Embodied Social Proxy: Mediating Interpersonal Connection in Hub-and-Satellite Teams

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ABSTRACT

Current business conditions have given rise to distributed teams that are mostly collocated except for one remote member. These "hub-and-satellite" teams face the challenge of the satellite colleague being out-of-sight and out-of-mind. We developed a telepresence device, called an Embodied Social Proxy (ESP), which represents the satellite coworker 24x7. Beyond using ESPs in our own group, we deployed an ESP in four product teams within our company for six weeks. We studied how ESP was used through ethnographic observations, surveys, and usage log data. ESP not only increased the satellite worker's ability to fully participate in meetings, it also increased the hub's attention and affinity towards the satellite. The continuous physical presence of ESP in each team improved the interpersonal social connections between hub and satellite colleagues.

ACM Classification Keywords

H.4.3. Information systems and applications: Communication applications: *Computer conferencing, teleconferencing, and videoconferencing*.

Author Keywords

Distributed collaboration, embodied video conferencing, telepresence, empirical study.

General Terms

Design, Experimentation, Human Factors.

SUPPORTING HUB-AND-SATELLITE TEAMS

Integrating remote workers into distributed teams continues to be a challenge, especially as more companies add remote sites to attract and maintain talent around the world. As companies transition from collocated employees at a centralized site to distributing work among newly added sites, teams may need to interact with isolated colleagues at remote locations. Asymmetrically distributed teams can also result from other business trends, such as out-sourcing, hiring or retaining someone who needs to live in a different location, or consultants that remotely join a team for a time interval. This asymmetrical distribution brings a focus on the challenges of integrating these remote *satellite* workers with the center of gravity of collocated workers at the *hub*.

We are interested in supporting these *hub-and-satellite* teams, which are an important and under-studied class of distributed team. This fundamental asymmetry presents distinct challenges compared to other topologies of distributed teams. Collocated teammates reap the benefits of face-to-face communication, continuous awareness of others' availability and work activity, and readily initiated ad hoc conversations [9, 22]. Teams that are evenly distributed between two or more sites offer a social context at each site. The solitary remote satellite worker, however, is a secondary participant in meetings, unable to participate in hallway conversations, and, in short, out-of-sight and out-of-mind. The satellite worker experiences the technical limitations of remote collaboration technologies (e.g., audio, video, awareness), *and* the social effects of being separated from the team's center of gravity.

We developed the Embodied Social Proxy (ESP) concept to address these deficits by giving the satellite worker a physical embodiment in the workspace of the hub team. An ESP is a videoconferencing terminal dedicated to a specific satellite worker for realtime communication (Figure 1) and otherwise provides awareness information about his availability and work activity (Figure 3). ESP is small enough to be moved among meeting sites but large enough to show the satellite worker at roughly human-scale.

RELATED RESEARCH

Much of the research in CSCW has been dedicated to understanding how to support distributed work. Studies of how informal communication occurs in organizations [9, 22] have informed the development of a wide range of systems to support distributed collaboration.

One line of exploration investigated using video connections among physically distributed teams. Media space systems [2, 7, 18] have enabled high-fidelity video and audio connections among individual offices and shared

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Figure 1: A meeting where one remote satellite worker is represented by an Embodied Social Proxy.

common areas. Media spaces typically focused on connecting physical spaces, some of which were dedicated to people (offices) while others hosted a range of people that flowed through them (lounge areas). While media spaces have been used to create a "shared office" between specific remote collaborators [1], they have not been used to provide a persistent connection to a particular person, especially as that person moves around in space.

Another line of research explored various embodiments of remote participants. The Hydra system [20] embodied each participant into a separate desktop videoconferencing terminal to enable users to naturally refer to each other. Android-like embodiments [19] of the remote participant were explored to naturally evoke human interaction patterns with them. Laptop-based portable embodiments [24] enabled carrying a video conferencing terminal into a variety of environments where it could be set up on a table to interact with meeting participants. Robotic embodiments [12, 17] enabled a remote user to move about and engage with people in a variety of locations. AccessBot enabled disabled people to join meetings through a robotic life-sized, high-fidelity display [11]. Jouppi's system [8] even put the remote operator in a CAVE to simulate mutually embodied interaction, reducing the asymmetry between the environment of the mobile robot and that of the operator.

Each of these prototype embodiments explored a different space along the dimensions of amount of technology, implementation practicality, and the amount of mutual experience or immersion between the remote and hub collaborators. While various prototypes have demonstrated concepts, we are not aware of any long-term deployments of these technologies to date. We aimed for a point that would afford viable implementation and deployment of a number of units in our company to enable studying and understanding long-term deployment issues and the impact on the social dynamics of the team.

While video provides a natural and potentially effortless way of sharing one's activities, other approaches may be more efficient and less intrusive. Nardi et al.'s [14] study of instant messaging (IM) in the workplace showed that a large amount of awareness information can be shared among a distributed group using only text. Other systems

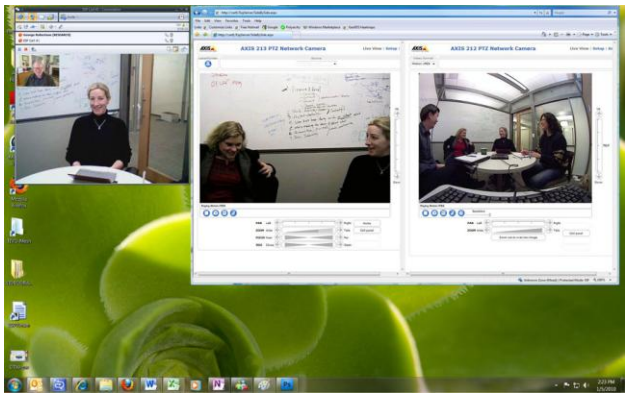

Figure 2: The remote satellite worker's view of the meeting shown in Figure 1 consists of three camera feeds.

have explored sharing occasional snapshots [5], other indicators of activity awareness inferred by the computer [4], and even physical manifestations of others' awareness information [10]. Erickson et al. [6] developed a concept of social proxies as visualizations of the actions of distributed team members on shared tasks to enable more shared awareness among them. A recent survey collected more kinds of awareness needs among distributed workers [3].

Studies of systems deployed in real usage have yielded some surprises. Even though text is very low fidelity, its pervasiveness and lightweight usage have fueled the popularity of instant messaging, and more recently Facebook status updates and Twitter. While video is high fidelity and easy to use, it also brings privacy concerns about the information it reveals. Since collaboration prototypes inherently connect people together, their design must also attend to the social context and patterns of acceptance and use that they evoke.

Recent studies have also explored the dimensions that characterize the distribution of teams. O'Leary & Cummings [16] identified how spatial, temporal, and configurational dispersion of teams affect collaboration. Beyond physical proximity, Wilson et al. [23] found that communication engagement, organizational factors, and even individual differences can affect the *perceived proximity* among collaborators. While prior work identified contextual factors that affect collaboration, we explore how technology affordances can influence a sense of proximity.

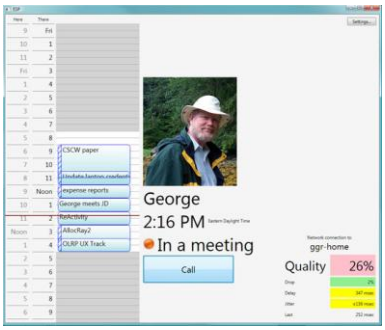

Figure 3: When not being used for videoconferencing, ESP displays some awareness information about the satellite.

METHODS

We conducted studies of ESPs in three phases. First, we performed *iterative design* on two ESPs representing two satellite members of our own research group. Second, we contracted an external consultant to do a *pilot* study of the use of these two units. Third, we studied four ESPs in unrelated product groups within our company in a *deployment* study to see how teams outside of our research group would react to ESPs.

Iterative Design

We initially designed ESP to meet our own need to integrate two satellite members into our research team. The two satellite workers (George and John, co-authors on this paper) were both employees of our company and members of the same research organization. They both interacted with colleagues located in the company headquarters site. George worked from his home office located three time zones earlier than the hub; John had a desk in the open plan workspace of another organization in the company 1400 km away but in the same time zone as the hub.

ESPs were used to conduct everyday meetings with colleagues at our headquarters site. Beyond meetings of the ESP research project itself, they were used in many other meetings that the satellite workers were involved in, and included non-research colleagues (e.g., product managers, patent lawyers). As of this writing, George and John have been using their ESPs for 15 and 12 months, respectively.

The design (shown in the video figure) evolved to include a 20" LCD screen, a webcam, a mechanical pan-tilt-zoom network camera, a fisheye network camera, and an echo-cancelling speaker/microphone all mounted on a cart (Figure 1) along with a CPU, uninterruptible power supply and networking hardware. Videoconferencing could be initiated and terminated by either the hub or the satellite. While in videoconference mode, the satellite's video filled the screen (Figure 1) and the satellite saw multiple video feeds (Figure 2); otherwise the screen showed the satellite's calendar, current and historical IM availability, and connectivity information (Figure 3).

Pilot

We contracted an external researcher to study our research team's use of two ESP units. At the time of the pilot study George had been occupying his ESP for seven months and John for four. Three primary techniques were used to gather data: a diary study, one-on-one interviews, and direct observations of meetings where one or both ESPs were used. Data included daily diaries of ESP use by the occupants, audio recordings and transcripts of interviews, and video recordings and photographs of meetings involving ESP usage, from both hub and satellite sites.

Deployment

We built four more ESPs for four different hub-and-satellite product teams in our company (see Table 1) and studied the deployment using an A-B-A design. We studied the deployment through ethnographic meeting observations, interviews, surveys, and usage logs. Our data collection focused on the short-term effects of ESP on meetings and the long-term effects on the relationships among the team.

Table 1: We deployed ESP units to four product development teams for six weeks.

Team name	Shared Components	Enterprise Software	Language Design	Product Management
Satellite pseudonym	Fernando	Songyi	Noah	Robert
Satellite role	Jr. Software Developer	Jr. Software Developer	Sr. Software Architect	Sr. Business Product Manager
Time on team	8 months	8 months	8 months	36 months
Distance	200 KM	200 KM	1400 KM	5000 KM
Time zone	Same	Same	Same	+3 hours
ESP home location	Empty office and absent coworker office	Manager's office	Noah's office in hub location	Three different offices of absent coworkers; hallway
Activities performed during deployment	Design (week 1-2); Coding (week 3-6)	Debugging (week 1-6)	Language Design (week 1-6)	Product planning (week 1-6)
Satellite's headquarters visits	Once per month, 1 day per visit	Few	Every other week, 4 days per visit	Once per month, 4 days per visit

During the initial "A" phase we established a baseline for the communication practices and interpersonal relationships in the four teams. We observed at least one meeting for each team. We interviewed the satellite worker and 2-3 of his closest coworkers using a semi-structured interview technique. We deployed a survey to a broader selection of coworkers, receiving 5-7 for each team.

During the "B" phase, we deployed ESP units to the hub teams for a period of six weeks. We observed at least one meeting per week for each team. At the midpoint of the deployment, we performed another round of interviews with the satellite worker and his handler (i.e., the person(s) at the hub responsible for moving ESP to meetings and ensuring that it was working). Throughout the deployment, software on ESP automatically logged its own usage. We removed ESPs from the teams at the end of the B phase.

During the final "A" phase we sought to see how the teams reacted to working without ESP, as well as to identify any changes that might have occurred independent of ESP during this time. We observed one meeting for each team and conducted final interviews with the satellite worker and his two close colleagues. We reissued the survey, receiving 6-8 responses from each team.

We totaled 42 hours of meeting observations. In all meetings we took detailed notes of the meeting dynamics and contents. We recorded some meetings in video or audio and analyzed the recordings afterwards. We coded our notes to identify interaction patterns among the meeting participants. We identified major episodes and recurring patterns in our observations and analyzed them in detail.

The initial interviews explored the collaboration practices of the team and the state of the interpersonal connection between hub and satellite workers. The mid-point interviews probed for changes of in-meeting interaction between satellites and hubs; changes in the social connection between satellites and hubs; and patterns of usage of ESP. The final interviews assessed how ESP withdrawal highlighted the effects of ESP on communication and probed for long-lasting effects that ESP brought to the relationship between satellites and hubs. All interviews were transcribed and manually coded to identify recurring patterns and major themes.

Our survey instrument tracked how hub participants' perceptions about different aspects of their relationship with the satellite worker changed before and after ESP deployment (Figure 4). The survey contained questions that explored in-meeting dynamics when the satellite participated remotely (12 questions), the hub's awareness of the satellite (4), and the social connection between satellite and hub workers (8). The latter included four questions from the social presence instrument developed by Nanda and Benbasat [13]. A within-respondent, one-sided Sign test showed that all seven measures increased significantly ($p < 0.01$). While the hubs' perception of the satellite worker improved for all teams, Noah appeared to benefit the most. While all three topic areas showed significant improvement, in-meeting dynamics appeared to show the greatest improvement.

We coded the ESP's activity log to collect statistics on their usage, as summarized in Figure 5 with total usage time according to the kind of activity for all six carts. The data correspond to the six week period of the deployment study for each of the four participants as well as George and John in our research organization during the same timeframe.

THE SITE OF DEPLOYMENT

All the teams of our deployment had a strict hub-and-satellite configuration, with only one member in the satellite location and the rest of the teammates at the hub. All had their hub at our company's headquarters on the West Coast of the United States. For each team, the hub teammates were collocated on one floor of a single building. All the teams had been working together for several years on the same project.

The satellites varied in their seniority, time working with the team, travel frequency to the hub location, home locations, and time zones (summarized in Table 1). The teams varied in the activities they performed, their working cycles and communication needs. These variations allowed us to contrast multiple dimensions that affected the usage of ESP and the team's interactions.

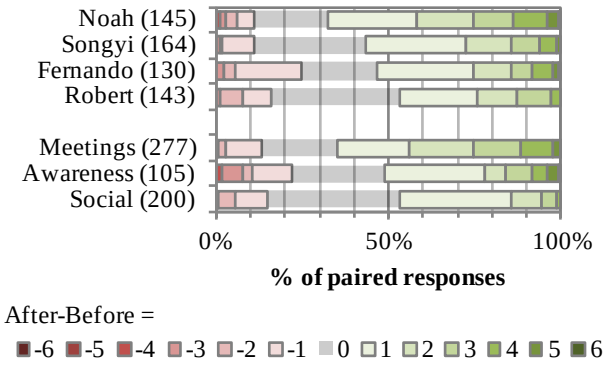

Figure 4: Summary of the changes in the hub coworkers' survey responses before and after deployment. The top four bars aggregate paired responses grouped by team; the bottom three bars aggregate paired responses grouped into three topic areas (across teams). The number of paired responses is shown in parentheses. All questions used a 7-point Likert scale, normalized from 0 (low engagement) to 6 (high).

The Teams

The Enterprise Software team developed a specific component of a large enterprise collaboration product, which had a huge customer base and had to be very reliable. The Language Design team guided the high-level design and architecture of a programming language and compiler. The Shared Components team created the API for a set of software components, used in several different products. The Product Management team worked on the business planning of a large software package, serving as internal interface between business and technical teams, and with large external clients and industry analysts.

The Enterprise Software and Shared Components teams had straightforward engineering tasks to perform using well-established processes. In contrast, the Language Design and Product Management teams engaged in creative, somewhat chaotic ideation and design processes. Their work practice required many ad-hoc approaches, with a great need of continuous, informal communications.

The Satellite Workers

In the Language Design and Product Management teams, the satellite member was a senior employee. Robert, satellite of the Product Management team, was based on the U.S. East Coast and was well integrated with his team having worked remotely with them for three years. Noah, based in a U.S. West Coast city, had been a senior architect of the Language Design team for only eight months at the start of the deployment. Noah described his first few months as "ramping up" with the technology created by his team and building relationships with the team.

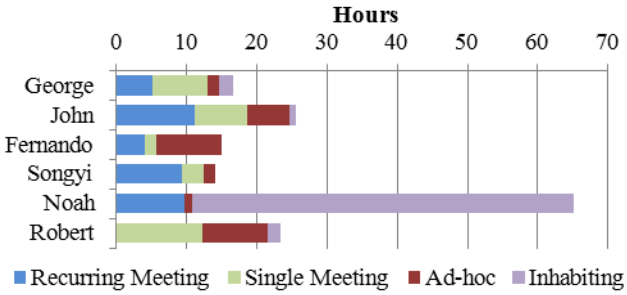

Figure 5: We coded the automated logs to estimate ESP usage according to type of usage activity over six weeks.

To contribute to these teams, their satellites had to proactively participate in the decision process, be vocal, and clearly communicate their points of view. Robert and Noah's remoteness was continually in tension with their need to influence the decisions that their teams took with respect to the products they oversaw. To mitigate this, both senior satellite workers maintained a regular travel schedule to our company's headquarters as a way to remain "influential" in the team decisions.

The other two teams had junior developers as satellites, both based out of a company location in Western Canada. Fernando, from the Shared Components team, and Songyi from the Enterprise Software team, had been in their teams for less than a year. Fernando traveled once a month to his hub location, but Songyi did not. Both had plans to transfer to the company's headquarters locations in the near future.

FINDINGS

We found two main categories of effects that ESP had on the participants of the study. First, we found a series of immediate effects on the interactions of meeting participants when the satellite worker participated remotely using ESP. Second, and more interestingly, we found a series of long-term effects that ESP had in the relationship between hubs and satellite, inside and outside meetings.

In-meeting Effects: "Noah is in the room"

We observed several ways in which ESP increased the ability of the satellite to fully participate in meetings. This enhanced participation created a sense of closeness between the satellite and hub. Tore, Noah's handler, explained:

"What I like about it is that through its combined properties, it actually succeeds in creating the workable illusion that Noah is in the room. It does manifest its physical presence, to a sufficient degree to which … it overcomes the barrier of his physical distance."

Overcoming "the barrier of his physical distance" was not only about seeing and listening to Noah, but engaging with him in a productive dialog while working in the meeting room. Several factors contributed to create this sense of increased interaction within meetings, as explained in the following sections.

The survey results indicated consistently positive changes in the hubs' perception of the satellite's effectiveness in meetings (fifth bar in Figure 4): in-meeting ease of communication with the satellite worker, in-meeting naturalness of interacting with the satellite worker, and the increased satellite worker's in-meeting ability to understand and get involved in discussions with multiple participants.

A physical representation of the satellite worker

The mere physical presence of ESP was seen as powerful reminder of the presence of the satellite worker in the meetings. Will, the handler of Songyi, explained why ESP gave more presence to Songyi in the meetings:

"Just the fact that it is a physical entity that represents Songyi in the meeting. It is hard to think a telephone…, or even a picture of him on another participant's laptop, or a RoundTable device, really does not give him as much presence as an object whose sole purpose is to represent Songyi. So that is kind of powerful in itself."

ESP provided a constant image of the satellite worker, contrary to normal videoconferencing where the video of the satellite would often be obscured by a presentation or document windows displayed by the room's projector. The dedicated video display showing on the human-scale ESP cart positioned at the table combined to provide a powerful reminder of the presence of the satellite in the meeting.

Turn taking in rapid-fire conversations

ESP enabled the satellite workers to naturally take turns in fast-paced discussions. Before introducing ESP, satellites tended to be withdrawn, as they had difficulties acquiring turns and following the context of these fast-paced discussions. ESP put the satellite in a much better position to participate effectively and consistently in these meetings. This was apparent in observations, interviews and question 9 of the survey results (Figure 4).

ESP enabled this enhanced interaction by providing dedicated video to the satellite and having the audio spatially localized with his video. Video gave the hubs non-verbal cues (e.g., facial expressions, gestures) to allow the satellite to take a turn. Locating the speakerphone and display next to each other gave the impression that the satellite's "voice came out if its face," making it natural to turn and look to his image while he was actively speaking. Typical video conferencing arrangements often disrupt the hub's consistent and coherent perception of video and audio, which disrupts these natural turn taking mechanisms.

Multiple cameras for a better understanding

Our iterative design process using ESPs in our group led to multiple cameras to see all the participants, their reactions, and the artifacts to which they refer. In the deployment study, we found that the multiple cameras allowed the satellite worker to have a better understanding of the meeting environment, especially with respect to interactions around the whiteboard. Prior to deploying ESP, satellites found it impossible to follow discussions around objects drawn on the whiteboards. This problem was particularly bad in brainstorming and design meetings, where whiteboard drawings were extensively used to illustrate ideas. Satellites had to either ask for a verbal description of the whiteboard, or remain left out.

During the deployment, the ESP cameras enabled the satellite worker to follow discussions centered around whiteboards. The wide angle provided a whole room view, to see and understand the hub's reactions, and to get information of where to direct the ESP's pan-tilt-zoom camera. For example, when the wide angle camera showed someone approaching the whiteboard, the satellite could use the pan-tilt-zoom camera to focus on what was being written. The pan-tilt-zoom camera was also used by the satellite to attend to the current speaker.

Video was also used to identify the active speaker, helping the satellite workers share more of the context in large meeting discussions. This usage was especially helpful for the non-native English speakers in our deployment, Songyi and Fernando. Keeping track of who said what allowed these two satellites to improve their comprehension of the hub colleagues' comments.

Eye gaze awareness in meetings

ESP's design enabled satellites to naturally see when hub colleagues' were looking towards them through ESP. However, gaze awareness of where the satellite worker was "looking" among the physical context of the hub colleagues was *not* preserved. The satellites and hubs in our deployments became aware of the lack of correct gaze awareness of the satellite, and some tried to mitigate it. Nat commented that the inability to maintain visual contact with Fernando made using ESP more like talking to "Virtual Fernando" rather than the real Fernando.

Noah was conscious that ESP did not convey a good sense of his gaze to the hub. To mitigate this, he configured the video window layout on his workstation to give the hub a sense whether he was looking left or right. Noah positioned his webcam between his two monitors and split the video coming from the wide angle camera into two halves: the right half on his right monitor and the left half on the left monitor. He hoped this arrangement would cause his ESP image to accurately reflect to which side of the hub room he was looking. While Noah was unaware if this configuration had the desired effect, it served as a constant reminder to him that non-verbal elements of his communication might not be well understood by his hub peers.

ESPs as Conduits for Social Interaction

While ESP's positive impact on in-meeting interactions were important, they were largely expected from research on supporting meeting activity. However, our long-term deployments of ESP enabled us to observe how the continual *physical* presence of the ESPs in the hub location was a conduit to induce *social* bonding interactions with the satellites over time.

Naming and dressing the proxy

ESPs were appropriated to better represent the satellite as a person, which caused the devices to become better reminders of the presence of the satellites. Without any prompting, each of the teams gave the ESPs a nickname: "Virtual Fernando," "Virtual Songyi," "The Dalek" (a reference to British TV series *Doctor Who)*, and "Robbatar" (a word play with the word *avatar* and the name Robert). Nicknames demonstrated the attachment between the ESP and the person it represented. Referring to ESPs by their nickname in everyday work situations evoked the satellites in an intimate and playful way.

The carts were also "dressed" to personalize the ESPs and augment their representation of the satellite's participation on the team. In two cases, the ESPs donned hats, to visually relate the devices to the people they represented. Before the deployment, Noah wore a fedora in the office because it "made a big difference" in having his teammates recognize him. To extend this personal statement to his ESP, Noah placed an identical fedora on top of his "Dalek," unequivocally relating the ESP to him.

Robert's ESP was also adorned with a baseball cap by a coworker. The cap became a way to recognize Robert's ESP more easily. Sandy, Robert's coworker, reported that when strolling the "Robbatar" down the hallways people sometimes would say "Hi Robert!" even if the ESP was not streaming either audio or video, just to acknowledge Robert's "presence" among them.

Familiarity and being remembered

The long-term effect of using ESP, in and out of the meeting room, induced a sensation of familiarity and closeness to the satellite worker. This was especially evident in the case of Songyi, who had seen his direct coworkers only twice since starting at the company. Songyi's team members attributed this sense of familiarity to the exposure to the video image of the satellite, and to ESP's constant physical reminder of Songyi.

For both sides, hubs and satellites, seeing each other's faces, body language, and ways of reacting was very important. Songyi described how he perceived the changes in the interactions he had with his coworkers:

"I think that they feel more familiar [with me], ever since the cart [ESP] was introduced… I can see their face, and they can see my face. When we had a meetings [with the previous conferencing systems], there was no space in the screen for displaying [the video call window], so they were not able to see my face."

This sense of familiarity made the hub coworkers feel they were communicating with a real person that was part of their team, rather than a "disembodied voice on the speakerphone" that was "somewhere up in Canada."

Bodies in the room

ESP enabled the satellites to be both the object and participant of jokes around the carts as the satellite "body" which resulted in bonding interactions. Tore, from the Language Design team, explained:

"[T]here is no end to the amount of jokes that people have told about the Dalek, and the amount of fun that people have had fun around it. It becomes one of these funny things that people share. I think that this is partly because it is attached to him, it becomes his virtual presence. So uh, I think that is a good thing. It helps people overcome the barriers that always come with a new technology. It helps him be present on the team …"

During our baseline observations, satellite workers rarely participated in the meetings' jokes or small talk, missing the opportunity to bond with the hubs in these occasions. ESP changed this situation, both by making the satellites more easily available, since it was continuously dedicated to

them, and by ESP itself becoming a humorous thing, from the start of the deployment, to share among the team.

The physical presence of ESP allowed the hub workers to go beyond verbal references to using their bodies to interact with the satellite worker in ways that are not possible with most computer mediated communication tools. For instance, in a Product Management team meeting, Robert, who was using the ESP, commented on his lack of knowledge of a specific feature that Arthur, his peer, managed. Arthur, also in the room, jokingly demonstrated his disapproval by approaching the ESP monitor and making a gesture of "slapping" Robert. Everyone in the room laughed loudly. Right after this, Rajesh, another product manager in the room, acknowledged that he was also unfamiliar with the same feature, so Arthur repeated the same "slapping" gesture with Rajesh, causing further laughter in the room. Arthur was able to express his disapproval with a joke to Robert using the same gesture that he used with Rajesh. This kind of playful interaction involved the whole team in a bonding experience with the satellite worker, as if his body was physically there.

It is important to note that in most of the instances we observed, jokes involving the body were initiated by the hub coworkers, who experienced the physical presence of the ESP. Satellites went along with these jokes, but generally did not initiate them. The satellites had no physical representation of the hubs to interact with at his location. Also, the satellite's interactions with the hub were limited to what he could do inside of the screen. As one hub team member noted, the satellite worker's ESP lacked "legs" and "arms" to "nag" people on his own. So it was impossible for the satellite to make a gesture like the one Arthur made to Robert, as the ESP was unable to move and approach anyone.

Showing Commitment

ESPs were used in a number of ways to demonstrate the commitment that both sides of the team, satellite and hubs, had to support each other's work activities.

The home location and mobility

The importance of the ESP "home" location evolved from our early design iterations. An early ESP prototype used in our group was kept in a locked lab and brought out only for meetings. This obscure, out-of-sight location limited the usage of ESP, so we moved it to an unoccupied office close to the center of our team's offices and left it on all the time. Small, unplanned meetings began to happen in that office and our pilot study identified the importance of the home office for encouraging interactions with the satellite.

For our deployment study, we asked each team to dedicate office space in the hub to be an ESP home office, which also indicated the hub's commitment to the satellite. Noah's ESP was located in a private office with the display easily visible from the hallway. The privacy and location of this office afforded impromptu and regular one-on-one design meetings there. By contrast, Songyi's ESP was parked in the corner of one of his coworker's office, making it difficult to freely have one-on-one meetings with him.

The diaries during the pilot study documented that almost half of the meetings involving ESP took advantage of its mobility to meet with colleagues in another location. However, moving ESPs around required a hub colleague to take responsibility as *handler* for the ESP. The handler first unplugged ESP from the network and power in the home office, wheeled it to the meeting room (possibly using an elevator to go up or down floors), determined an appropriate location for the ESP, connected the network and power in the meeting room, placed the microphone on the table, and adjusted the audio levels. Our pilot revealed that the success of leveraging the mobility of ESPs depended on the social commitment of handler(s) and the satellite's ability to maintain the handlers' commitment.

The donuts episode

The following story illustrates the commitment of Fernando's manager, Nat, to help integrate Fernando into the Shared Components team. The original home location for Fernando's ESP was out of the way for the team. To encourage more interaction with Fernando, Nat borrowed an office of a coworker who was on vacation for two weeks and moved ESP there. Then, Nat brought a box of donuts and sent an email to the whole team saying: "Donuts are outside the temporary office of Virtual Fernando." Nat used the email to create a sense of familiarity towards Virtual Fernando, as if he was in the office all the time.

Nat's efforts to integrate Fernando had some success. Fernando reported that around five people came to say "hi" to him using ESP that day. When Fernando visited headquarters two weeks later, he was recognized and approached by several of his coworkers, prompted to talk to him by the donuts at his ESP. Fernando said that in previous visits he did not receive such attention.

One-on-one meetings

Meeting one-on-one between the satellites and hubs was a way of demonstrating commitment to have a deeper, engaged conversation. One-on-one meetings were not the original focus of ESP's design. However, its users appropriated this usage to have an engaged conversation, with less distractions, with the satellite worker. In several of the deployments, the ESPs were used consistently to meet one-on-one with the satellite worker.

Nat had regular one-on-one meetings with Fernando, several times a week, to discuss project status or career development issues. These meetings were set up to ensure a good communication between Nat and Fernando, since informal communications were not as consistent as with the rest of Nat's collocated reports. Nat chose to meet with Fernando using ESP because it gave the meetings a more "formal" feel. For Nat, moving away from his desk to call Fernando signaled that he was giving his complete attention during the meeting. Nat used the "formality" of the ESP

one-on-one meetings to signal his devoted attention to Fernando, away from any other distraction.

Noah expressed that ESP changed his one-on-one technical discussions with hub coworkers, providing an "immediate" and "productive" medium, "almost as productive as if I were here." Prior to introducing ESP, he would sometimes suspend deep technical discussions with his coworkers, saying, "We will talk about this when I come to town." With ESP, Noah often continued these discussions, even extending beyond the scheduled meeting time to complete them. The hubs considered that ESP enabled these technical discussions by readily supporting the use of the whiteboard and videoconferencing (which some of them had not configured their desktops to support).

Being there, inhabiting the ESP

Some satellites maintained an open A/V channel through ESP to show that they were available to their teammates. They "inhabited" the ESP by opening a video call during the majority of the work day, even outside of any meeting interactions. Since the satellite could be seen on the ESP display, hub colleagues could notice the satellite's presence as they passed the home office and initiate an impromptu conversation. Inhabiting signaled a strong commitment from the satellite to be available to his hub colleagues.

Noah and Robert regularly inhabited their ESPs during the course of the deployment (see Figure 5). Noah spent the most time inhabiting his ESP, with up to 21 hours in his fourth week. He explained that ever since he learned that inhabitation was possible, it seemed "like the right thing to do: the second next best thing to work every day in the headquarters office." For Noah it was difficult to maintain constant communication with his coworkers, as many of them did not use IM, and the informal discussions he held with his peers often needed a whiteboard.

Feeling connected with his hub team was very important for Noah, motivating him to inhabit his ESP regularly. "I feel that I get a lot out of that, of being here in a virtual way," he explained. Inhabiting ESP allowed Noah to feel more integrated with his team, inducing impromptu conversation with his immediate collaborators. But even if his colleagues did not come to talk with him constantly, "just hearing the voices of the people around me as they go by and talk to each other" was a way of feeling that he was not "isolated."

Inhabiting ESP required effort from Noah's side, demonstrating his commitment to maintain open communication with his teammates. To inhabit ESP in a reliable way, Noah had to work out of his local office (with its reliable intranet connection) instead of working from home. Outside of using ESP, there was little incentive for Noah to work at this local office, since no one from his or related teams worked there.

Differences in the Use Value of ESP

We found differences across the teams in how much value ESP added to the team. Two differentiating factors we observed are the nature of the work that a team is involved in at the time and the seniority of the satellite.

Type of work activity and use value

Teams involved in creative design activities perceived a greater use value of ESPs, as they allowed the satellite members to more fully participate in the design process, inside and outside meetings. Design meetings exercised ESP's support for efficiently participating in fast-paced discussions. ESPs also enabled the satellite to closely follow highly visual explanations of design issues, which often involved whiteboard drawings or gestures from the hubs. Noah explained that drawings and diagrams made on whiteboards were "placeholders for pieces of the systems" that were designed in their meetings.

ESPs allowed the satellites to have a channel for informal communication, allowing the whole team to build consensus for design decisions. Informal interactions were a way of clarifying why certain decisions were taken and how they should be addressed. For Noah it was especially useful to use ESP as a way to get people to "drop by" and discuss, maybe using the whiteboard. As is typical with hub-and-satellite teams, Noah's team would informally talk face-to-face but not go through the effort of a video call, especially because many did not even have a webcam or VoIP client installed on their machines. By inhabiting ESP in a visible home office, Noah was able to attract more informal interactions with his teammates.

The two development teams, Shared Components and Enterprise Software, had more engineering-driven work guided by a software development process. They found that ESP's main value was to help them acquire greater familiarity with the satellite worker. During the second week of deployment, however, Fernando's team had to address low-level design issues before entering a coding stage. During five hours of ad-hoc design meetings, participants expressed that ESP was "very useful" to collaborate with Fernando. Nat expressed that the ESP was great during design meetings as it increased attention to the satellite worker, nuanced understanding of people's reactions in meetings, and ability to see the whiteboard. Taken together with the experiences of the other product teams and our own research group, we see how ESPs are especially useful in design and planning work.

Social standing and use value

The use value of ESP increased with the seniority of the satellites. Both Noah and Robert, the two senior participants, needed to remain "influential," in the decisions that their teams made and ensure that their points were conveyed. ESP gave them, within the context of their team, a way to be heard and remembered, allowing them to exert their influence.

Robert, from the Product Management team, commented that ESP saved him "at least two trips" to our company's headquarters, since he was able to participate remotely in important team meetings. These team meetings were about

contentious issues that, without ESP, would have required travel to the hub location. After using ESP for a few weeks, Robert felt confident to attend remotely using ESP. The meetings were satisfactory for Robert, and he reported he was able to get enough attention, connect well with his teammates, get his points across, and maintain the overall degree of influence he needed in the meeting.

It is important to note that ESP does not eliminate the need for travel, as meeting in person is still important to establish rapport and gain influence with people outside of the team. Shortly after using ESP for the team meetings described above, Robert had to travel for delivering a series of executive briefings. In this context, with people unfamiliar to ESP, he could not risk a technical or social failure in the middle of the meeting. This incident also points out the necessary social context of the hub team that has become accustomed to the technology and is committed to work through the inconveniences of ESP.

DISCUSSION

Based on our experiences with ESP in both our pilot and deployment studies, we found evidence showing ESP improves in-meeting interaction between hubs and satellites and, perhaps more importantly, that it facilitated the social integration of the satellite into the hub team. Nardi developed a framework for understanding the formation of feelings of connection among people [15], which provides a structure for describing ESP's effects on the teams. She identified that interpersonal connection is created along three dimensions: gaining the other party's *attention*, necessary before establishing any kind of communication; establishing *affinity* to create situations where people develop feelings of connection to one another; and *commitment* to express the engagement one has in a mutual project or interest.

ESP drew attention to the satellite worker from the beginning of the deployment, initially due to its novelty and physical presence. This initial burst of attention was sustained by ESP's ability to enhance participation in meetings by enabling the satellite worker to perceive nonverbal cues and engage in rapid-fire conversations.

As time passed in our deployment, ESP was used to create situations that increased the affinity between satellites and hubs. Joking about ESP as the satellite's virtual body fostered an affinity, as both sides experienced ESP together.

ESP allowed both sides to demonstrate commitment to supporting each other in their work activities. Certainly, the home office and the handlers' work in moving the carts around to participate in meetings demonstrated ongoing commitment to the satellites. Conversely, the satellites' inhabiting ESP demonstrated their commitment to be available for impromptu interaction with the hub.

Using Wilson et al.'s [23] model of perceived proximity, we found that ESP usage reduced communication uncertainty and increased engagement, leading to a stronger sense of proximity. While O'Leary and Cummings focused on the impact of physical distance [16], ESP showed how the design and usage practice of the technology could reduce the social distance among distributed colleagues.

ESP increased the social connection between satellite and hubs by providing a proxy to bridge the asymmetry between them [21]. Much of the interactions within the hub that fostered social connection happened in face-to-face situations. ESP provided a way to include the satellite in some of these practices, e.g., chatting before starting the meeting, saying "hi" in the hallways, or joking about the ESPs. While the interactions through ESP cannot substitute for face-to-face encounters to create connection, the continued physical presence of these devices in the hub location provided a way of maintaining the connection between the hubs and satellites.

Reflecting on the distinct needs of hub-and-satellite teams, we note that the asymmetrical distribution was at the root of the challenges of socially integrating the satellite. Nardi et al. [14] found that social connection could be established using lean electronic media, such as IM, in situations where groups are fully distributed. However, our focus on asymmetric hub-and-satellite teams identified situations where the common practice of face-to-face interactions within the hub made using leaner electronic media to connect with the satellite problematic. The inherent asymmetry of the hub and satellite gave rise to the need for a telepresence device to provide an effective way to maintain interpersonal connection.

FUTURE WORK

Our studies document ways in which ESP supports the work of hub-and-satellite teams and identify ways that our prototype could be improved. We must address the eye-gaze miscues caused by the multiple cameras, perhaps by synthesizing the video feeds into a single panorama. We would like to explore how to encourage more ad-hoc conversation. It would also be interesting to augment the prototype with a robotic means of enabling mobility.

Our study was necessarily limited in ways that suggest factors for future study. All the satellite workers and most of their hub teammates were male. Might there be gender effects in ESP adoption? All teams were within a single corporate culture. How would other company or even non-corporate hub-and-satellite environments differ? We deployed ESPs for six weeks and have been living with them for over a year. What are the longer-term effects of ESP? How would ESP change the newcomer-socialization process if it were used from the satellite worker's first day? We selected teams which had ideal hub-and-satellite distribution patterns. Would ESP be relevant to other distribution patterns?

A fundamental design decision in the ESP concept is the persistent association of one device with one satellite worker. While our study documents many advantages of this arrangement, we also encountered people wanting to

use ESPs on an as-needed basis. We need to understand how our "hotline" model of ESP could be complemented by a "telephone" model of a videoconferencing terminal that could be used by anyone (e.g., [24]).

We developed the Embodied Social Proxy device as the physical representation of a satellite worker in a hub team space. The key feature of the design is that a given device always represents a given person. Beyond the design details of the device, we contribute a study of its long-term effects on social relationships in the team. We found that ESP was effective both for supporting the immediate interaction within meetings and the long-term social integration of a satellite worker into a hub team.

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