Robotic Telepresence at Scale

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ABSTRACT
Telepresence robots offer a relatively new way for people to project their presence remotely. However, these experiences have only been studied in controlled or small scale installations. To broaden our understanding of the successes and limitations of telepresence robots in large-scale venues, we conducted a study at CHI 2016 where five factors increased over past research: (1) number of local attendees; (2) ratio of remote users to systems; (3) variety of activities; (4) time zone differences; and, (5) environment size. Our results reveal that unlike small-scale venues and situations, remote users take a more socially isolated and functional approach to remote attendance while combating challenges around scheduling and large navigational spaces. Our results reveal new opportunities for thinking about the design of robot personalization, availability, and navigation for systems targeted at large-scale public contexts.

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H.5.3. Information Interfaces and Presentation: Group and Organization Interfaces - CSCW

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Telepresence; robots; academic conferences

INTRODUCTION
Telepresence robots—physically independent videoconferencing systems that allow a user to autonomously move in a remote environment—have expanded in the commercial space over the past five years. As these systems have become more affordable, they have been installed in a variety of contexts, including medical facilities [5], workplaces [11, 25], schools [30], museums [14], stadiums [10] and professional conferences [17]. While each of these installations is envisioned to enable remote users to realistically experience a distant environment, our understanding of the factors influencing their success is still in its early stages.

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Figure 1: Beams at CHI 2016 at one of two main dock zones.

Research to date has examined these systems to build a grounding of minimal requirements for success [3] and identify how some of these system characteristics may contribute to collaborative outcomes [7, 19]. Work has also examined how these requirements might change outside of controlled laboratory and work settings, such as in the home [2], at restaurants [20] or at academic conferences [13]. While these studies have contributed to our knowledge of how robotic telepresence systems operate, they have typically focused on small scale or confined usage. For example, they have been in controlled or domestic settings [1, 7], the number of users has been relatively small [13], or most users have been close to the remote location (in or near the same time zone) [7, 19, 13]. As a result, whether the knowledge from these studies is generalizable to use cases outside of these circumstances has yet to be explored.

In this study, our goal was to investigate telepresence robots outside of workplace or private interactions, with a particular focus on extending prior work by observing the use of these systems in the context of large-scale events. Attending a concert, visiting a famous museum across the world, or going to a tradeshow, all operate at a larger scale than research has thus far observed along several dimensions. For example, the number of users and bystanders present, the possibility of access to the system as a scarce resource, the need to transition between a variety of activities in a single experience, the difference in distance and time zone, and the varying terrain that remote users encounter, may all be significantly increased in such scenarios over what prior work has observed. Additionally, in these shared system contexts, access to the system before and after use is likely to be limited, constraining the ability to customize the system for identification purposes [11, 13, 27].

To explore the generalizability of past work as these dimensions increase, we conducted a study of 33 remote attendees from across the world within one type of large-scale event, an academic conference. These remote attendees shared access to ten telepresence robots called Beam Pros (Beams) to participate in the ACM Conference on Human Factors in Computing 2016 (CHI) in San Jose, CA, USA (Figure 1). In our study, the number of participants, ratio of remote users to available systems, time zone differences, variety of activities, and spatial challenges were all increased beyond the scope of prior work by at least a factor of two (e.g., increasing the number of bystanders from ~800 to ~3700). Our research goal was to understand the effects that increased scale—growth in size to accommodate larger events—has on: navigation between locations; social interactions; the scheduling of telepresence robot usage, identity representation; and privacy—all research topics that have been studied in small-scale deployments.

Our study contributes to the validation of prior research by highlighting the generalizability of past findings, such as robotic telepresence increasing both positive and negative social attention and navigational difficulties in crowded spaces. We also extend these findings by providing new insights into the emergence of targeted functional behavior over socializing as a means of optimizing the experience for remote users. Our results suggest that telepresence robots, in their current form, may not be the most ideal medium for attendance at large-scale events. In contrast, other design solutions that adapt to changing needs as various factors are increased may be more appropriate. This broadens our understanding of using robotic proxies, and provides insights for the design of future systems.

RELATED WORK

Since the concept of using technology to remotely interact with others was proposed decades ago, shifting from audio [22] to video [15] to robotics [16], the efficacy of such channels has been subject to study [22]. As robotics has emerged as a viable addition to these systems, research has primarily been conducted in one of three settings, controlled laboratory experiments, dedicated semi-private settings—such as at a company, school, or in the home—or at a public venue, such as a museum, restaurant, or conference. Next, we describe work from each of these contexts.

Telepresence Robots in the Lab

Lab work on robotic telepresence has focused on understanding how a variety of design choices affect collaborative outcomes between remote users and those local to the system (locals). In this area, discoveries have been made about the effects that varying system capabilities have, for example, greater range of vision increasing accuracy and confidence in a collaborative task [7] and connection latency on the ability to navigate [3]. Additional work has examined how the presence and appearance of the system embodiment influences user interactions, such as the strength of the embodiment increasing trust development [19], awareness of the physical appearance decreasing enjoyment [23], and taller systems increasing levels of cooperation over shorter systems [19].

These studies have contributed to the design and implementation of current robotic telepresence systems, providing a starting point for understanding their use in semi-structured and real world settings.

Telepresence Robots in Dedicated, Semi-private Settings

In addition to lab work, robotic telepresence has been studied in the wild in early adopter, semi-private settings. For example, the medical field has experimented with using telepresence robots, showing that they can be successfully deployed to provide timely medical care in areas where stroke specialists may be unavailable [28] and to reduce disruption when high levels of traffic may interrupt patient care [9]. Research has also provided insight into how these systems can facilitate positive outcomes in educational settings, such as allowing hospitalized children [30] or remote students [6] to attend school with their classmates. Findings from studies in workplace settings have extended this knowledge, showing that robotic telepresence enables remote users to engage in opportunistic interactions [11] and have greater participation in hub-and-satellite teams [27]. In home settings, researchers have explored situations where telepresence robots may aid in providing home care [12] or help those with mobility needs [1, 26].

This prior work has laid a solid foundation for understanding the effects of robotic telepresence in a variety of contexts. However, in all of these cases, systems were assigned exclusively to single or relatively few users, without challenges or negotiations to gain system access. Additionally, these studies were unable to explore the effects of large time zone differences (e.g., greater than 10 hours) on users.

Telepresence Robots in Public Spaces

As robotic telepresence systems have matured, research has begun to move outside of controlled or semi-private settings into public spaces, such as museums, restaurants, and conferences. Although relatively nascent, work in this area has developed a framework to understand the tradeoffs and requirement differences between varying contexts and environments [20]. In this framework, factors such as the physical and social environments are described as changing between contexts, suggesting that the needs of specific scenarios require different solutions. This work also posited that the framework may be used to predict such needs, facilitating informed design choices in future systems [20]. Further research has continued to explore how differences in context shape system requirements by looking at academic conference attendance (Ubicomp/ISWC 2014). Their results highlighted the link between personalization and identity, privacy challenges due to the difference in remote and local contexts, and the difficulties that missed social cues can cause [13]. Yet this research has only explored small-scale usage of telepresence robots—seven people using dedicated systems—in an event of moderate size (~800 local attendees and 3 parallel sessions) and has suggested the need for further research where these factors are increased.

Our study extends this work and tests its generalizability for a large-scale event. By doing so, our goal is to identify whether increasing factors, such as the ratio of users to each system, may reveal additional insights, change where breakdowns or challenges in usage occur, or alter the effects seen in smaller, more controlled contexts.

STUDY METHODOLOGY

The goal of our research was to extend our understanding of the telepresence robotics space in large-scale, public venues. We were interested in understanding the role that scale may play in affecting navigation between locations, resource negotiations, identity representation, and privacy—all research topics that have been focused on in small-scale deployments, but not large-scale ones. To explore these topics, we increased the scale of the event by five factors:

(1) Number of People: The largest setting explored by prior work was at Ubicomp/ISWC 2014, with local attendance of approximately 800 people [13]. We increased this number by hosting the study at CHI, the flagship conference for human-computer interaction research. For CHI 2016, in-person attendance was approximately 3700 people at the San Jose Convention Center.

(2) Ratio of Users to Available Systems: We had 33 people (18 female) attend via telepresence where remote attendees shared access to 10 Beams. Prior work has generally only studied a one-to-one ratio of remote user to robot in work and home contexts [1, 11, 26]. At Ubicomp/ISWC 2014, seven participants used six Beams [13] and recommendations were made to increase the number of users to require time-sharing of systems. In all of these prior situations, there was little need for schedule coordination because of the low number of remote users when compared to the number of available robots.

(3) Variety of Activities: The largest number of activities seen in previous studies limited participants to three parallel conference tracks and coffee breaks, with one person attending the conference reception [13]. In contrast, telepresence attendance at CHI supported 16 parallel tracks, multiple video-streamed plenary talks, workshops, breaks, poster sessions, interaction showcases, lunches, and receptions.

(4) Time Zone Differences: Remote attendees participated in CHI from a variety of countries, with 17 from North America, 8 from Europe, 4 from Asia, and 4 from Australasia. As such, time zones varied from no differences to 19 hours, compared to prior work where the largest difference was 9 hours [13].

(5) Environment Size: The conference activities took place in a variety of settings, including presentations at the front of the room with audiences between several hundred and several thousand in size, small discussions conducted at group tables, hallway space divided into a variety of exhibits, and a large expo hall with booths and posters. These settings were distributed across three floors of the conference center. To provide context, the largest environments examined by prior work were multiple sessions in 10,000 sq. ft. (929 m^2) at a hotel [13] and a single activity at a museum across approximately 93,750 sq. ft. (8709 m^2) [20]. Our study had multiple activities taking place over 143,000 sq. ft. (13,285 m^2), shown in Figure 2 and described in more detail in the following section.

Participants

Remote participants were recruited via the CHI conference website, mailing list, and social media. Those interested in attending remotely completed an online questionnaire describing

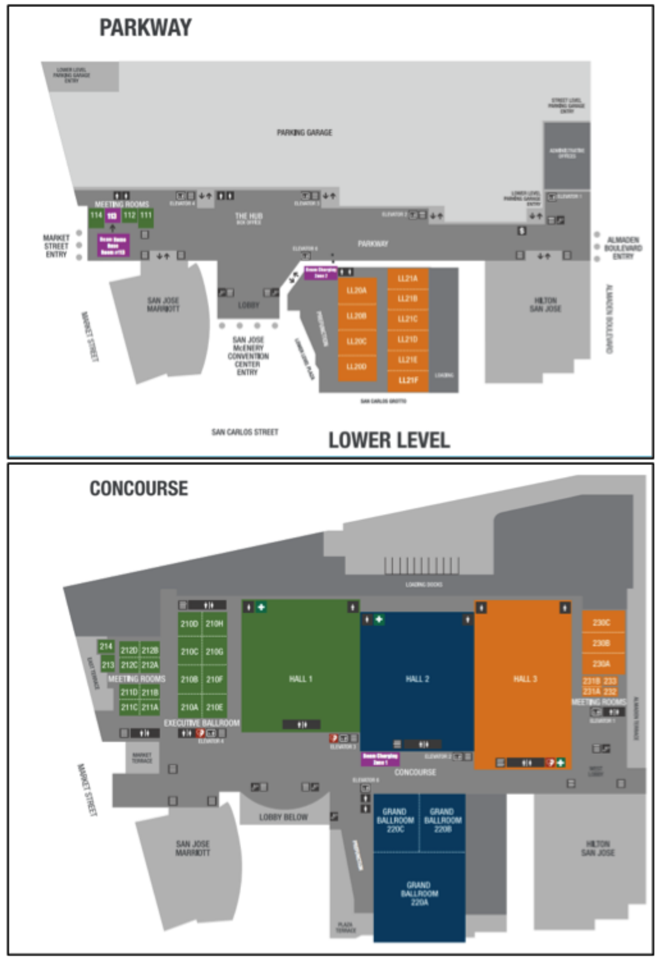

Figure 2: Maps of the convention center given to participants. Bright purple areas were docking stations for the Beams.

their motivations, location, affiliation, and number of times attending CHI in the past. We prioritized applications that faced travel restrictions or had accessibility needs. Using these criteria, all but two people were accepted (these two were local to the conference area). During the conference, we added several additional participants as circumstances arose that warranted remote attendance (e.g., changes in last minute travel plans).

Remote attendees had a variety of backgrounds, including 15 faculty members, 13 graduate students, 4 industry practitioners, and 1 post-doctoral researcher. Attendees had a mixture of experience attending CHI, ranging from six first time attendees to one participant who had attended more than 10 times. Five remote attendees faced accessibility challenges (e.g., mobility issues, new baby). Three participants only attended a workshop, two attended a workshop plus the main conference, and the rest all attended various portions of the main conference (e.g., parallel tracks and receptions). Six people attended one day of CHI, 12 attended two days, 9 attended three days, and 6 attended all four conference days.

Remote attendees selected the days that they wanted to attend and then paid $75 USD per day as a registration fee. This was approximately 1/4 of the normal registration cost and reflected the experimental nature of remote attendance. Remote attendees were asked to complete a short training session with Event Presence, the Beam rental company, prior to the conference. This covered basic navigation and social skills for telepresence robots.

Telepresence System and Setup

We used 10 Beam Pros (Beams) as the telepresence robots (Figure 1). Beams are navigable using a keyboard/mouse or an Xbox controller and contain two cameras, one facing forward and one facing down at the ground. These Beams were connected to a dedicated Wi-Fi network at the conference that was hidden from other attendees.

We integrated design recommendations from prior literature in several ways to test their effects:

1. To address the need for personalization and to test feelings of ownership [11, 13, 27], we assigned a unique color (red, orange, yellow, bright green, dark green, teal, light blue, dark blue, purple, and brown) to each Beam and augmented each system with a flag of that color.
2. To integrate past design recommendations that systems be uniquely identifiable from the side or at a distance, the flags stood at approximately 6’8" (2m) in height, making them easily visible from all angles and in a crowd [13]
3. A photograph of the flag-decorated Beams was provided to remote attendees via an informational website before and during the conference to provide them with an understanding of their appearance when using the system [23, 13]
4. We designated the color of each system on the attendee schedule, allowing them to choose their system, to test whether remote attendees would develop a sense of ownership [13] toward specific colors or would choose to identify themselves by consistently using the same colored system.
5. We attached a map of the convention center, shown in Figure 2, to the Beam to instruct physically present attendees on how to help abandoned Beams (with no one logged in) by pushing them to the nearest charging station [13].

Convention Center Layout

The conference took place in the San Jose Convention Center and spanned three floors: the Concourse, which contained the plenary talks, workshops, and parallel tracks (Figure 2, top); the Parkway, which contained the registration desk and a small number of parallel track sessions (Figure 2, bottom); and the Lower Level, which contained parallel tracks (Figure 2, bottom). The Lower Level was a small section of the Parkway that required additional stairs or an elevator to reach. We placed Beam charging stations on each level, shown in purple on the maps, near either an elevator or high traffic area. It took approximately five minutes to drive a Beam—at top speed, with no local attendees present and without being stopped by people for interactions—from one end of the Concourse level to the other end.

Scheduling

Remote attendees received the maps shown in Figure 2 as recommended by prior work [13] and we posted a schedule online that allowed them to pre-select times that they wanted to connect into the conference with a priority rating. After participants had requested time slots, we modified the schedule to optimize for people’s highest priority requests and the availability of Beams, assigning ten people at most to any single time slot. Times with fewer than ten high priority requests were left open and remote attendees were allowed to sign up and log in on a first-come first-serve basis. Included in the schedule was a listing of all ten Beams, each identified by their unique color, and their last known location. Remote attendees were asked to update the location each time they disconnected. Our goal was to allow remote attendees to see where the Beams were docked, in case they wanted to pick a Beam in a certain location (e.g., near the talk they were about to go to). When a participant’s time slot came up, they could connect into their reserved Beam. They were told to return the Beam to one of the docking stations after their usage. Beam batteries lasted between 6 and 8 hours, so this was necessary to ensure that they had enough charge to last the full day. It also created several common locations to find the Beams when connecting.

Management and Technical Support

Telepresence was managed and supported by the two telepresence co-chairs and two on-call student volunteers (SVs) that rotated every two to four hours depending on the time of day. We created a backchannel in Skype for conversations, monitored by both the co-chairs and the student volunteers, where remote attendees were told that they could ask for technical support or converse with other remote attendees. The level of involvement and commitment varied by the SVs. Some were highly proactive and moved around the conference venue to find and help remote attendees. Others were passive and waited for problems to arise, at which point they would respond. In addition to monitoring the backchannel, the co-chairs and the student volunteers also did regular rounds of the convention center to recover Beams that had lost connection or to help remote attendees that seemed stuck.

DATA COLLECTION AND ANALYSIS

Due to the scale of the venue and number of potential activities that remote attendees might be engaged in, we chose to collect data in several ways.

Pre-Conference Survey or Interview

Participants were asked to complete a pre-conference survey so we could gauge their expectations prior to the conference. For example, we asked them what they planned to do at CHI, how they were preparing for the conference, and if they had any concerns before attending. Sixteen participants completed the survey and we asked the same questions in semi-structured interviews with an additional four participants to gain a deeper understanding of a select group of attendees. For these interviews, we purposely picked four participants with different geographic locations, affiliations, and work positions.

Daily Online Survey

We created an online survey that participants were asked to complete at the end of each day of their conference attendance. The survey asked open-ended questions about any difficulties they had experienced, preparations or accommodations they had made, and about their choice of system. For example, “Did the size of the convention center or volume of people affect your experience? If so, please explain." “Did you find it beneficial to have Beams parked in various locations? Why or why not?" and “Did you take any special care with the way that you appeared to others at the conference? If so, what did you do?"

Twenty-six of the 33 participants completed the daily survey. The median number of daily survey completions per participant was one with a maximum of four. We used open, axial, and selective coding to analyze the daily survey responses where we looked for main and recurring themes and categorized them.

Field Notes and Observations
We observed the remote attendees throughout the conference, taking field notes and comparing them between experimenters each day. Due to the venue size and number of systems in use, observations were largely opportunistic, varying between fly-on-the-wall and direct interactions. Observations took place in the hallways, conference talks, and exposition areas where we noted where Beams were located and parked, how they interacted with local attendees, and how they navigated through the environment. We analyzed our observations and field notes in conjunction with our interview responses as part of a coding process where our observations yielded a more detailed understanding of the interview results.

Focus Groups
We held two focus groups, one Wednesday in the late afternoon and one Thursday morning (the main conference sessions ran from Monday-Thursday). We invited all remote attendees to join these groups to discuss their experiences, hosting a Skype call for those who were not scheduled for a Beam. We chose the varying start times to accommodate attendees in different time zones.

The goal of the focus groups was to probe more deeply into participants' experiences and build on the daily survey responses. Discussions and questions focused around navigation, personalization, interactions with local attendees, and the conference venue. Only one person attended the first focus group and five people attended the second. Each focus group lasted approximately one hour where we were able to more deeply engage with the select group of remote participants about their experiences. We performed a thematic analysis on transcripts from the focus groups to draw out key insights.

Backchannel
We logged the Skype backchannel and performed coding line-by-line. We also identified and categorized the (most likely) intended recipient of the message and subject of the post. Our goal was to understand how the backchannel was used, including the conversational focus and participants.

CHI Attendee Survey
In addition to the daily surveys completed by remote attendees, we asked two questions in the post-conference CHI survey, requesting that participants describe how they felt about having the Beams available and why they may or may not recommend using them in the future. We received 369 qualitative responses and performed a thematic analysis to understand local attendee perspectives.

Next we discuss our findings for each of the factors that were increased in scale. In each section, we first provide context for our observations in relation to prior work, then highlight additional key insights. Some results occur as a result of multiple scaling factors and, in these instances, we point to the new insights in multiple sections to highlight the factor-specific findings. Quotes list the data source of the quote, followed by P#, where the # denotes the remote participant's ID.

(1) NUMBER OF PEOPLE
In prior work, remote users have operated in environments with multiple users, such as workplaces [11], museums [20], restaurants [20], and conferences [13]. These studies have surfaced insights into the effects that robotic telepresence may have on the behaviors of locals as well as people who are not directly interacting with the remote user (bystanders). We describe how these findings manifested at CHI, along with additional insights.

Validation: Novelty Effect and Local Disruption
Past research has illustrated that in public settings, an increased number of bystanders—people that are not directly interacting with the remote participant—also increases the amount of disruption caused by the presence of the system [13, 20]. This novelty effect [8, 13] draws attention to the remote user and can invoke a variety of feelings. Some people enjoy the additional attention they receive, while others feel self-conscious and sometimes dislike it [20]. We found this to be consistent with the experience at CHI, with 44 open responses from local attendees saying they felt the Beams were disruptive and most remote attendees voicing concerns:

> *“It's real work. It's really difficult. I really like that I have the feeling that I'm at the conference as a person. On the other hand, I feel like an alien because everyone wants to take a picture with me, and everyone talks to me, and it's ... I don't know. It's very strange, and I have mixed feelings about it."* – Focus group, P1

New Insight: Pranking and Abuse
Although research has briefly touched upon the possibility of pranking being directed at remote users of robotic telepresence systems [13], our study is the first to observe and report this behavior:

> *“4 times in one day, a guy would step on my Beam to stop it from moving, and then titter amongst his friends. They always travelled in a gaggle, and seemed to think it was funny. That the SV on two occasions voiced the attitude that "boys will be boys" didn't help. Does that tell us they aren't seeing it as a person? Or that it's more ok to bully when telepresence is involved (we know that!)."* – Daily survey, P6

Remote participants seemed to experience increased levels of harassment as the conference continued:

> *"I also noticed that the attendees were less patient with me today than other days; again, I got the impression that I was an annoyance and inconvenience, which is not a great feeling when trying to participate in a conference. People seemed to feel free today to push my Beam around and in general to act as though I was a piece of furniture rather than an attendee. Not good."* – Daily survey, P22

We also observed local attendees jumping on or kicking charging stations and remote attendees' Beams during sessions. The severity of these cases seemed to increase over time, escalating to reports of vandalism, where remote attendees reported someone ripping the colored flag and antennae off of their Beam, and defacement, where people plastered all of the Beams with stickers from their university's research group.

New Insight: People as Obstacles

Although prior work has cited some difficulties with physical obstacles and maneuvering through crowds [13], our study is the first to report observations where people presented serious obstacles and collisions. Of the 194 comments about use of the Beams by local attendees, ten reported being run over or hit by a robot; however, although remote participants said they were worried about hitting people, none reported awareness of collisions. People became obstacles not only in the break areas between sessions [13], but also in the transitional hallway spaces between talks and the expo halls. For example, a number of the parallel sessions were overcrowded, with attendees spilling out into overflow areas outside of the rooms. In these crowds, many local attendees sat on the floor. These factors increased the number of places where remote attendees had difficulty navigating. Participants also reported having difficulty attracting the attention of locals:

> *"I really want Ben Hur spike wheels – or a way to nudge ppl out of the way, OR that "beep beep" noise that trucks make when they are backing up or that airport carts make – anything to get ppl out of the way. Esp. when ppl are busy looking at their mobile phones – they walk right in front of oncoming robots...even in party mode [sound setting], they either can't always hear me or they are just too focused TO hear...I did YELL "BEEP BEEP" but that didn't always work."* – Daily survey, P6

Similar to prior research [13], we observed remote users finding workarounds, such as positioning themselves in the back of presentation rooms, giving up on seeing the slides and choosing to just listen to talks. A new solution that remote users engaged in was dedicating part of each coffee break to pre-position their Beam, described next.

New Insight: Pre-positioning Breakdowns

A combination of all five of the factors we explored created conditions where a new workaround behavior emerged among remote users. The obstacles presented by the number of attendees, venue size, and environment complexity added to the time required to maneuver between locations. The scarcity of systems constrained options for the placement of Beams. Activities happening in one's local time zone were sometimes misaligned with the conference time zone making it hard to get to a session at the 'right' time.

As remote users became accustomed to these constraints, they began to adapt their behavior, logging in early or using coffee breaks to pre-position the Beam at their next session:

> *"I want to go to Part 1 and 2 of UI Design in Agile later this pm. Can I just leave Beam in the room (210G) during the break? I have it signed out. (I am in CT- will need to eat dinner and feed a baby, so 40 minutes is already cutting it close)"* – Backchannel, P10

Student volunteers noticed this behavior during the first day while doing routine checks for systems that had disconnected in session rooms. In each case, we would check on a Beam to find that a remote participant was there, often sitting by themselves in the room, waiting for the next session to start. Some participants mentioned in the backchannel that they had pre-positioned a Beam to prevent it from being moved by others:

> *"Just parked the Light Blue 2 in LL21F for the next session in a front position, would be great if you can leave it there"* – Backchannel, P12

We witnessed several breakdowns that occurred as a result of this type of behavior.

Scheduling collisions. Although some participants had requested contiguous time slots throughout the day, many had prioritized attending events that occurred at sporadic times. This meant they only had access to a Beam at certain times in the day and these were often not contiguous. When participants either had difficulties getting out of crowded talk rooms to return to the docks or attempted to log in before their reservation to pre-position the Beam, systems would sometimes become overbooked and remote attendees with reservations would not be able to log in. These problems surfaced in the backchannel, when Beams were abandoned away from the charging docks:

> *"I used Dark Blue few minute ago but I'm sorry I can't go back to dock in time. I didn't reserve Beam for current session. Now I signed off. Please use this Beam, if you want."* – Backchannel, P18

Unintentional eavesdropping. The combination of system scarcity and participants pre-emptively positioning systems meant that once a remote attendee had moved a Beam, they sometimes did not want to log out for fear of the Beam being taken or moved by another user. This often meant that remote attendees were left sitting in an empty room waiting for the break to end. During this time, some remote attendees walked away from their computers or covered their cameras to signal that they were unavailable, similar to strategies found in prior work [13]. However, unlike prior findings where balancing public and private environments resulted in locals overhearing information from remote participants' private lives [13], we found remote attendees eavesdropping on unaware locals:

> *"I was in the digital civics thing. I put this [paper up to block my camera]. As soon as I put this thing on, I was sitting at some table with, I think it was <name removed> actually, and he said, "oh yah, let's unplug her." There was another woman there and she kicked me. Not hard,*

> *but lightly, and she said, "yeah, unplug her." And I was like what the hell is going on here. Let's turn it off, and I just turned it off. I was like, "whatever." Did they feel threatened? I don't know. It was bizarre."* – Focus group, P9

In other cases, the remote attendee would suddenly react or interrupt a conversation without having been visible, introducing an awkward element to the exchange. In one case, the remote attendee did not verbally or visually engage, but instead periodically placed a comical image on the screen, resulting in the disruption and abrupt disengagement of the local conversation.

(2) RATIO OF USERS TO AVAILABLE SYSTEMS

Unlike prior work, remote attendees shared access to a limited number of telepresence robots. We observed that participants tended to stay on the same Beam until the end of their time slot and that the scarcity of Beams led to low numbers of no-shows and high participation.

New Insight: Hierarchy of Telepresence Needs

One of the surprising insights was the priority system that remote attendees used to choose a Beam.

> *"I chose based on floor, and how well the beam was working (i.e. one had low battery, another audio that cut out) and what was available."* – Daily survey, P11

From the observed patterns and interview responses, it was clear that participants had a hierarchy of telepresence needs dictating how they were selecting a telepresence robot. At a basic level, participants had to ensure that a working Beam was available to connect into. Following that, they cared about conveniences such as the proximity of the Beam to a desired location and its battery life. Only after those needs were achieved, which sometimes did not happen, did remote attendees think about the personalization of the Beam and their ability to self-project their identity.

Utility over personalization. A number of past studies in robotic telepresence have explored the advantages of personalizing the system and illustrated that users may develop a sense of ownership over time [11, 13, 27]. Informed by this work, we equipped each Beam with a uniquely colored flag to allow remote attendees to personalize their system choice.

We found that although prior literature suggested that a unique appearance, being able to visually distinguish the system from all angles, and awareness of how the system appeared would increase usability, we found that remote attendees prioritized convenience (e.g., location and charge) over identity construction (e.g., colored flags), as shown in Figure 3.

System hopping. Participants on workshop days capitalized on available systems by "hopping" from system to system to jump across the convention center, thus avoiding the need to navigate:

> *"It was convenient to be able to beam to the coffee station. But that might not be possible on a weekday when all Beams are being used. It would have been nice if there was a sign next to the docking stations so you knew where you were."* – Daily survey, P21

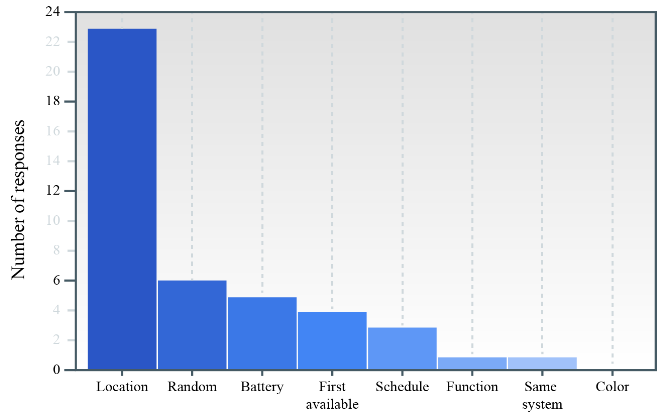

Figure 3: Criteria remote participants prioritized in choosing what system to use.

While this could have theoretically been done at any point during the conference, the scarcity of the Beams and the fact that they were fully booked during the main conference program meant that this valuable and timesaving strategy for navigating the large conference venue was only possible on workshop days (only three people attended workshops).

Coordinating system swaps. Although they weren't able to hop between systems during crowded times, participants compensated by attempting to coordinate with others (from the previous timeslot) in the backchannel, trying to match their desired location with others who were trying to log out. However, this broke down when the system was intercepted by an unintended user:

> P14: *"is (sic) anyone beaming out on the second floor? i need to go to 220B"*
> P24: *"I'm heading ot the hallway then I'll Beam Out...Drak Green available...or at least I'm not in there anymore"*
> P28: *"hey i signed on to the dark green. hope thats ok? gotta get to a demo"* – Backchannel

(3) VARIETY OF ACTIVITIES

Similar to prior work, we found that participants enjoyed the ability to participate in interactive sessions [13]. Beyond this work, we saw an increase in the variety of activities that remote users attended.

Validation: Going Rogue

Prior work had one participant "go rogue" during the conference, using the system outside of the organized parameters [13]. We experienced a similar situation with several remote attendees at CHI; however, the number of systems that this occurred for and the area that they were distributed in was increased over past findings.

(4) TIME ZONE DIFFERENCES

Insights from prior work in remote telepresence at an academic conference identified some of the challenges faced by remote users in balancing the demands of their local job with their remote attendance [13]. Over the course of the conference, we observed a number of strategies and adaptations.

New Insight: Planning Strategies

Participants planned for the challenge of balancing local demands, such as family needs, with remotely attending a conference in a variety of ways. Some participants set up a dedicated station for logging in and ensuring that a sufficient connection existed:

> *"Yes, because I was worried my wifi connection at home was not sufficient for the Beam, I stayed at the office until the end of my Beam sessions. On Monday, this was until 3:30 am. On Tuesday and Wednesday, this was until 1:30 am."* – Daily survey, P28

Other participants took time off from their regular work:

> *"Actually because I was doing this I actually said, "I'm not coming in to work," because during those two days, I'm going to be working at home at night going to the conference. It wasn't bad. I rearranged my schedule around it. It does get tiring. At midnight, I'm pretty much pooped."* – Focus group, P9

While some participants planned these changes ahead of time, others adapted as they grew more experienced:

> *"I'm on an eight hour time difference. On the first day, I tried to come to the university and do work in the morning and then do the conference, so I was at the interactivity grand opening which ended at 3:30am. The next day I just decided that I'm going to treat this as work and start my day later and end my day later."* – Focus group, P28

Large time zone differences had varying effects on participants. Many remote attendees in Europe took advantage of their time zone differences to log in after their workday:

> *"Time zone difference was very convenient. Used the Beam from 14:00-1:00 which works nicely with my weekend schedule."* – Daily survey, P21

Participants with extreme time zone differences, such as the Australasia region, made adjustments to sleep schedules:

> *"Everything between 2am and 6am for me, which is the bulk of the day in San Jose."* – Daily survey, P9

One participant with a 16 hour time zone difference put in a full day of work and spent her entire night remotely attending the conference for three days straight, napping for 1-2 hours between shifts:

> *"Time zone of San Jose is quite different from that of Japan, but I attended events all night. Actually, I'm sleepy now."* – Daily survey, P18

New Insight: Unexpected Logins

The time zone differences also resulted in unexpected logins by remote attendees at odd hours. We found that during the night, some systems had been accessed despite being in a locked up area and at least one remote attendee stated that he had logged in to practice driving.

(5) ENVIRONMENT SIZE

Work in teleoperation [4] and robotic telepresence [7, 13] has focused on the disorientation and difficulties with navigation for remote operators. While we saw manifestations of similar difficulties, we also observed several new challenges.

Validation: Disorientation and Navigation Challenges

Although we followed design recommendations from prior work by providing remote attendees with a map of the venue [13], participants still reported difficulty orienting themselves:

> *"It takes quite a while to 'walk' from one level to another! At one point I got lost in the big exhibit hall. I'm finding it very difficult to keep my bearings in the big open spaces; I simply could not find the exit and ended up asking a group of students to help me to get out."* – Daily survey, P2

The number of remote attendees and the inconsistencies in participants updating the location when logging out increased the disorientation experienced when at login:

> *"I had a very hard time matching the Beam dock to the map–very disorienting to suddenly appear and not know where I am and which direction to go!"* – Daily survey, P2

New Insight: Shared System Disorientation

The scarcity of systems, size of the environment, and technical glitches occasionally meant that Beams were abandoned in random places. Remote attendees commented on how disorienting it was to log into a system in unexpected locations:

> *"I just found a beam in an elevator. Does it belong to someone?"* – Backchannel, P11
> *"<name removed>, did you just leave brown somewhere? I Beamed in, but it is not at a dock, so not sure where I am ??"* – Backchannel, P10

New Insight: Focus on Navigation and Utility

Remote attendees felt that having the Beams in different areas was helpful and it facilitated their choice of system. In particular, having charging stations on each floor allowed many participants to avoid the elevator, where they needed to request help.

> *"I really like the fact that there are upstairs and downstairs beams. This makes it much easier to get around. However, the downstairs beams are close to session rooms but the upstairs beams are not. IT (sic) would be nice to have a shorter 'walk' to rooms since one has to get there so early. The downstairs beams also seem to be close to the main stairway attendees use, which makes them great for serendipitous bumping into folks. I don't know if that is true of the upstairs ones."* – Daily survey, P11

This focus on navigation and utility is reflected in the earlier Section: Hierarchy of Telepresence Needs.

New Insight: De-emphasis on Opportunistic Interactions

Literature in robotic telepresence systems has heavily emphasized that having a physical embodiment increases the frequency of opportunistic interactions—taking advantage of a chance encounter to engage in an unplanned interaction [11, 27]. These interactions are usually cited as taking place while transitioning through the local environment [11, 27]. However, we observed that as remote users navigated through the environment, they optimized for different outcomes. The strategies of pre-positioning, schedule pre-planning, and shifting to a priorities based on a hierarchy of telepresence needs led to participants sometimes perceiving opportunistic interactions as obstacles:

> *"I want to get to somewhere before the talk starts. I want to be there early so I can actually get into a good spot, but I couldn't because I kept getting stopped by people to take selfies."* – Focus group, P26

As remote attendees adapted to the additional challenges of interruptions caused by abuse and increased attention due to the Beams' novelty factor, the priority placed on navigation and pre-positioning above socializing became increasingly apparent.

DISCUSSION

While our results support the generalizability of findings from a number of previous studies, they also highlight the need for careful consideration of how these effects evolve as they grow to meet large-scale event demands. For example, while literature has touched on the possibility of pranking targeted at remote users [11], we observed instances of abuse that became more severe over the course of the conference. This effect may be tied to the phenomena of crowd psychology [21], where being part of a larger group may grant a sense of anonymity and loss of a sense of responsibility. Such a shift suggests that venues with large populations (e.g., sports events or larger conferences) may not be a good fit for the use of robotic telepresence systems, as there may be an increased threat of systems being permanently damaged or rendered unusable. Or, if telepresence robots are used in such settings, designs should provide increased mechanisms to promote additional security (e.g., cameras to easily see behind the robot, location tracking of robots) such that people may be deterred from such negative acts.

Prior work has also examined strategies for time-shifted globally distributed teams and found that people work hard to align their calendars with remote colleagues, including shifting their schedules and sometimes working from home to accommodate others [24]. Although our findings had some similarities, the circumstances in our study differed in a number of ways. For example, our participants attended a limited time event with an inflexible schedule and high number of parallel tracks. Additionally, remote participants shared access to the telepresence systems and the interactions at the conference were not expected to be sustained over a long-term collaborative project. As a result, remote attendees in our study were willing to engage in arguably unsustainable strategies to compensate for time zone differences, such as staying up all night or taking days off of work.

Although little can be done to temporarily change time zones, future systems could be designed to provide a bidirectional shared context. For example, telepresence robots might be able to display contextual information about the remote attendee such as where they are and what time it is in their location so that local attendees can understand their context better and adjust social expectations accordingly. This might be done through simple on-screen visualizations showing a timeline or map.

During the conference, we also observed new situations, such as three remote attendees using their lack of physical presence to attend the Diversity Lunch. Despite having not signed up for the lunch, they were able to participate, possibly because they did not need food, a seat, or any of the 'SWAG', as they were not actually physically there. This concept of leveraging the lack of physical presence opens up new opportunities for future research and design innovation. For example, explorations into how a physical proxy may alter social norms or making design changes to allow remote users to transition in and out of embodied form to match the level of interactivity required. This might involve changing the representation of the user on the telepresence robot's display, or even altering the physical form of the robot in some way. For example, a robot that can fold or compact itself when not in use might become unfolded into a standing form when in use.

Last, our new insights into the prioritization of needs and observed workarounds suggest that robotic telepresence, as currently designed, may not be an optimal solution for remotely attending large-scale public events. Participants found some successes, such as leveraging their ability to jump between systems to circumvent physical limitations and improve their experiences, yet, overall, one could argue that remote attendees did not use the telepresence robots in a way that maximized the physical presence of the system. Rather than the Beams providing a physical proxy, akin to the experience of attending a conference in person, many of the features designed to enable remote users in smaller, more controlled situations, were correlated with additional obstacles or breakdowns when environmental factors were scaled up. Instead of using the robots as social proxies of themselves, remote attendees focused their behaviors around achieving specific tasks where the tasks most often targeted viewing technical content over socializing with others. Participant responses also supported a growing body of literature suggesting that effective telepresence systems may require a divergence from designing to simulate physical presence and that a context-specific approach may provide a better experience [20, 18]. We explore the design implications of this point in the next section.

Design Implications

The insights drawn from our research suggest that as various factors, such as population, remote users, activities, time zone differences, and venue size increase, new behaviors and user strategies may emerge. These behaviors have implications for the design of future systems.

For example, the added complexity of large numbers of people, activities, and space suggests a need for investing effort into supporting better tracking of systems. Such systems might show the location of telepresence robots within the conference center on a map as well as other contextual cues such as when a person logged in last. The increase in levels of disorientation as the number of remote users grows suggests a new focus on creating a less abrupt login experience, an area where little attention has been spent to date. For example, designers may want to consider ways of easing remote users into the system environment by gradually fading in the audio/video or providing snapshots of the surroundings at the login page.

Additionally, the design of current systems has largely been binary in the status that they have afforded remote users: either connected or disconnected. While the Beam does have a hold feature, this proved insufficient in our study where remote attendees engaged in a strategy of pre-positioning their Beams and leaving their camera view on. Future systems targeted at large-scale public events with a variety of activities or multiple pauses (e.g., a sporting event) may require additional options, such as allowing users to flag a system as reserved, facilitating a way for users to make positional requests when systems are shared between users, and giving remote users a way to signal a status of being within earshot while not visible.

Our findings highlight that in large-scale events where activities and contexts may vary dramatically, changes to various factors, such as venue size or number of users sharing a system, may result in behavioral shifts. Our results support recommendations for individual systems, such as the ability to connect into a multitude of stationary displays placed in key locations with audio and video streaming capabilities to promote social mingling. Presentation situations or activities where the remote participant is a passive viewer may be better supported through online streaming since few, if any, social interactions happen while remote attendees are listening to talks (except for the question/answer period). Other large-scale events may require other design solutions, such as creating stationary systems that provide better audio in crowds and support body movement to participate in cheering for sporting events.

While changes may be made to current telepresence systems to more effectively target them at particular activities, the variety of activities, obstacles, and ever-changing contexts we observed suggest that a single one-size-fits-all system may not be the optimal solution for large-scale events. Instead, we propose that a more effective approach may be a group of telepresence technologies that allow remote users to transition between them. For example, allowing remote attendees to migrate between life-sized situated displays that maintain a visibly available presence in crowded mingling environments, robotic telepresence in interactive sessions where mobility is critical to the experience, and livestreaming combined with a summative video display for activities where the remote participant is a passive viewer, may facilitate a better user experience and allow users to more gracefully adjust to the shifting needs of large-scale events. While our results largely highlight new behaviors and insights in academic conferences, they also reveal opportunities for a new generation of research and design in telepresence for large-scale events.

LIMITATIONS AND GENERALIZABILITY

Although our study successfully increased five factors from prior work and placed remote attendees in a large-scale public event, it was not without limitations. The large space, number of activities, higher attendance, and time zone differences made it impossible to observe all of the interactions that took place. While we used multiple data sources, we were unable to report a ground truth on the frequency and rate of adoption of many behaviors. As a result, we were not able to report precise numbers for some of the reported insights. Although we collected responses from the post-CHI survey, the limit of two questions also meant we were not able to gain a nuanced understanding of local attendee perspectives. Additionally, the novelty of having robotic telepresence systems may have affected participant behaviors and further research is required to ascertain whether the behaviors we observed would continue in situations where such systems are commonplace.

Last, our work looked at one type of large-scale event, an academic conference with a technology focus. Large museums and tradeshows are likely quite similar to portions of academic conferences like CHI. They both have a large volume of local attendees, are housed in large venues, and have exhibitions or booths that share characteristics with the poster presentations and demonstrations at CHI. People may also connect from around the world. However, the types of people that would attend these events would likely be much broader than the technology researchers and practitioners that attend CHI. This may create different reactions to telepresence robots. Large-scale events like concerts would also resemble CHI in the volume of attendees, venue size, and breadth of geographic locations that people may attend from. Yet the environment could be quite different with loud noise and greater difficulties with positioning oneself to see the view of the stage, as compared to seeing a speaker at a conference. Thus, although our findings share many characteristics with a variety of large-scale events, further study is required to test the generalizability of our insights.

CONCLUSION

Research in robotic telepresence has largely taken place in small, semi-private settings using dedicated systems. However, robotic telepresence systems are envisioned to empower users beyond these contexts, helping them to attend large-scale public events such as concerts, sports games, museums, and professional conferences. Our study tested the generalizability of prior findings by increasing five factors to more closely match the needs of large-scale events: (1) number of people; ratio of users to available systems; (3) variety of activities; (4) time zone differences; and (5) environment size. Our results showed that as the scale on such factors increased, remote users altered their behaviors to prioritize functional utility. Our findings raise new considerations for how the users of these systems should be treated and highlight opportunities for optimizing the design of these systems for large-scale public venues.

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