediated communication, potentially accelerating the local user's process of adaptation to the technology. We therefore highlight the need for designing platforms with high levels of embodiment, particularly in the current design space where a majority of users are unfamiliar with these systems. Additionally, to prevent perceptions of the use of telepresence robots as being gratuitous, rather than providing location, designers may strive to display information that provides more context on the remote user (e.g., that they are far away, they have a physical disability, they have a tight schedule/unable to leave their office, etc.).

We also show evidence that users of technologies may have their own mental models of the need for these systems which influence their perceptions of when it is socially acceptable to use them. While using a cellphone to contact a family member from across the country may be deemed as necessary, using a cellphone to call a family member that's in the other room may violate social norms, leading to a negative reaction. Frequent violation of these norms may eventually result in a rejection of the technology (e.g., a "no cellphones in the house" rule). Designers of communication technologies need to begin to consider the metaphors that might be invoked when developing new platforms and how these metaphors match projected use cases.

6.6.5 Limitations and Future Work

We employed a confederate in our study, similar to prior work in this area [16], to create a more consistent manipulation across conditions. However, future work in this area should examine how distance affects both local and remote users and whether this effect is asymmetric.

Additionally, we chose to use a commercial telepresence robot and our negotiation task to increase study generalizability. While our results provide a first glimpse into the effects that the embodiment of the system may have on perceptions of distance and cooperation levels, more work is needed to thoroughly explore system factors that may strengthen or weaken perceptions of the embodiment. For example, future studies may investigate whether the horizontal or vertical visual weight of the system, the screen size, the opacity of the system design, the fluidity of movement, the sound volume, or the interface quality affect user behaviors.

Although we failed to replicate previous findings on the effects of distance in videoconferencing and have suggested that this may be due to increased experience by users, future work should further explore this phenomena by contrasting experience with mediating technologies and user comfort levels. Additionally, our results highlight the need to understand user mental models or the metaphors that they are using to make sense of new technologies. Future work, for example, may seek to test whether our results hold true if participants are told that the remote user is physically unable to travel or has other reasons that necessitate use of the technology.

Finally, although results from our first questionnaire showed partial support for our hypotheses, care should be taken when interpreting these results due to lower alpha levels in our confirmatory factor analysis. While some of our results are marginal, we believe that they point to trends that provide valuable insights that inform the direction of future work in this area.

6.7 Conclusion

In this study, we examined how the physical embodiment provided by telepresence robots influenced the local user's perceptions of the remote user's physical distance. We investigated how the *perceived distance* of the remote user and the *system embodiment* shaped outcomes in self-presentation, collaborative, and negotiation task settings. In contrast to prior work, we found that a greater perceived distance resulted in less self-deception by local users. We also found that participants were more likely to perceive the remote user as present in the room with them when using a highly embodied system (e.g., a telepresence robot) than when using a system with low embodiment (e.g., a videoconferencing system). Finally, in negotiation tasks, we found that lower levels of system embodiment increased performance differences between users when the remote user was perceived as being across the country. Our results illustrate the importance of the physical embodiment on perceptions of the remote user and provide a contrast to prior work, opening the door for future research opportunities. Additionally, we extend computer-mediated communication theory by contributing evidence that the physical embodiment of the system provides additional information cues for the remote user and point to the need to consider the experience of users in interpreting the effects of system features, as comfort with the technology may diminish their effects over time.

7 | Mobility

Videoconferencing systems have seen use as early as the 1970s [175]. Since that time, researchers, inventors, and designers have sought to bring video-mediated communication closer to face-to-face interactions, to simulate the sensation of actually "being there" by creating a more embodied experience. A common approach to achieving this goal has been to improve audio [159] and visual connections [26] between remote communication partners. Another approach has been to augment videoconferencing systems with robotic platforms, also known as robotic telepresence systems [45, 121]. By enhancing the sensation of "being there" in the remote location, or *presence*, these systems promise to impart some of the same benefits that being physically present would provide, such as increased coordination and awareness. Through capabilities such system maneuverability, laser pointers as deictic indicators, and the provision of a physical embodiment, research on robotic telepresence systems has explored ways to support increased presence for remote users. For example, past studies have demonstrated that robotic telepresence systems increased the local users' feelings of the remote user's presence, improving collaborative team outcomes [88, 124, 166]. However, few studies have examined the effects that these systems may have on the remote user's, the *remote's*, perceptions of their own presence in the local environment.

In domains such as manufacturing, construction, or exploration, the ability to change perspectives and maneuver in the environment may not only enable the remote user to offer the local user guidance and instruction, but may also directly contribute to task completion. By enabling the remote user to interact with the surrounding space, these systems may increase the remote's awareness of the physical environment, facilitating task-oriented actions, such as mapping an area, locating objects, and conducting visual checks. However, because many of these systems have been designed for use

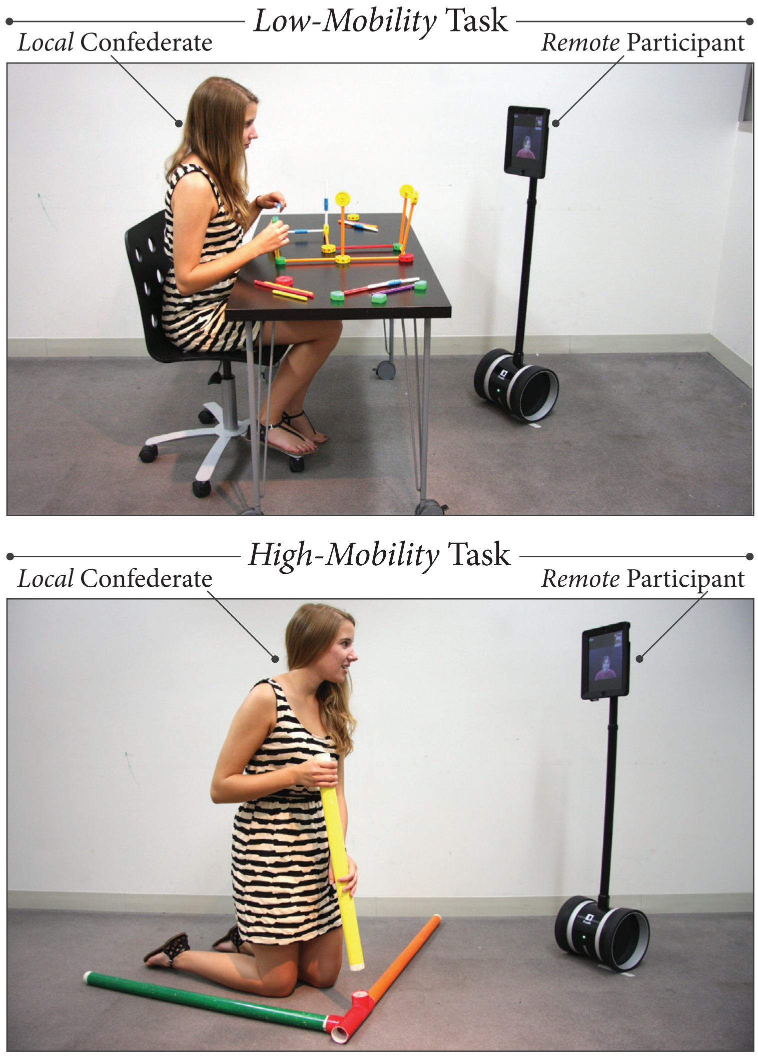

Figure 7.1: Participants remotely collaborated with a local confederate in a construction task that either took up a small amount of desk space, requiring *low* levels of mobility, or a large amount of space, requiring *high* levels of mobility, in the room.

in office settings [3, 38, 52, 130, 146, 168], previous literature has primarily focused on the contexts of conversation and collaborative meetings. In these scenarios, once the system has been positioned in front of the local user, the *local*, the mobility of the system no longer plays a key role, and the robotic platform becomes the equivalent of a videoconferencing display. As a result, how mobility affects the remote's sense of presence and contribution to task outcomes, particularly in settings where maneuverability directly impacts task completion, is unclear.

Our goal in this study is to investigate the role that mobility plays in instilling a sense of presence in the remote user and to increase our understanding of how it may improve team performance in physically oriented tasks. Specifically, we seek to gain a better understanding of how mobility supports the remote user's contributions in tasks that require different levels of mobility (Figure 7.1)—in tasks that are visible from a single view, requiring *low* levels of mobility, and tasks where the ability to maneuver gives the remote user greater latitude to participate in the completion of team goals, i.e., tasks with *high* requirements for mobility. By exploring these questions, we hope to inform the future design of mobility features for robotic telepresence systems and to deepen our understanding of how mobility shapes remote collaboration.

The next section provides an overview of related work on remote collaboration, focusing specifically on presence and task awareness. This overview is followed by a description of our hypotheses and our study design. We then present our results and discuss their implications for design and research. Finally, we summarize the study's limitations, areas for future work, and our conclusions.

7.1 Related Work

Previous work on supporting remotely distributed teams has focused on the importance of *workspace awareness*—how knowledge and awareness of where others are working and what they are doing might facilitate the coordination of action [57]—and on supporting *grounding*—the process of creating common ground to achieve mutual understanding [7]. For both workspace awareness and grounding, the ability to track the presence and spatial positioning of others is key for successful collaboration. In this section, we provide an overview of work that has examined presence and task awareness in both virtual and physical telepresence environments.

7.1.1 Presence

The domain of workspace awareness in computer-supported cooperative work focuses on improving collaborative outcomes by simulating a physical workspace in a virtual environment. By designing tools that provide users with timely information about the task at hand, such as who is present, where they are working, and what they are doing, these systems translate the affordances found in physically shared workspaces into online tools that support group work [17, 43, 56, 57]. For example, by using digital representations of user arms to create a sense of where they are active in a virtual workspace [39], providing historical logs of past exchanges [41], and preserving spatial relationships [153], these systems facilitate coordination between users and improve group efficiency. In these examples, indicators of collaborator presence are implemented as representations of information, such as positioning and availability, that users would have access to in a non-virtual workspace.

Previous research on robotic telepresence has examined how having a physical embodiment might support the remote user's presence in the local user's environment. Findings from this work have demonstrated that these platforms improve the local users' sense of the remote user's presence, increasing the frequency of informal interactions between co-workers—shown to be critical for organizational coordination [82]—and the remote user's ability to participate in meetings [88, 166]. Additional research has examined how other aspects of robotic telepresence systems shape interactions, such as the effects that embodiment and control have on the development of trust between users in negotiation tasks [124], how the height of the system shapes the local's perceptions of the remote user's persuasiveness [126], and the role that system appearance plays on the local's feelings of team membership toward the remote user [125]. Previous work has also explored manipulating the camera's mobility in a telepresence system to increase the remote user's feelings of presence; however, the stationary nature of the task and the camera's limitations resulted in few users utilizing this capability, making it difficult to draw definitive conclusions [110].

While this past research illustrates how various aspects of robotic telepresence systems affect and improve the local user's perceptions of the remote user's presence [1], we lack a clear understanding of whether these systems truly improve the remote user's sense of "being there" in the local environment.

7.1.2 Task Awareness

Research in workspace awareness has explored different ways of conveying critical information and supporting grounding by informing users about movement within the online workspace. For

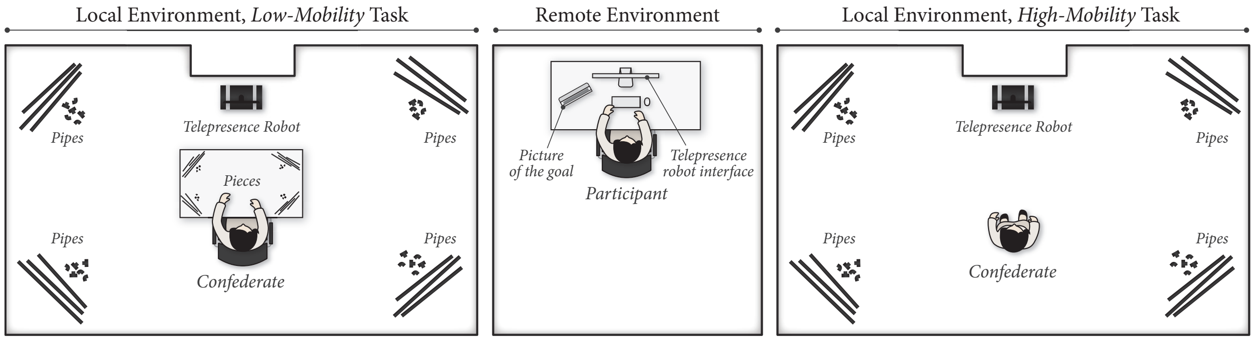

Figure 7.2: The physical arrangements of the study room in the *low-mobility* task condition, the participant's environment, and the study room in the *high-mobility* task condition on the left, center, and right, respectively.

example, prior work has explored the use of workspace miniatures to show the location and activity of others in the workspace [58] and the use of indicators of availability [17] to aid in collaborative coordination.

Within the sphere of robotic telepresence, prior literature has sought to understand user needs for movement and awareness within specific contexts, such as office [88, 160], medical [8, 163] and educational [44] settings. Research in teleoperation has explored the design of control interfaces that aid remote users in being aware of their surroundings to accomplish solo exploration tasks, including the avoidance of obstacles and successful navigation [45, 95, 99]. While these bodies of work inform the design of interfaces that more effectively support mobility in the remote environment, they do little to aid us in understanding how such mobility facilitates task awareness, coordination, and feelings of presence. Mobile telepresence systems offer a unique opportunity for remote users to not only benefit from the tools developed in workspace awareness research and teleoperation, but also to directly contribute to tasks in a physical workspace.

In our study, we seek to understand the contribution that mobility may have in supporting remote users' feelings of presence, facilitating their ability to contribute to task completion. To this end, we focus on two types of tasks: tasks where mobility requirements are low and movement does not aid in the completion of goals, such as conversations, negotiations, and activities limited to a small workspace, and tasks where the requirements are high and the ability to move in the physical space facilitates performance, such as construction, manufacturing, and exploration. In other words, when does mobility matter?

7.2 Hypotheses

Informed by previous research in workspace awareness and robotic telepresence systems, we formed two hypotheses predicting the role that the mobility of the system would play in different task types.

Hypothesis 1. Remote users will report more presence in the local's environment when the system is mobile than when the system is stationary.

Hypothesis 2. In a task that requires high levels of mobility, using a mobile system will improve collaborative outcomes over using a stationary system, while mobility of the system will not affect these outcomes in a task that requires low levels of mobility.

7.3 Method

To test these hypotheses, we designed a controlled laboratory experiment in which remote participants worked with a local confederate in a collaborative construction task. In the study, we manipulated the mobility of the robotic telepresence system and the movement or mobility required by the task. We measured the effects of these manipulations on the participant's sense of presence in the local environment and team task performance outcomes, such as completion time and errors. The paragraphs below provide further detail on our study design, participants, measurements, and analyses.

7.3.1 Study Design

Our study followed a two-by-two between-participants design. The independent variables were *mobility*, varied by the use of a stationary or mobile robotic telepresence system, and the levels of *mobility or movement* required by the task, low vs. high. In order to maintain consistency across

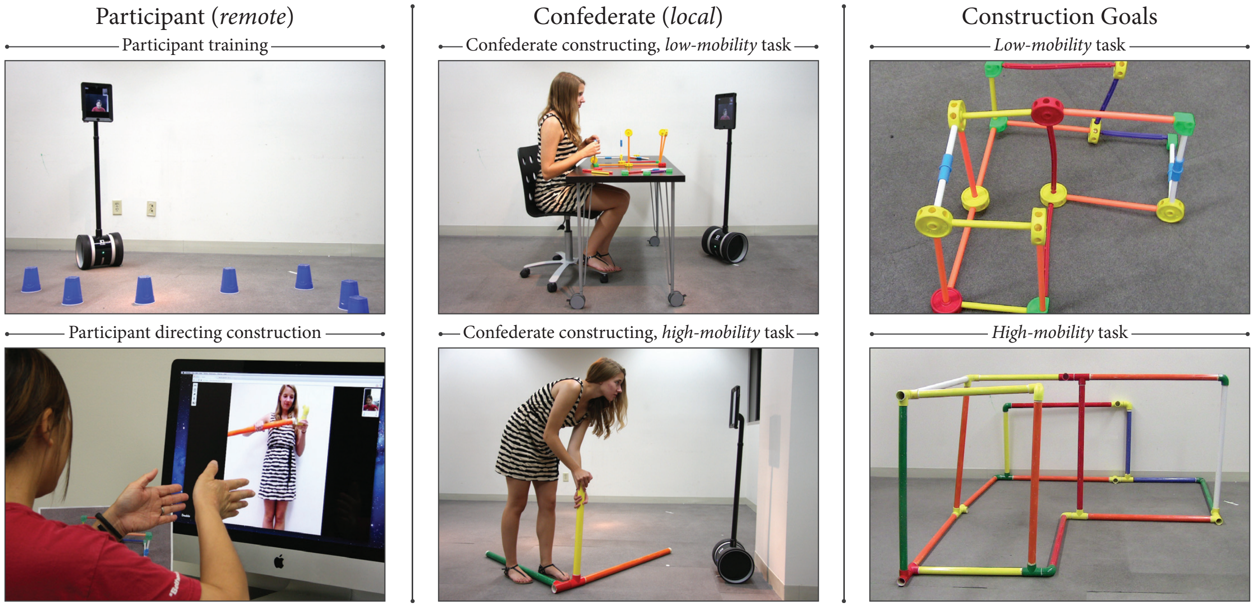

Figure 7.3: *Left*: participant controlling the telepresence robot in the training phase and the remote setup in which they provided the confederate with instructions. *Center*: the local setup for the low mobility and high mobility task conditions in which the confederate carried out the construction of the object. *Right*: pictures of the completed objects for the small and large tasks provided to the participant.

participants, we developed a task to construct an object that could be built on a small scale with TinkerToys, or on a large scale with PVC pipes. When built on a small scale, the completed object measured approximately 22 inches (55.88 cm) in length and 3.5 inches (8.89 cm) in height, fitting on a table that was fully visible from the telepresence system's camera. When constructed on a large scale, the completed object measured approximately 7 feet (182.88 cm) in length and 3 feet (91.44 cm) in height, requiring it to be built in a clear floor space that was not easily visible from the telepresence system's camera. The construction of small-scale and large-scale objects served as *low-mobility* and *high-mobility* tasks, respectively. Figure 7.2 illustrates the arrangement of the study environment across the task manipulation.

Although both local and remote users of a telepresence robot may benefit from the level of mobility that the remote user has, we were chiefly interested in the remote user's experience and perspective for two reasons. First, prior work has primarily been dedicated to understanding robotic telepresence interactions from the local user's perspective [1, 125, 126]. Second, because face-to-face interaction participants have the ability to move in the environment, we expected that providing the remote user with the ability to maneuver would have a greater impact on the remote user's experience. To this end, we asked participants to act as the remote user and used a confederate—one of our experimenters, who pretended to be a participant—as the local user in our task. The locations of the participant and the confederate are illustrated in Figure 7.2.

7.3.2 System

Both stationary and mobile interactions in our study took place via a Double telepresence robot[1] (shown in Figure 7.1), which has a weight of 15 pounds and an height that is adjustable to either 47 inches or 60 inches (101.6cm to 152.4cm). The Double allows remote users to drive in the local's environment, switch between a front and bottom-view camera, and adjust the height to two different settings. The telepresence robot's screen was an Apple iPad 2 tablet computer[2] with a diagonal screen size of 9.7 inches (24.64 cm) and a screen resolution of 2048×1536 and 264 ppi. The front camera of the tablet computer provided a video stream of what the system was facing to aid with communication, and the back camera showed the immediate surroundings of the robot using a mirror directed toward the ground to aid with navigation.

The participant and the confederate communicated via the Double videoconferencing interface, shown in Figure 7.3. In the stationary condition, participants were not instructed on the controls for moving the system and the system was plugged into the wall, preventing movement. In the mobile condition, participants were provided with an instruction sheet on the controls for moving the system and were able to freely maneuver around in the experiment room.

7.3.3 Construction Task

In our study, participants engaged in a construction task with a confederate where the pieces were either small, 3.35 inches (8.51cm) to 10.85 inches (27.56cm) in length, or large, 2 feet (60.96cm) to

[1] http://www.doublerobotics.com/
[2] http://www.apple.com/ipad/

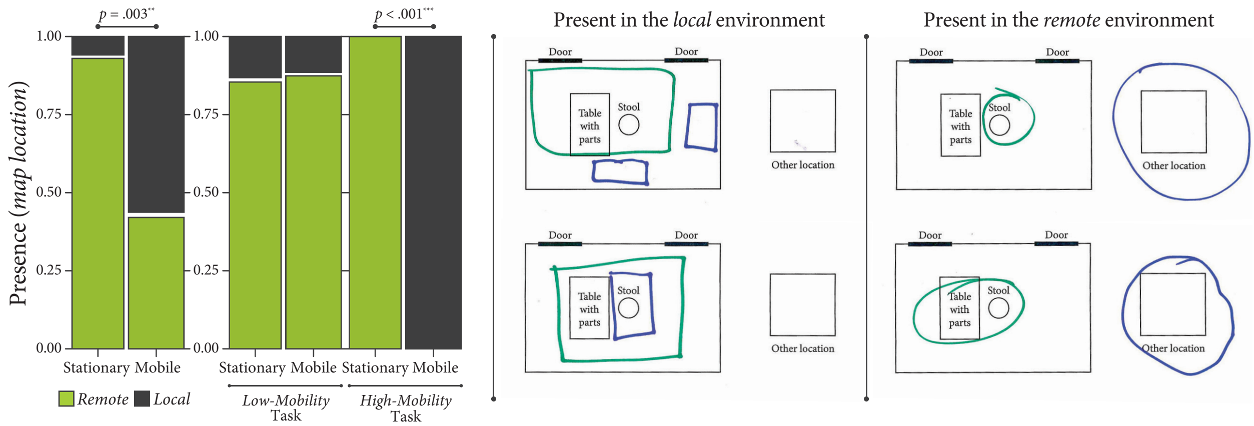

Figure 7.4: *Left*: Data from the measures of presence across mobile and stationary conditions and broken down to tasks requiring low and high levels of mobility. (***) and (**) denote $p < .001$ and $p < .01$, respectively. *Center and right*: Example data from the presence measure, participants used blue to circle the area that they worked in and green to circle the area that their partner worked in. The examples in the center illustrate data from participants who felt present in the room where they were tele-present, rather than the "other location" where they were physically located, and those on the right illustrate data from participants who felt present where they were physically located.

3 feet (91.44cm) in length. The completed object had a total of 35 parts—22 straight pieces and 13 connecting joints—with varying orientations and colors. Participants were told that they would be working together with another study participant to build the object, that they would have the instructions, and that the other person would have the parts. We motivated participants to work as quickly and accurately as possible by adding an incentive; if they were able to build the correct object faster than any other teams from the study, they would receive an extra dollar. They were also told that they could begin the task as soon as the timer was started and that the timer would stop when they told the experimenter that they were finished. Participants received a picture of the completed object that they were not allowed to show to the confederate, as shown on the right in Figure 7.3.

7.3.4 Measures

To measure the collaborative outcomes of the construction task, we utilized a number of objective and subjective measures.

Measures of Presence

In order to measure the remote user's feelings of presence, we asked participants to mark where they and their partner worked during the task on a map of the rooms. Figure 7.4 shows example data from this measure. Markings on the map were coded as "in-room" if participants noted that they and the confederate were in the room where the object was being constructed. They were coded as "separate" if participants marked that they and the confederate operated from separate rooms. In order to avoid biasing participants, the map of the room was not changed between conditions, but participants were warned that the layout of the rooms or the objects included on the map may not be accurate.

Measures of Task Performance

We used the time taken to complete the construction of the object as a measure of task efficiency. Time was marked in seconds from when the timer was started to when the participant opened the door of the study room and announced that they were finished. The number of mistakes in the completed object, i.e., errors in the orientation or position of the pieces, served as a measure of task accuracy.

Other Measures

While we did not pose any specific hypotheses about subjective evaluations, we created an exploratory post-experiment questionnaire to better understand the effects that the mobility of the system might have on the remote user's perceptions of teamwork, team recovery, workspace awareness, and environmental awareness. Participants were asked to rate their agreement on a five-point Likert scale, $1 =$ Strongly disagree, $5 =$ Strongly agree, with 34 statements (e.g., "I was aware of my position in the room," "We made fewer errors than other teams," "I was able to prevent errors from being made during the task," and so on). Statements were modified from items in the Networked Minds Measure of Social Presence [10] and NASA's Situational Awareness Rating Technique [157].

In addition, participants were asked to rate their feelings of closeness with their partner using the Inclusion of Other in the Self Scale [4].

7.3.5 Procedure

An experimenter greeted the participant at the entrance of our laboratory and obtained informed consent. The experimenter then seated the participant in front of a computer and gave the participant up to 10 minutes to practice either driving the telepresence robot around (in the mobile condition) or practice moving through a maze (in the stationary condition). Once 10 minutes had elapsed or the participant announced that they were finished with the practice, the experimenter disconnected the participant's terminal from the robotic telepresence system (in the mobile condition), instructed the participant on the construction task, and provided the participant with a picture of the finished object, as shown on the right in Figure 7.3. Following these steps, the experimenter reconnected to the robotic telepresence system and introduced the confederate as another participant in the study. The participant was reminded that they could begin when the timer was started and to open the door and announce when they were finished. After answering any questions, the experimenter started the timer and exited the room. During the task, the confederate did not initiate actions or provide guidance, acting only to complete participant instructions; this was to prevent affecting the speed of task completion or the number of mistakes. The confederate also limited her responses to a scripted list (e.g., "Like this?," "What next?," "Here?," "That's it? Great!") to maintain consistency across participants. Once the participant had opened the door of the experiment room and announced that the task was completed, the experimenter re-entered, turned off the timer, told the confederate to log out of the system, and administered the post-study questionnaire. Each session took approximately 30 minutes.

7.3.6 Participants

A total of 32 adults (four males and four females per condition), whose ages ranged between 18 and 30 years, $M = 20.9$, $SD = 2.37$, volunteered to participate in the study. We recruited from

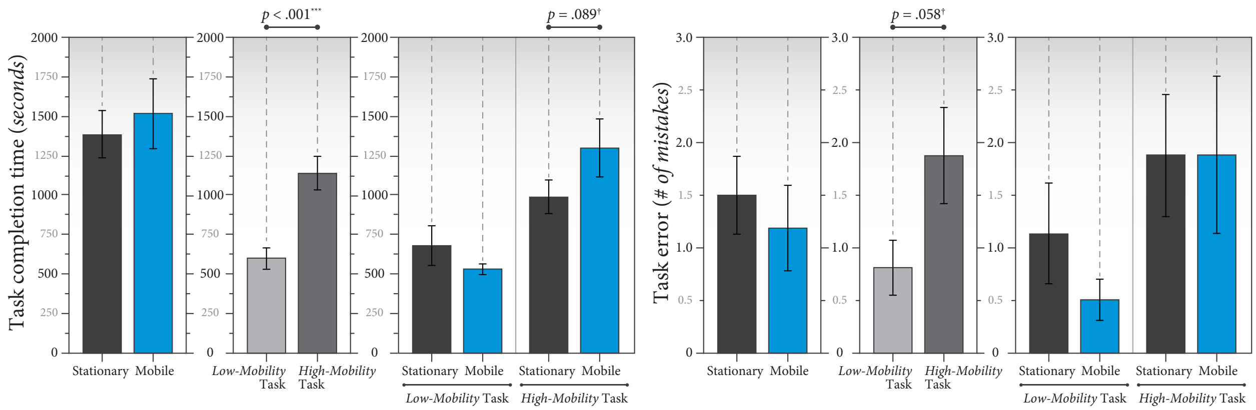

Figure 7.5: Data from measures of task completion time and task error. (***) and (†) denote $p < .001$ and $p < .10$, respectively. On the left, the high-mobility task took significantly longer to complete than the low-mobility task, and participants in the high-mobility task took marginally longer to complete the task when using the mobile vs. the stationary system. On the right, participants made marginally more mistakes in the high-mobility task than the low-mobility task.

the University of Wisconsin–Madison campus community using online job postings and in-person recruitment. Participants reported that they were familiar with videoconferencing, $M = 4.8$, $SD = 1.7$ ($1 =$ not very familiar, $7 =$ very familiar) and on average used videoconferencing once a month, $M = 2.2$, $SD = 0.8$ ($1 =$ I did not use videoconferencing in the past 6 months, $2 =$ I used videoconferencing at least once a month in the past 6 months, $3 =$ I used videoconferencing at least once a week in the past 6 months, $4 =$ I used videoconferencing at least once a day in the past 6 months). Although we told participants that they would receive an extra dollar if they were the fastest team to complete the task correctly in order to motivate faster completion times, all participants received a total of $5, which included the completion bonus.

7.3.7 Analyses

We tested age, gender, and videoconferencing experience as potential covariates and found that none had a significant effect ($p > .05$). A two-way fixed-effects analysis of variance (ANOVA) was conducted with the mobility of the system and task mobility requirements as input variables and completion time and number of mistakes as response variables. Planned comparisons in all tests used the Scheffé method. A Pearson's Chi-squared test was used to determine the effects of mobility on the participant's feelings of presence in the drawn map measure.

To construct scales from items in our questionnaire, we conducted an exploratory factor analysis, which resulted in four factors that corresponded to scales of teamwork (four items; Cronbach's $\alpha = .84$), team recovery (four items; Cronbach's $\alpha = .71$), workspace awareness (two items; Cronbach's $\alpha = .70$), and awareness of the environment (two items; Cronbach's $\alpha = .70$).

7.4 Results

Our first hypothesis predicted that remote users would feel more present in the local environment when communicating with the confederate using a mobile system than when they used a stationary system. We found full support for this hypothesis; remote users reported themselves as present in the room with the confederate significantly more frequently when they used a mobile system than when they used a stationary system, $\chi^2(1, n = 31) = 8.7$, $p = .003$. A closer examination of these results showed that, when engaged in the low-mobility task, system mobility had no effect on feelings of presence, $\chi^2(1, n = 15) = .10$, $p = .73$. However, in the high-mobility task, all participants using a mobile system reported themselves as being present in the room with the confederate (where

Measure	F(1,28)	*p*
Completion times		
System mobility	.426	.519
Task mobility	18.573	.000***
System * task mobility	3.389	.076†
Mistakes		
System mobility	.338	.565
Task mobility	3.913	.058
System × task mobility	.338	.565†

†$p < .10$, ***$p < .001$

Figure 7.6: Effects of system mobility and mobility required by the task on completion times and the number of mistakes. (†) and (***) denote $p < .10$ and $p < .001$, respectively.

the object was being constructed), while all participants that used a stationary system reported themselves as being in a separate room (where they were physically seated), $\chi^2(1, n = 16) = 16.0$, $p < .001$. Figure 7.4 illustrates these results and provides examples of responses from participants who felt present in the room with the confederate and those who felt separate, i.e., present in the room where they were physically located.

Our second hypothesis posited that mobility would improve task performance in a high-mobility task but not in a low-mobility task. Our results did not provide support for this hypothesis. First, we found that it took participants significantly more time to complete the high-mobility task, $M = 1138.31$, $SD = 497.84$, than the low-mobility task, $M = 601.94$, $SD = 497.84$, $F(1, 28) = 18.57$, $p < .001$. There was also a marginal difference in the number of errors made between tasks, participants making more mistakes in the high-mobility task, $M = 1.88$, $SD = 2.15$, than in the low-mobility task, $M = 0.81$, $SD = 2.15$, $F(1, 28) = 3.91$, $p = .06$.

We found no main effect of system mobility on completion time or the number of errors. There was no significant difference in the time it took participants to complete tasks using the stationary system, $M = 829.50$, $SD = 497.82$, versus the mobile system, $M = 910.75$, $SD = 497.82$, $F(1, 28) = 0.43$, $p = .52$. There was also no significant difference between the number of errors made when the system was stationary, $M = 1.50$, $SD = 2.15$, versus when the system was mobile, $M = 1.19$, $SD = 2.15$, $F(1, 28) = 0.34$, $p = .57$.

However, we found that mobility had a marginal interaction effect between the mobility of the system and the mobility requirements of the task, $F(1, 28) = 3.39$, $p = .08$. The high-mobility task took marginally longer when using the mobile system, $M = 1293.50$, $SD = 514.48$, than when using a stationary system, $M = 983.13$, $SD = 295.53$, $F(1, 28) = 3.11$, $p = .09$. There was no difference in the time it took participants to complete the low-mobility task between using the mobile system, $M = 528.00$, $SD = 94.50$, and the stationary system, $M = 675.88$, $SD = 367.03$, $F(1, 28) = 0.71$, $p = .41$.

We found no interaction effects for the mobility of the system and the mobility requirements of the task on the number of errors. Planned comparisons showed that participants using a mobile system made marginally more mistakes in the high-mobility task, $M = 1.88$, $SD = 2.10$, than in the low-mobility task, $M = 0.50$, $SD = 0.54$, $F(1, 28) = 3.28$, $p = .08$.

Finally, we found no significant effects of system mobility or the mobility required by the task on the remote user's perceptions of teamwork, team recovery, workspace awareness, and environmental awareness.

7.5 Discussion

Consistent with our first hypothesis, our results showed that system mobility significantly improved the remote's feelings of being present in the local's location, particularly when the task required high levels of mobility. In these situations, we observed that all participants using the mobile system not only actively moved in the task space, but also exhibited more present behaviors. For instance, when constructing the large object, participants who were driving the system used language that referred to themselves in space, such as "Where am I?" and "I'm just trying to get into a position where I can see the corner." However, when using a stationary system or in the low-mobility task, we observed requests and statements by the remote user that referred to actions of the local confederate, such as "Can you push the object back please?" and "I can't see what you're doing, can you hold it up?"

Contrary to the predictions of our second hypothesis, greater mobility did not increase task efficiency or accuracy. Using a mobile system was actually detrimental to task performance in the high-mobility task and had no effect in the low-mobility task. We believe that the reasons for this outcome fall into two primary categories: a high burden of attention for the remote user and an instability in the remote user's frame of reference, which are discussed in the paragraphs below.

7.5.1 Burden of Attention

During the task, we observed a number of behaviors that seemed to indicate that participants found performing the task and maneuvering the telepresence robot to require high levels of attention. In their comments in the post-study survey, participants illustrated task difficulties with comments such as “It was hard to communicate everything you wanted to say using non-verbal actions and more directions verbally instead,” “[It was] difficult describing connectors,” and “I’m pretty horrible at this [the construction task].” Many users were unfamiliar with the shapes of the joints and had trouble articulating differences between pieces and directions for the construction. Participants also reported difficulties with translating the photograph into three dimensional space, sometimes resulting in an object that was a mirror image of the one in the instructions. We also observed participants having difficulties with maneuvering the telepresence robot. Although users were given 10 minutes to train with the system and were provided with an instruction sheet explaining the controls (the four arrow keys on the keyboard for moving in four possible directions), users still experienced challenges. For example, participants were observed to back into walls, run into pipes on the ground, or to move extremely slowly to avoid collisions. These difficulties resulted in one user tipping the system over during the training period and crashing it, such that the system had to be recovered from a prone position on the floor.

In NASA’s Situational Awareness Rating Technique (SART) [157], the primary factors for understanding a user’s situational awareness include the user’s division of attention, spare mental capacity, concentration, and familiarity with the situation. While each of these factors individually may not have been a problem for participants, our observations were that the combination of being presented with an unfamiliar control system, coping with the task, having to divide attention between the photograph and the video of the other room, the pressure of competing in time and accuracy, and the concentration needed to interact with the local confederate, may have been overwhelming for users in the mobile system condition. This high cognitive load may have resulted in an inability to take full advantage of the system’s mobility, decreasing their ability to work quickly. This effect may have been particularly strong in the high-mobility task, as the low-mobility task did not require participants to move.

7.5.2 Instability of Reference Points

Psychological research on spatial cognition has studied the cognitive techniques that people use to understand their own positioning and the positioning of objects in their environment [105]. In this work, spatial reference systems are divided into three categories, *egocentric reference systems*, where location is specified with respect to the observer, *environmental reference systems*, in which locations are specified with respect to other objects, and *intrinsic reference systems*, when people learn a particular spatial layout of objects or a pattern [105]. This work provides strong evidence that memories of room-sized layouts are mentally represented in terms of egocentric reference systems (e.g., to my left [37]) or intrinsic reference systems, particularly when objects may be grouped into higher-order clusters [105].

In our task, when participants were not able to maneuver around the environment, their frame of reference was fixed in an egocentric view, where their spatial understanding was limited to object positioning in relation to the robotic telepresence system, or "themselves." However, when the mobility of the system enabled participants to change their field of view, their mental model for understanding object positioning may have changed to an intrinsic reference system. This may have led them to attempt to gauge where objects were in relation to other features in the environment (e.g., "the red piece behind the chair"), causing problems for the three reasons discussed below.

First, the system provided the remote user with a narrow field of view, making it challenging for participants to see multiple objects at a time. As a result, once the participant had moved in space, relating new objects to old ones became increasingly difficult. During the high-mobility task, participants using the mobile system occasionally asked the confederate for help in relating the objects that they could see at that moment with the locations that they had previously been, (e.g., "Is this the orange piece from the corner you just added the green thingy to?" and "Wait, is this the one across from the red pipe?").

Second, when physically present, people may rely on a number of environmental and kinesthetic cues to estimate their changes in position. In the robotic telepresence system that we used, no feedback was provided for how far the system had rotated or the distance that it had moved, creating distortions in egocentric frames of reference. Exacerbating this situation was our decision to remove all distinguishing characteristics from the study room in order to minimize distractions from the task at hand. While there were several features (such as doors, windows, and furniture) which would be common in an office or factory setting, the environment was not as rich in cues as more naturalistic settings might be. We observed participants in the mobile condition moving the system forward, then pausing to turn back and forth to get a better understanding of their position and surroundings. In some cases, participants would back up to their previous position and make remarks such as “Ok, so that’s there...” before driving forward again, leading us to the conclusion that they were searching for objects in the environment to use as navigational aids. We also observed occasions in which the participant rotated the system and lost track of how far they had gone, ending in their facing a wall and having to ask the confederate, “Where are you now?”

Third, the most distinguishing objects in the room were the pieces for constructing the object and the confederate. As required by the task, both the pieces and the confederate were in constant movement under the direction provided by the participant. When using the stationary system, we often observed participants referring to the confederate’s position when the confederate was not in view of the camera, as in the statements “There should be a green joint on your left and a red one on your right...” and “Yeah, right where you are now.” In contrast, when using a mobile system, participants appeared disoriented about the confederate’s location in relation to their own, leading to backing repeatedly into walls while trying to locate the confederate or the object.

Previous work in computer-mediated communication has identified that the remote user’s inability to understand how they are situated in the local user’s environment can cause problems or frictions between users [61]. When viewed from the perspective of robotic telepresence systems, this lack of positional awareness significantly limits the ability of these systems to support task collaboration and has the potential to render them unusable. While the ability to navigate has shown dividends in creating an orientation-free mental representation of the environment versus an orientation-dependent representation developed from a map or photographs [148], our results highlight the gap between having the ability to move and the user actually benefitting from the capability.

One potential solution for supporting the remote user's navigational needs is to leverage heads-up displays to create a realistic three dimensional representation of a virtual environment, such as a recreation of the local's surroundings, and to simulate a correct perspective for the user by monitoring the relative position of the user's eyes or head [5, 96]. However, head mounted displays introduce other challenges for users of robotic telepresence systems, as they obfuscate the remote user's face.

7.6 Design Implications

Our findings suggest that while the addition of mobility may provide remote users with a greater sense of presence in the local's environment, simply providing them with the ability to maneuver is not enough. The ability to drive the telepresence system not only adds the burden of understanding its spatial positioning in relation to other objects in the environment, but also divides the remote user's attention, significantly increasing cognitive load. Walking and talking becomes a much more difficult proposition when trying to interact with others through a mobile system.

While these problems are not insurmountable, our research points to the need for designers to consider ways of supporting the remote user's efforts. For example, providing the remote user with a wider field of view may allow them to gain a better intrinsic understanding of the location of obstacles in the environment. Adding indicators in telepresence interfaces that show the distance traveled, the degrees of rotation turned, or the position of the telepresence robot on a simple map of the local environment, such as those provided in gaming interfaces, may aid in maintaining an egocentric view of the system's position. Providing the remote user with the ability to offload the controls for movement, either by providing pre-planned paths or more intuitively mapped control systems, such as game or gesture-based controllers, may reduce cognitive load, allowing the remote user to more fully focus on the task at hand.

7.7 Limitations and Future Work

Based on our study, we believe that there are informative lessons learned and fruitful paths forward for future work. First, to control for the difficulty of maneuvering the robotic telepresence system, it is critical for future studies to provide a flexible training period that allows participants to become comfortable and agile with the system. This lengthened training period would enable achieving a certain skill level instead of training for a set period of time. Alternatively, a longer-term study could examine task performance over time. Second, to be able to make broader claims about the use of robotic telepresence systems in spatially-oriented tasks, it is important for future work to explore a wider variety of tasks, such as collaborative exploration, search and rescue, and so on. Third, providing a richer, more naturalistic environment with stable reference points, such as additional furniture or wall hangings, may not only improve overall task performance with the robotic telepresence system, but may also offer greater external validity. While we chose to use a commercial system for our study to more accurately simulate real-world conditions, the use of a custom system in follow-up studies would allow greater latitude for a deeper investigation into how mobility might best be supported. Furthermore, there are always limitations of a study's participant pool in terms of how representative it is of a broader population of people with diverse educational, professional, and cultural backgrounds, which may be addressed by conducting follow-up studies, e.g., across different professional environments or cultural contexts. For this purpose, we have sought to provide sufficient detail in the Methods Section to allow future repeatability of our study.

7.8 Conclusion

Our work explored the effects of mobility on collaborative outcomes in two different task scenarios—a "small" task that required low levels of mobility and a "large" task with high mobility requirements—seeking to answer the question, "When does mobility matter?" To this end, we conducted a controlled laboratory experiment that followed a two-by-two (system mobility: stationary vs. mobile; task mobility requirements: low vs. high) between-participants design in which participants acted as the remote user and a confederate acted as the local user. Our results showed that the mobility of the system significantly improved the remote user's feelings of presence, particularly in tasks requiring high levels of mobility. However, contrary to our prediction, we found that mobility lowered task performance in measures of efficiency in high-mobility tasks. Our results suggest that, although the ability to maneuver the system provides remote users with immediate benefits such as a greater sense of presence, there is an often overlooked burden that controlling a mobile system adds to the remote user's cognitive load. These findings not only have implications for the potential consequences of providing the remote user with additional features, such as mobility, but also highlight new opportunities for designing tools to support remote users. Robotic telepresence systems offer the unique chance to participate in and to directly contribute to physically situated tasks. However, our findings highlight the need for a deeper understanding of how mobility may be integrated in the design of robotic telepresence systems to best support the demands that such tasks place on the remote users.

8 | General Discussion

This work has focused on exploring the premise that telepresence robots offer a unique design space for creating embodied experiences. Drawing from theory in embodied cognition, ecological psychology, and communication research, I predicted that by providing a strongly-embodied system that represented the remote user, feelings of presence would increase and collaborative outcomes would be improved.

To investigate this, I used a systematic approach to isolate specific features and variables within the robot-mediated communication design space in a series of five studies. These studies collected quantitative and qualitative data to find empirical evidence supporting my predictions. My findings, summarized in Figure 8.1, provides evidence that using the strongly-embodied system of telepresence robots does improve feelings of the remote user's presence from both user perspectives. However, I found little evidence for a connection between increased feelings of presence and improved task outcomes, such as user trust, cooperation, or negotiation.

8.1 Key Insights

Although I found a number of individual results in my work, two main themes or insights emerged across my findings.

1. **The need to separate (tele)presence from other outcomes.** Past work has inextricably linked the concept of telepresence—feelings of "being there" or being present—to improved user experiences, task outcomes, and interactions. This assumption has its roots in early definitions of telepresence [100] and the treatment of face-to-face interactions as a gold standard.

	Manipulations	Findings
Study 1 Embodiment & Control	Embodiment	
	Weak	
	Strong	▲ Increased Trust
	Control	
	Local User	▲ Increased Trust
	Remote User	▼ Decreased Trust
Study 2 Height & Authority	Relative Height	
	Shorter	▲ Increased Dominance
	Taller	
	Authority	
	Follower	
	Leader	▲ Increased Feelings of Control
	Height × Authority	
	Taller + Leader	▲ Increased Cooperation
	Shorter + Leader	▼ Decreased Cooperation
Study 3 Visual & Verbal Framing	Visual Framing	
	No Decoration	
	Decorated	▼ Decreased Cooperation
	Verbal Framing	
	Interdependent	▲ Increased Cooperation
	Independent	
	Visual × Verbal Framing	
Study 4 Embodiment & Distance	Embodiment	
	Weak	
	Strong	▲ Increased Presence
	Distance	
	On Campus	▼ Decreased Self-Honesty
	Cross Country	
	Embodiment × Distance	
	Strong + Cross Country	▲ Increased Negotiation Equality
	Strong + On Campus	▼ Decreased Negotiation Equality
	Weak + Cross Country	▼ Decreased Negotiation Equality
	Weak + On Campus	▲ Increased Negotiation Equality
Study 5 Mobility and Task Movement	System Mobility	
	Non-mobile	
	Mobile	
	Task Movement	
	Low	
	High	
	Mobility × Movement	
	Mobile + High	▲ Increased Presence ▼ Decreased Performance
	Non-mobile + High	▼ Decreased Presence

Figure 8.1: A high-level summary of the results from my five studies, triangles pointing up indicate an increase in the listed outcome, triangles pointed down indicate a decrease in the outcome. For interaction effects, only conditions showing a significant effect are listed.

However, the results of my explorations yielded little evidence for a tight connection existing between feelings of presence for either the remote or local users and improved collaboration. In fact, some of my results suggested that the features of embodiment or mobility may even decrease task performance because of a lack of support for effectively using these capabilities. For example, although being able to drive the embodiment around may improve feelings of presence, it may still incur cognitive costs or tradeoffs, resulting in decreased task performance.

Although telepresence robots and embodied communication systems may increase feelings of user presence, my findings point to the need to separate the concept of telepresence from other task outcomes, particularly in collaborative settings, leaving behind the assumption that "being there" is the ultimate goal of these systems. What I propose is that telepresence work in collaboration reconsiders treating these platforms as monolithic devices, where an ultimate surrogate system exists that is indistinguishable from "being there." Instead, I suggest that future work in this area may instead focus on identifying possible outcomes in collaboration to construct a framework or taxonomy. From this framework, we may then begin to more accurately map variables within the telepresence design space to their effects in collaboration, developing more targeted measures for these outcomes. In the context of proposing this framework of outcomes, I next present my second insight.

2. **Presence as an outcome.** By separating feelings of presence or telepresence from other objectives, we can begin to explore when presence is worth pursuing and how it correlates to other benefits. For example, in my work on creating a framework for telepresence design and understanding, I identified 17 categories of scenarios that users reported wanting to use a telepresence system for [127]. Of these scenarios, several are situations where feeling present may be the main desired outcome, for example, watching a grandson's baseball game where you *feeling present* and your grandson *feeling that you were there* are of the most importance. In other scenarios, such as goal based collaboration, users may benefit more from systems that focus less on making them feel like they're there and more on facilitating the achievement of their goals. Treating presence as an outcome may aid future research in workplace collaboration

to gain a more nuanced understanding of the effects that variables in the design space have and the way that they interact.

8.2 Implications

By disentangling feelings of presence from other outcomes and viewing it as an equal, rather than ascendant, goal, researchers and designers may be able to break from past approaches of viewing face-to-face interaction as a final objective. Being freed from this perception may have the following implications:

- **Practical Implications**: Breaking from the goal of designing telepresence systems to create a stronger sense of presence, designers may be able to better focus on the needs of users in the specific contexts where the system is envisioned for use. Rather than making the assumption that feeling present and improvements to collaborative work will go hand-in-hand, designers can instead focus on optimizing for other identified outcomes, such as building trust, improving cooperation, or increasing feelings of group membership.
- **Research Implications**: Treating presence as its own outcome, researchers in collaborative telepresence will be better able to identify what factors influence presence and disambiguate its connection to other effects. For example, by constructing a framework of potential outcomes in telepresence work, future research can explore whether a relationship exists between feelings of presence and self-presentation, or presence and dominance.
- **Methodological Implications**: To date, the concept of presence has remained nebulous, with numerous efforts being made to define what it means and to accurately measure it [10, 100]. By treating presence as its own objective, independent of other outcomes, future research may be better able to explore and define what it means to feel present, leading to better measurements and standards across research areas (e.g., virtual telepresence vs. robotic telepresence).

- **Theoretical Implications**: Embodied cognition and ecological psychology suggest that having a more embodied experience should improve user cognition, perceptions, and the ability to act. While my findings did not uniformly support this prediction, they did point to the need to consider how the interface best supports acting within the local user's environment. Additionally, by disconnecting feelings of presence from other task outcomes, further explorations may examine the role that presence plays in theories of embodiment and what these may mean for future teleoperated or telepresence systems.

8.3 Limitations

This work is not without its limitations. Although I have explained my rationale for largely using commercial telepresence robots to increase generalizability, this has limited the extent to which I was able to explore some of our research questions. The form factor of telepresence robots, generally consisting of a video screen mounted on a mobile base, also limited the amount of exploration that we were able to do. Factors such as the balance and stability of the system, the power of the motors, and battery life, all contributed to decisions that were made in designing these experiments.

8.3.1 Methodological Validity

The relative nascency of these systems also added limitations to the generalizability of our findings. When participants acted as remote users, we provided them with training time to familiarize themselves with the controls. Observations of these training periods revealed that a number of participants were actually very bad at driving, colliding with walls and at some points even tipping the robot over. Despite these observations, many participants ended the training period early, reporting that they were comfortable and felt expert with driving the system. Unfortunately, in a majority of our studies we were unable to detect or to capture whether participant expertise in driving significantly affected task performance. As these robot-mediated communication systems become more commonplace, the potential effects of having novices use the system should diminish, however, until that time, future studies should take care to provide additional training and to create objective measures for the driving ability of participants. The newness of telepresence robots also affected participant familiarity with the systems, leading to potential novelty effects. To address this, we worked to account for these variables by including training time with the system and by measuring participant familiarity with videoconferencing and robot technologies.

Our use of a confederate in a majority of our studies to reduce potential confounds across participants has the potential of limiting our methodological validity. While providing more consistent behavior, the use of confederates may have had several effects on the generalizability of our studies. First, the use of confederates meant that participants were always working with or interacting with a stranger, unlike a majority of the interactions that are projected to take place when using telepresence devices [127]. This is particularly important when considering that the SIDE model suggests that some of the effects of technology diminish over time. Second, although our tasks with confederates were semi-scripted, the natural flow of dialogue with participants would sometimes require an unscripted response resulting in some variation between users.

8.3.2 Generalizability

A major factor in the generalizability of our results lies in the controlled nature of our studies. We chose this approach because prior work in the robotic telepresence space has primarily focused on the use of these systems in the field. While these studies provide insight into the effects that these systems have on organizational structures and in-situ behaviors, they are unable to isolate which features are the causes of the observed behaviors. We therefore felt that examining the effects of these features and variables in a controlled environment would reveal complementary insights into how user interactions are shaped by these technologies.

8.3.3 Assumptions

By taking the approach of using controlled laboratory studies to examine the effects that select features or variables had on user behaviors and perceptions, my findings require further work to identify their generalizability to interactions in the wild. Additionally, by examining these features or variables in the context of telepresence robots, I have made assumptions about the generalizability of my results to other robot-mediated communication systems. As a next step, my findings should be validated across several different platform types to establish whether the effects that I uncovered are particular to robotic telepresence, or if they may be applied across systems.

8.4 Experimental Tasks

A majority of the experimental tasks that were developed in my research were grounded in measures that had been previously validated and tested in prior work. However, in order to accommodate the use of a telepresence robot or to achieve more generalizable results, I made some modifications to these measures. For example, in the Desert Survival Task [84], pre-testing revealed that several of the items from the original task were no longer common knowledge among participants. Additionally, the use of all twelve items resulted in the task taking significantly longer; something that we were cognizant of due to constraints on facility access and experimenter time. When changes to experimental tasks were performed, I have detailed them within the study and provided documentation to support reproducibility.

In our studies, we focused on collaborative or negotiation tasks to examine the effects that system features or variables had on user interactions. Although these revealed effects in participant trust, cooperation, persuasion, presence, and dominance, we did not have the opportunity to examine other contexts, such as creative or competitive tasks.

8.5 Research Platforms

Using telepresence robots as a research platform offers its own challenges. Although these systems have started to see commercial use, many of the platforms that have been available have either been in the early stages of development or have been extremely expensive to procure. As a result, the studies in this document were conducted using the best available platform, first the Texai Alpha [147], then a Double [38], and finally a Beam Pro [146]. The use of these commercial systems has also limited the number of modifications that we were able to make. While we were able to adjust the height of the Texai Alpha, later systems like the Double and the Beam Pro have much more closed systems, making them difficult to modify. Relevant details on the specifications of each system and any modifications that were made have been included in the matching study. Robot-mediated communication in general and the telepresence robot area in particular would benefit from work to create a robust research system that supports the same quality features as those found in commercial systems.

8.6 Future Work

My findings in this work point to a number of promising avenues for future research.

8.6.1 Design Space Explorations

Although I investigated some of the features and variables in the design space of telepresence robots, a great many more exist to be explored. For example, when considering the embodiment of the system, a number of variables, such as the screen size and aspect ratio, voice modulation, visual weight of the system, proportion of screen to body, customization options for the remote user, and form factor, may all act to shape user perceptions and behaviors. Features such as system mobility also offer further variables for investigation, such as system velocity, grace, acceleration, flight or three dimensional movement, path, autonomy, and motion noise. Further research may also seek to consider other areas in the telepresence design space, for example, looking at systems that generally operate autonomously to accomplish tasks but that may be used as telepresence platforms.

My research focused on one-to-one interactions between users, but future work may look at one-to-many or many-to-many interactions, both when users share a system and when multiple telepresence robots are in use. Work may also be done outside of the direct interactions between users, studying how the use of these systems affects bystanders. Additionally, my approach to exploring the features and variables in this design space used controlled laboratory settings, manipulating two variables at a time. As a result, I was only able to observe limited interaction effects, however, these systems consist of a large combination of design features and variables. Once specific design variables have been isolated and studied, future work may seek to examine how each of these variables interacts with each other. Finally, my work examined task outcomes in the context of collaboration, however, it is possible that these outcomes may be affected differently in other contexts. Futher work may seek to replicate and extend my findings by examining whether they hold across other scenarios (e.g., when socially mingling or remotely sharing a meal together).

8.6.2 Work In Presence

By providing insights into the lack of ties between feelings of presence and collaborative outcomes, my findings suggest a number of ways that these results may be extended. Further work in this area may seek to construct a framework of telepresence outcomes, including factors such as presence, trust, and cooperation. Once these outcomes have been clearly identified, more accurate measures may be developed and the relationship between them may be established, providing us with a more nuanced understanding.

Additionally, past work in telepresence has treated presence as a nebulous concept, muddied by attempts to tie it to observable task outcomes. By creating a distinct separation between presence and other objectives, future work may be better able to focus less on reproducing or reaching parity with face-to-face interactions and instead look beyond, creating systems with broader capabilities (e.g., 360-degree views, multiple manipulators, multiple embodiments). In going beyond the human form factor, these systems may be less likely to create feelings of presence, but may be a better match for user needs.

9 | Conclusion

Over the years we have developed a number of platforms to aid us in communicating across distances. In doing so, we have assumed the premise that creating embodied systems will increase feelings of "being there" by more accurately mimicking face-to-face interactions and will improve collaborative outcomes.

This work makes the following contributions to the field of telepresence:

- **Practical Contribution**: The exploration of specific features and variables in the telepresence design space, facilitating the creation of actionable guidelines that allow designers to make conscious and deliberate choices when developing robot-mediated communication systems.

- **Theoretical Contribution**: The construction of a body of knowledge on how aspects of the telepresence design space affect user interactions and the key insight that feelings of presence are not strongly associated with improved collaborative outcomes, pointing to the need to consider presence as its own outcome.

- **Methodological Contribution**: The development of tasks to test the effects of variables within the robot-mediated communication design space as well as the construction of a new measure for feelings of presence.

By making these contributions, this work lays a foundation for exploring other features and variables within the telepresence design space. My findings also have implications for collaborative telepresence, providing evidence that supports the disentangling of presence from other outcomes. By creating a distinct separation between presence and other objectives, designers will be better able to create systems that match user needs in envisioned scenarios rather than striving to achieve parity with face-to-face interaction. Additionally, these insights facilitate the creation of a framework for collaborative telepresence outcomes, allowing researchers to gain a more nuanced understanding of their relationships.

Robot-mediated communication platforms stand at an inflection point. Whether they will grow to become broadly accepted alternatives to interacting across distances or sink into obscurity will depend heavily on the ability of designers in the next several years to make informed decisions that enable systems to meet user needs. These systems hold the potential for not just making it easier to communicate across distances, but also to empower those who are unable to be physically present, provide previously unattainable access to medical specialists, and improve people's everyday lives. By exploring the design space of embodied telepresence robots and contributing insights about the need to separate presence from other collaborative outcomes, this work helps to facilitate the success of these systems and brings us one step closer to making these promises a reality.

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A | Appendix

A.1 Disclosure Interview Questions

The questions used in the disclosure interview are listed below.

Participant Questions to Confederate:

1 How are you?

3 How old are you?

5 Do you have any siblings?

7 What's your favorite book and why?

9 What's your favorite type of food?

11 What's something that you want to accomplish before dying?

13 What's the craziest thing that you've ever done?

15 What's the worst thing that you've ever said to a friend?

17 What's a question that you wouldn't want to have to answer because it would be too embarrassing or personal?

Confederate Questions to Participant:

2 How are you?

4 Where are you from?

6 Do you have any pets?

8 What's your favorite movie and why?

10 What are your favorite things to do in your free time?

12 What are some of the things that make you angry?

14 What's your most negative childhood memory?

16 What is the meanest thing you've ever said to your parents?

18 What's a question that you wouldn't want to have to answer because it would be too embarrassing or personal?

A.2 Desert Survival Ranking Algorithm

The confederate used the ranking algorithm below in the Desert Survival Task.

Participant Rank: 1, 2, 3, 4, 5, 6, 7, 8, 9
Confederate Rank: 5, 6, 1, 2, 3, 8, 4, 9, 7

A.3 Negotiation Scoring Matrix Example

Signing Bonus	Points	Moving Expenses	Points
10%	0	100%	0
8%	400	90%	200
6%	800	80%	400
4%	1200	70%	600
2%	1600	60%	800
Job Assignment	**Points**	**Insurance Provider**	**Points**
Division A	0	Allen Ins.	0
Division B	-600	ABC Ins.	800
Division C	-1200	Good Health	1600
Division D	-1800	Best Ins. Co.	2400
Division E	-2400	Insure Alba	3200
Vacation Days	**Points**	**Salary**	**Points**
30 days	0	$90,000	-6000
25 days	1000	$88,000	-4000
20 days	2000	$86,000	-3000
15 days	3000	$84,000	-1500
10 days	4000	$82,000	0
Starting Date	**Points**	**Company Car**	**Points**
June 1	0	LUX EX2	1200
June 15	600	MOD 250	900
July 1	1200	RAND XTR	600
July 15	1800	DE PAS 450	300
Aug 1	2400	PALO LSR	0

Figure A.1: Example score sheet provided for participants during negotiation task.

Signing Bonus	Points	Moving Expenses	Points
10%	4000	100%	3200
8%	3000	90%	2400
6%	2000	80%	1800
4%	1000	70%	800
2%	0	60%	0
Job Assignment	**Points**	**Insurance Provider**	**Points**
Division A	0	Allen Ins.	800
Division B	-600	ABC Ins.	600
Division C	-1200	Good Health	400
Division D	-1800	Best Ins. Co.	200
Division E	-2400	Insure Alba	0
Vacation Days	**Points**	**Salary**	**Points**
30 days	1600	$90,000	0
25 days	1200	$88,000	-1500
20 days	800	$86,000	-3000
15 days	400	$84,000	-4500
10 days	0	$82,000	-6000
Starting Date	**Points**	**Company Car**	**Points**
June 1	2400	LUX EX2	1200
June 15	1800	MOD 250	900
July 1	1200	RAND XTR	600
July 15	600	DE PAS 450	300
Aug 1	0	PALO LSR	0

Figure A.2: Example matching score sheet provided for confederate during negotiation task.