Master's Thesis of Communication

Exploring How Telepresence Robots Facilitate Long-Distance Family Communication

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Abstract

Many children live far away from their parents' homes due to work, education, or marriage. This creates a need for effective communication tools to bridge distance gaps within families. While computer-mediated communication (CMC) tools, particularly video calls, have become widely used, they still lack support for physical interaction, shared activities, emotional expressivity, and feelings of presence, all of which are crucial for maintaining relationships. This study explores the potential of telepresence robots for facilitating long-distance family communication. Over a two-week period, eight families consisting of 17 local family members (e.g., parents and siblings) and 12 remote family members (e.g., children or children with new families) who had moved out of their parents' home participated in the deployment study. The study focuses on observing how participants engage in shared activities using the telepresence robot within the home environment. We examine key dimensions in telepresence robots that support family relationship maintenance. Ultimately, the findings contribute to discussing the challenges and opportunities associated with telepresence robots for family communication. We also provide design guidelines for designing telepresence robots intended as potential home tools.

Keyword: Human-Computer Interaction, Computer Supported Cooperative Work, Family Communication, Relationship Maintenance, Social Presence, Telepresence Robots

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Chapter 1. Introduction

In today's interconnected world, many individuals live apart from their families for various reasons, such as pursuing education, career opportunities, or marriage. However, this physical separation often presents challenges, including adapting to new environments, coping with homesickness, and missing loved ones (Kelly et al., 2021; Shakeri et al., 2023). To overcome these challenges and maintain a sense of closeness, families often turn to digital technologies, specifically computer-mediated communication (CMC) tools, which allow them to stay connected despite the distance (Hindus et al., 2001; Stafford, 2005; Shklovski & Cummings, 2008; Tee, 2009; Ballagas et al., 2009; Massimi & Neustaedter, 2014).

While email, text messages, and phone calls were primary communication methods in the past, advancements in computer-mediated communication (CMC) tools have revolutionized long-distance interactions. Video calls and social media platforms now enable real-time communication, complete with non-verbal cues that simulate face-to-face interactions (Neustaedter & Greenberg, 2012). Video calls are effective for family connections as they foster feelings of closeness and shared experiences (Aguila, 2012). Nevertheless, these tools may only partially fulfill essential factors such as physicality, joint activities, awareness, and expressivity, which are critical elements in mediating and nurturing feelings of relatedness for maintaining intimate relationships (Canary & Stafford, 1991; Hassenzahl et al., 2012). To bridge these fundamental gaps in current CMC tools, emerging technologies are needed to offer physical presence and interactions akin to living together.

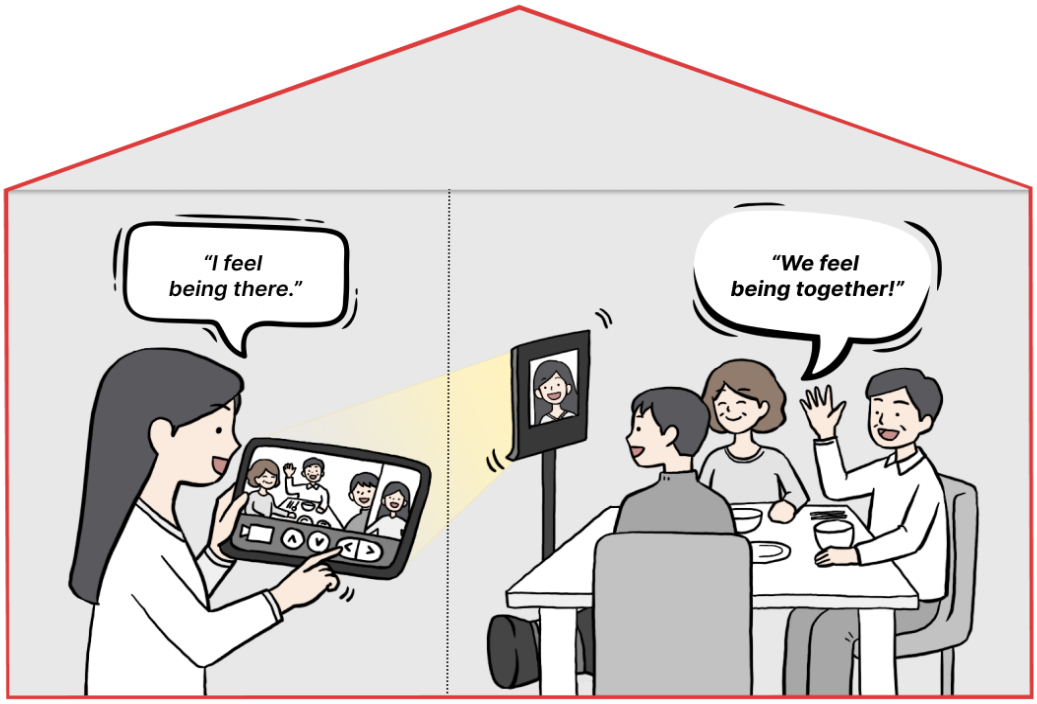

Figure 1. Overview of using telepresence robots: long-distance family members interact with each other via telepresence robots in remote situations.

The telepresence robot emerges as a promising technology that facilitates long-distance family communication. Unlike current computer-mediated communication (CMC) tools, telepresence robots offer physicality, mobility, autonomy, and interactivity, providing a more immersive experience for maintaining intimate relationships (Yang & Neustadter, 2018). These robots can navigate and interact freely within a remote environment, creating a sense of presence as if the user were physically there. The user controls the telepresence robot through a wide-view screen, effectively embodying the remote family member and allowing for more authentic in-person interactions. Furthermore, a robot controlled by a human adds a familiar element, bridging the gap between humans and machines and enabling more human-like interaction (Yang & Neustadter, 2018).

Figure 2. Examples of Interacting via Telepresence Robots in Parents' Homes: local family members engage with their remote family members through the use of a telepresence robot (used with permission).

While researchers have conducted studies on telepresence robots in various public settings such as workplaces, schools, and healthcare facilities, there is a significant gap in understanding how these robots can foster intimate family relationships in home settings. Previous studies have focused on specific contexts, highlighting the positive impact of telepresence robots on interactions between professionals, clients, or patients (Markoff, 2010; Lee & Takayama, 2011; Neustaedter et al., 2016; Newhart & Olson, 2017). However, further exploration of telepresence robots is needed for family communication within home environments. With the increasing affordability of telepresence robots for individual households (e.g., Ohmni, Ava, Meeting Owl Pro 360, and Kubi Classic), our research aims to investigate their potential and utilization in family contexts. Additionally, although previous research has examined the impact of telepresence robots like Beam on facilitating one-to-one intimate relationships within home settings (Yang et al., 2017; Yang & Neustadter, 2018; Yang & Neustaedter, 2020), further investigation is necessary to

understand the interactions of multiple individuals within home environments. The home setting provides an ideal environment for studying family communication dynamics, as families can communicate comfortably and privately. By considering the diverse characteristics and perspectives of family members spanning different generations, examining family communication through the lens of telepresence robots can offer a more comprehensive understanding than focusing solely on other intimate relationships.

Moreover, we acknowledge the challenges of asymmetry and privacy highlighted in previous studies (Yang & Neustaedter, 2018). In our study, we deployed telepresence robots in parents' homes, allowing remote family members to control them. This approach enables us to examine the dynamics and settings of local family members and remote family members, taking factors such as asymmetry and privacy into account. Therefore, our investigation will delve into various factors in family relationships.

In this paper, we aim to address the following research questions (RQs):

- **RQ 1.** How are telepresence robots utilized in long-distance family communication in a home environment?
- **RQ 2.** How do telepresence robots contribute to supporting the key dimensions of maintaining intimate relationships?
- **RQ 3.** What challenges and opportunities are encountered in using telepresence robots for long-distance family communication in a home context?

To answer these research questions, we adopted a mixed-methods approach, primarily focusing on observational studies. We deployed telepresence robots for two weeks in participants' homes and conducted pre and post-interviews and surveys before and after deployment. Additionally, we held ideation sketch sessions at the end of the post-interview session. Through this comprehensive methodology, we aim to uncover the potential of telepresence robots for enhancing long-distance family interactions.

Our research findings revealed that participants expressed high satisfaction and reported positive experiences while using telepresence robots for communication. They actively engaged in various shared activities, such as exploring each other's homes, sharing daily routines, interacting within different spaces of the home, participating in physical activities together, and being part of family and home events. Through our observations, we identified key dimensions that contribute to telepresence robots effectively maintaining intimate relationships and fostering social presence based on these observed activities. Additionally, we also identified and addressed the challenges that telepresence robots present in the context of family communication. Therefore, this research delved into the immense potential of telepresence robots in bridging the physical distance between family members and significantly enhancing their long-distance relationships. The deployment of these robots resulted in improved overall communication experiences within their homes. Moreover, by taking into account the diverse characteristics and perspectives of family members spanning different generations, we gained a deeper understanding of how telepresence robots can serve as valuable tools for households and offer a more comprehensive perspective on the dynamics within the home environment.

Therefore, the contributions of this paper are as follows:

- Investigating the utilization of telepresence robots in long-distance family communication within the home.
- Examining the key dimensions that support effective interactions within the family to maintain intimate relationships through telepresence robots.
- Discussing the challenges and opportunities of telepresence robots in facilitating family communication.
- Providing design guidelines for telepresence robots for family home communication tools.

Chapter 2. Related Work

We have focused our related work on three major categories: (1) understanding the concepts of social presence and proxemics in telecommunication, (2) previous studies on the use of Computer-Mediated Communication (CMC) in family interaction to maintain intimate relationships, and (3) discussing the current support provided by CMC tools for long-distance intimate relationship maintenance and the potential of telepresence robots for defining telepresence.

2.1 Social Presence and Proxemics in Telecommunication

In telecommunication technology, social presence has garnered significant attention, particularly in communication within long-distance relationships. Social presence refers to the degree of presence and prominence experienced by individuals when engaging in mediated communication, such as teleconferencing (Short et al., 1976). It is crucial to establish a sense of '*being with others*' and create psychological connectivity in remote interaction environments facilitated by digital technologies (Biocca et al., 2003). Previous research has highlighted the importance of perceived social presence in one's communication partner to strengthen closeness and connectedness (Ruyter et al., 2003). Staying connected with family is widely believed to significantly influence well-being and relationships (Crespo, 2011). Moreover, intimate relationships rely on interdependence and require effort to fulfill each other's desires (Stafford & Canary, 1991). In line with these desires, families often prefer frequent and detailed updates about each other's lives, staying informed about recent events, upcoming activities, and any health issues affecting their loved ones (Tee, 2009; Neustaedter, 2006). Therefore, families value synchronous

communication to receive immediate responses and alleviate anxiety by directly experiencing each other's presence (Hertlein & Chan, 2020).

Depending on the communication tools used and the characteristics of the media, computer-based communication may have varying levels of social presence. While computer-mediated communication may be perceived as less immersive than face-to-face interaction, it has been observed that different computer-based communication platforms can generate varying levels of social presence among communicators (Chang & Hsu, 2016). Objective qualities, such as physical and emotional proximity, shape social presence theory across different media (Short et al., 1976). Researchers have sought to measure social presence and privacy by examining how five variables (social context, online communication, interactivity, system privacy, and feelings of privacy) significantly contribute to social presence (Tu, 2002). Additionally, others have developed and validated social presence measures with two dimensions, namely proximity, and awareness, within a multimodal presence scale (Kreijns et al., 2008; Makransky, 2016).

In long-distance family communication, the concept of proximity, which examines how individuals use and perceive space within a cultural context (Hall, 1966), becomes particularly relevant. Proximity, a crucial aspect of nonverbal communication, encompasses preferred physical and interpersonal distances that vary across cultures. Understanding proxemics is essential for designing technologies that facilitate meaningful connections and support intimate relationships among family members separated by distance. Furthermore, exploring how individuals interact with others and perceive physical and emotional presence is essential, considering factors such as interpersonal involvement and constraints imposed by media use (Gunawardena, 1995). Recent studies have delved into developing non-verbal intimacy and enhancing relationships among individuals without face-to-face contact, particularly in online environments (Dixson, 2016). Therefore, we aim to examine the key dimensions of telepresence robots in-depth

that support social presence to maintain intimacy in long-distance family relationships conducted remotely. Additionally, we seek to investigate the interplay between social presence and proxemics in home environments. This is crucial for designing technologies that facilitate meaningful and intimate connections among family members separated by distance.

2.2 Computer-Mediated Communication in Family Interaction and Relationship Maintenance

In the modern era, many individuals live apart from their families for various reasons. To bridge the geographical gap and maintain connections, computer-mediated communication (CMC) tools have become invaluable in supporting long-distance family relationships. Families rely on a range of CMC tools, including video calls, audio calls, text messages, and social media platforms, to stay connected when physical distance separates them (Hindus et al., 2001; Judge & Neustaedter, 2010; Neustaedter & Greenberg, 2012). These tools offer an effective means of maintaining relationships and fostering connections with family members far away (Shklovski & Cummings, 2008).

There are a variety of CMC tools available to individuals, depending on their preferences and specific circumstances. Video calls, in particular, have gained popularity as they enable rich communication by incorporating non-verbal cues such as body language and facial expressions, facilitating more advanced and nuanced interactions (Geiskkovitch et al., 2022). Video calls are especially beneficial for communication with children who rely heavily on body language to express themselves (Ballagas et al., 2009). Grandparents and other family members prefer to engage with them (Vutborg et al., 2010). Furthermore, video streaming has witnessed a rise, allowing remote sharing of significant life events, including graduations, weddings, and family reunions, in real-time with friends, partners, and family members who are physically distant (Massimi & Neustaedter, 2014). Moreover,

in long-distance intimate relationships, individuals have found unique applications for video chat tools, such as the concept of "Always-on" video, which emphasizes the importance of continuous presence and non-verbal cues in the CMC environment (Neustaedter & Greenberg, 2012). Therefore, as digital technologies continue to advance, video-based CMC tools have become invaluable in bridging distance gaps, nurturing family connections, and enriching long-distance relationships.

Intimate relationships thrive on a profound sense of connectedness and relatedness. Relatedness, known to significantly impact psychological well-being (Hassenzahl et al., 2012), encompasses personal contact, fulfilling the need for connection (Sheldon et al., 2001; Ryan & Deci, 2000), and expressing love and commitment to significant others – all crucial components of happiness and life satisfaction (Argyle, 1987). To facilitate intimate relationships through technology, various strategies have been identified, such as awareness, expressivity, physicality, and joint action (Hassenzahl et al., 2012). These strategies enhance relatedness by engendering a sense of presence, allowing emotional expression, establishing physical closeness, expressing appreciation, facilitating shared activities, and creating cherished memories. Moreover, supporting the senses of sight and touch also plays a role in fostering a feeling of connection within families (Shakeri et al., 2023).

Although these factors have been examined in different contexts, their specific application and effectiveness in long-distance family communication remain to be explored. Therefore, our study aims to investigate how family communication via telepresence robots can effectively support these relationship maintenance strategies. By doing so, we intend to promote a sense of closeness and emotional connection among family members who are physically separated. Understanding how these elements interact with the unique features of telepresence robots will provide valuable insights into

designing and utilizing these technologies to enhance family interactions and maintain strong bonds, even across geographical distances.

2.3 Current CMC Tools and Telepresence Robots

2.3.1 Partial Coverage of Relationship Maintenance Strategies

Current CMC tools partially address relationship maintenance (Shklovski & Cummings, 2008; Massimi & Neustaedter, 2014). A fundamental limitation is an inability to replicate presence or physicality in synchronous and asynchronous communication fully. CMC's remote environment needed more control over what they shared to feel their presence (Judgeet al., 2011). Holding and bringing their mobile phone to show a better and more accurate view was sometimes socially awkward. It also took much work to show gestures depending on what particular objects they wanted to show and their location (Sakata et al., 2013). Therefore, the camera, the essential feature of CMC, presented challenges and disturbed people's participation in the activity (Jordan & Henderson, 1995). These challenges also brought a need for more sharing and expressive communication. Different CMC tools influence conversations, with individuals focusing on topics suitable for specific media. This reduces engagement and flexibility in expressing support and care.

There are also some limitations caused by relying on each CMC tool. People who communicate through CMC systems tend to refrain from focusing on topics that are easy to discuss over the media, such as short text messages (Neustaedter & Greenberg, 2012). Family members became more comfortable sharing short texts or calls and awkwardly doing activities together in person. Moreover, some people in long-distance intimate relationships also use video chat tools in an unconventional manner, such as 'always-on' video. ‘Always-on’ video communication shows the significance of non-verbal cues and communication when connected in a CMC environment without directly engaging or talking to one another. Therefore, CMC tools tend to transmit and focus on visual and oral

information. Thus it still has limited flexibility in expressing support and mutual care simultaneously.

Additionally, researchers have delved into the realm of wearable devices and digital objects as potential means to foster a sense of physical presence for remote family members. Some wearable devices have been developed with the aim of supporting relatedness and intimacy between communicators, striving to fulfill partial physicalness and awareness (Joi et al., 2015; Liu et al., 2021; Kowalski, Loehmann, & Hausen, 2013; Mueller et al., 2005; Singhal et al., 2017). However, many existing technological tools primarily focus on transmitting information or limited non-verbal cues, such as specific biosignals, and tend to overlook the importance of subtle and emotional forms of communication.

Telepresence robots present a promising solution by offering physicality, mobility, and interactivity, thereby enabling authentic in-person interactions and supporting physical engagement with autonomy (Yang & Neustaedter, 2018). To fully comprehend how telepresence robots can truly enhance long-distance family communication, further research is warranted to explore the key dimensions that contribute to their effectiveness in bridging the gap between distant family members.

2.3.2 Telepresence and Telepresence Robots

Telepresence, which involves the sense of "being there" in a remote environment, is highly relevant to long-distance family communication. It creates a mental model of a mediated virtual environment that generates an illusion of physical presence for both the communicator and the receiver (Biocca et al., 2003). Presence, a fundamental aspect of consciousness related to perceiving stimuli within an environment (Loomis, 1992), is crucial for achieving telepresence by immersing individuals in mediated subjects and information (Biocca, 1995). Understanding telepresence requires exploring how individuals experience a sense of "being with others" and how different media interfaces

influence this experience. Researchers aim to identify essential factors contributing to interpersonal communication and nonverbal cue perception in remote environments (Biocca et al., 2003). Researchers also seek insights into maintaining and developing interpersonal relationships in mediated contexts. They investigate how individuals establish mutuality and direct their attention to instinctive nonverbal behaviors.

Telepresence robots are emerging as effective tools to support presence in telecommunications. These computerized artifacts enable remote interaction through visual and audio channels (Bang, 2018). Telepresence robots provide a controlled view of the remote environment and real-time audio reception equipped with cameras, microphones, and body control (Desai et al., 2011; Kristoffersson et al., 2013). They blur the line between the robot's features and the human operator, with their movement and facial expressions influencing empathetic responses (Bang, 2018).

In remote interactions, telepresence robots offer advantages such as multi-channel communication, autonomy, and interactivity (Yang & Neustaedter, 2018). They facilitate participation in daily life, increase helpfulness, and provide companionship (Yang & Neustaedter, 2018). Telepresence robots can connect with intelligent home tools, fostering a sense of belonging and social connection (Yang & Neustaedter, 2020). By engaging in shared activities and allowing playful interactions, telepresence robots enable affection and contribution to the relationship (Yang et al., 2018). They offer interactive and immersive experiences that simulate in-person communication, making them valuable for maintaining connections in long-distance relationships (Fitter et al., 2020).

Our study aims to investigate how telepresence robots provide an opportunity to overcome current challenges in computer-mediated communication by offering a more immersive and flexible communication experience. The ability to navigate and interact within a remote environment allows for shared activities and increased control over shared content, enhancing the quality of family communication. Moreover, there is a need for a

better understanding of empirical studies to explore telepresence robots' specific application and effectiveness in long-distance family communication within the home environment.

Chapter 3. Method

This research explores telepresence robots' potential opportunities and challenges to enhance long-distance family communication within home environments. Our study employed an observational approach, deploying the telepresence robot in the parents' homes of eight participating families for two weeks. By prioritizing qualitative data, we aimed to gain a deeper understanding of participants' experiences and uncover nuanced insights.

To capture the richness and complexity of participants' perspectives, we conducted pre- and post-interviews with idea sketch sessions. These qualitative methods provided a platform for in-depth discussions and allowed participants to express their thoughts, emotions, and experiences related to long-distance family communication facilitated by telepresence robots. In addition to extensive qualitative data collection, we administered pre- and post-surveys to compare participants' experiences using telepresence robots with other computer-mediated communication (CMC) tools. While the surveys provided quantitative insights, they were used to support and contextualize qualitative findings.

The selection of eight families, comprising 17 local and 12 remote family members, was based on their specific situations of living at a considerable distance from their parents' home, either domestically or internationally. By prioritizing qualitative data collection and incorporating complementary quantitative measures, we aimed to provide a comprehensive understanding of the potential opportunities and challenges associated with telepresence robots. This was to facilitate long-distance family communication within home environments.

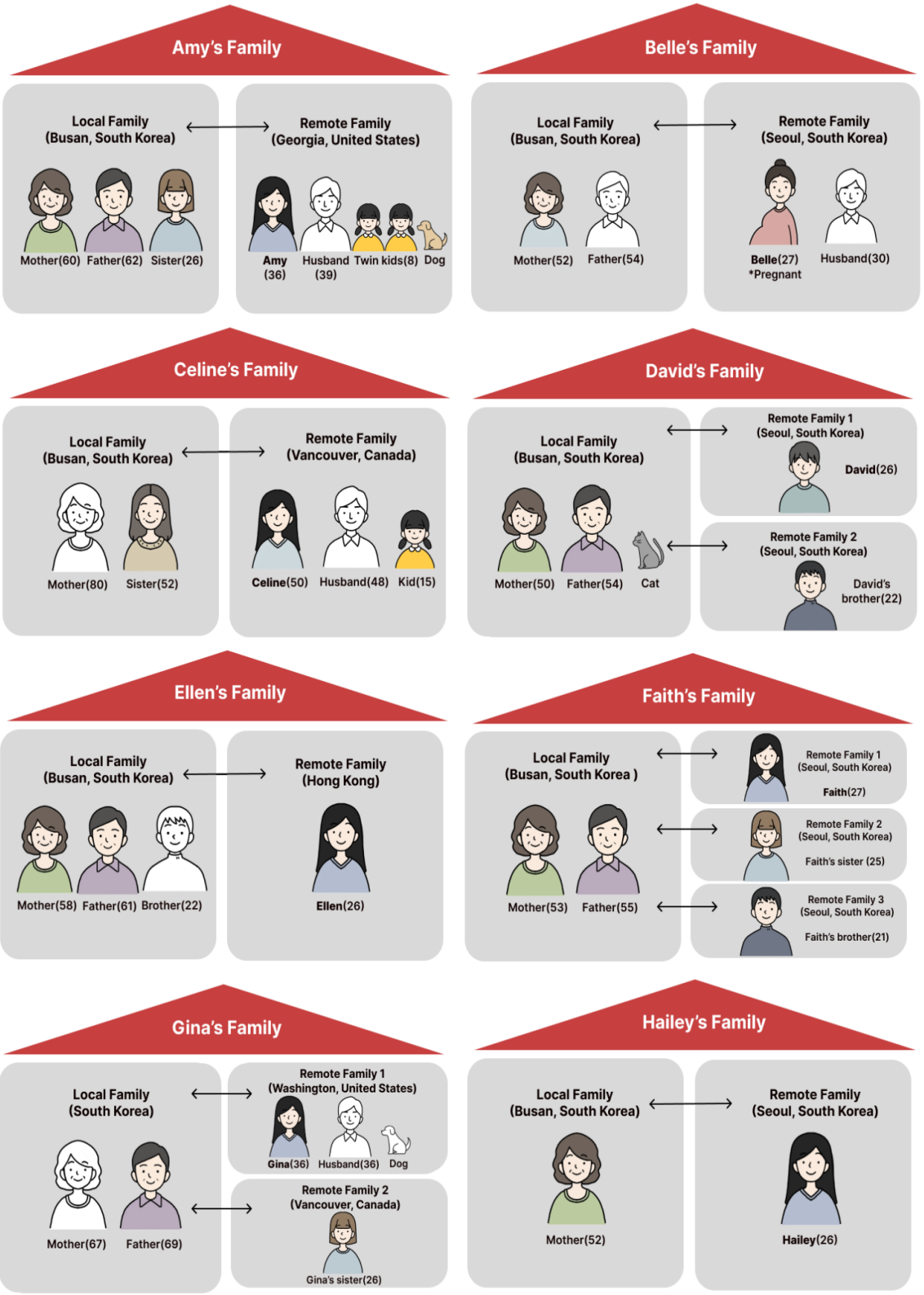

Figure 3. Structures of Eight Families: Primary users in each family are colored and relatively less engaged users expressed as colorless.

3.1 Participants

Using snowball sampling from our social networks, we recruited eight families for our study. It is significant to note that most of these families had direct connections to researchers. They were invited to open their private homes and record videos for the observational study. During the initial outreach to potential participants, there was high enthusiasm for using the telepresence robot to facilitate family communication. Many participants expressed excitement about the opportunity to try out this innovative technology.

However, it is worth mentioning that some family members with limited digital literacy initially had reservations and held low expectations regarding the telepresence robot. We acknowledged their hesitation and noted their concerns. Additionally, some participants raised concerns about deploying the robot in parents' homes where only elderly parents were present. This was even though remote children controlled most of the telepresence robots. As a result, not all individuals approached agreed to participate in the study. The final participants' list was confirmed with those who willingly agreed to utilize the telepresence robot to communicate with their family members. Furthermore, it is imperative to highlight that all participants' involvement in the study was entirely voluntary. We expected that this diverse range of perspectives would provide valuable insights into the opportunities and challenges of telepresence robots.

Table 1 provides details about each participating family. '**Local Family**' refers to family members (e.g., parents and siblings) who resided in the parents' home and had the telepresence robot physically with them. On the other hand, '**Remote Family**' refers to family members (e.g., children or children with a newly formed family) who moved out of their parents' home and controlled the telepresence robot in a distant place. Some remote family members moved separately due to marriage and now live with their spouses and children. Additionally, some families had more than one remote family member living

apart from the family home. This was especially true if they had two or three children who lived away from home. The study included 17 local family members and 12 remote family members. The duration of being apart varied from two months to twenty-two years. The distances between the families ranged from domestic distances of approximately 400 km to international distances from 2000 km to 12,000 km. These families represented common scenarios of long-distance relationships for reasons such as marriage, education, and work. Before using the telepresence robot, most participants relied on video and audio calls and family group chats through platforms like Kakaotalk and Facetime. Additionally, participants maintained frequent contact with each other, ranging from at least once a week to nearly every day. It is worth mentioning that some families had particular circumstances, such as pregnancy, kids, or pets.

Participants	**Length of Live Apart From Home**	**Reason of Live Apart From Home**	**Location**	**A Number of Local Family Member**	**A number of Remote Family Member**	**Time Difference**	**The Frequency of Call**	**Main CMC Used Before Study**	**Special Note**
Family #1	9 years	Marriage	International (South Korea - United States)	3	4	14	Once a week	Video call, Family Group Chat	Two kids and Pet
Family #2	2 years	Marriage	Domestic in South Korea (Seoul-Busan)	2	2		Almost Everyday	Audio call, text messages	Pregnant
Family #3	22 years	Marriage	International (South Korea - Canada)	3	3	17	Once a week or biweekly	Video call, text messages	Kid
Family #4 -1	2 months	Education	Domestic in South Korea (Seoul-Busan)	2	1		Once a week	Video call, Family Group Chat	Pet
Family #4 -2	2 years	education	Domestic in South Korea (Seoul-Busan)	2	1		Twice a week	Audio call, Family Group Chat	
Family #5	7 years	Work	International (South Korea - Hong Kong)	3	1	1	Once a week	Video call, Family Group	

								Chat	
Family #6 - 1	3 years	Education	Domestic in South Korea (Seoul-Busan)	2	1		Almost Everyday	Video call, Family Group Chat	
Family #6 - 2	4 years	Work	Domestic in South Korea (Seoul-Busan)	2	1		Almost Everyday	Video call, Family Group Chat	
Family #6 - 3	7 years	Work	Domestic in South Korea (Seoul-Busan)	2	1		Almost Everyday	Audio call, Family Group Chat	
Family #7 - 1	4 years	Marriage	International (South Korea-United States)	2	2	17	Almost Everyday	Video call Family Group Chat	Pet
Family #7 - 2	8 months	Education	International (South Korea - Canada)	2	1	17	Twice a Week	Video call Family Group Chat	
Family #8	5 years	Education	Domestic in South Korea (Seoul-Busan)	1	1		Almost Everyday	Video call, Text messages	

Table 1. Summary of participants (names anonymized)

3.2 Procedures

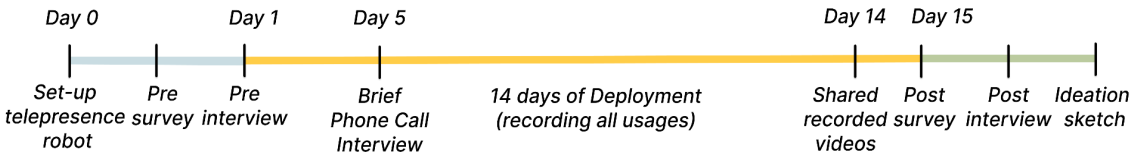

Figure 4. Overview of Study Procedures: Visual representation illustrating the step-by-step process followed in the study

During the study, we supplied a Double 2 telepresence robot to the home of a designated family member in each participating family. The families used the telepresence robot for two weeks, with no specific guidelines or restrictions on its usage. Throughout this period, we conducted pre and post-interviews and surveys to gather data on the effectiveness of the telepresence robot in enhancing family communication compared to

conventional computer-mediated communication (CMC) tools. Participants were asked to complete sub-scales of the Social Presence scale both before and after the deployment period to evaluate the impact of the telepresence robot.

We aimed to observe how families naturally incorporated the telepresence robot into their communication routines without imposing specific requirements or rules. The pre-interview was conducted on the first day of the study, during our visit to the family home to set up the telepresence robot and provide instructions. Additionally, a brief phone call interview was arranged a few days after the initial setup to address any technical issues that may have arisen. At the end of the study, the post-interview was conducted in person at the family home. Remote family members joined the interviews through the telepresence robot or by utilizing their preferred CMC tools such as Facetime, Kakaotalk Video Call, or Zoom.

Prior to the start of the experiment, we conducted a pre-survey; then we assisted remote family members in setting up accounts to access the 'Double' application, which controls the robot. During our first visit, we introduced Double 2's basic functionalities to both remote and local families. We explained essential features such as mobility, wide camera angle, loudspeaker, and height control to understand how each family utilizes the robot and explained how to charge, navigate, and park the robot in the family home. In addition, we included instructions on how remote family members could control it. We offer several options for controlling the robot through the app. We provide the necessary links for remote access using mobile phones, tablets, or computers. Once the remote family members logged into the app and initiated a call, local family members received notifications and could accept the call, establishing a connection. The initial setup process on the first day took approximately 15 minutes, and we also conducted a 20-minute pre-interview session. During the pre-interview phase, we specifically focused on understanding the family's patterns of interaction and communication while they were

living together in the family home. We also mainly explored how these patterns changed after being separated by long distances. These inquiries were crucial in gaining valuable insights into the dynamics of their family relationships and understanding how they adapt to and cope with physical separation. For example, we asked questions such as "*How often do your family members keep in touch?", "Which CMC tools does your family primarily use for communication?"* and *"What are the main challenges your family faces when living apart?"*

Before starting the post-interview, participants were asked to complete the post-survey; then, we gathered participants' experiences using the telepresence robot over two weeks. We asked them about the timing, location, manner, duration, reasons for their usage, and how they utilized the robot's functionalities in their family communication. The post-interview was conducted as a comprehensive hour-long interview. Before the post-interview session, we requested all participants to share recorded videos of each usage instance to gain further insights and formulate additional questions. The post-interview followed a semi-structured format, inquiring about participants' overall experiences using the telepresence robot, with customized questions tailored to each family based on the recorded videos. For example, we asked questions such as *"How frequently did your family use the telepresence robot in the past two weeks?", "Where did your family typically interact with the telepresence robot?", "Could remote family members and local family members share their most memorable usage instances?", "What activities did your family engage in?", "What aspects of telepresence for long-distance family communication left a lasting impression?", "To what extent did you perceive the telepresence robot as resembling a family member?", "What advantages does the telepresence robot offer compared to other computer-mediated communication (CMC) tools?"* and *"Did your family encounter any privacy concerns?"*

In the final part of the post-interview session, we conducted idea sketch sessions to gather design suggestions based on the pain points associated with current telepresence robots. We explicitly asked participants about the challenges of applying telepresence robots to long-distance family communication and encouraged them to provide suggestions through idea sketches. We received different sketch proposals from remote families and from local families. Remote family members focused on the system user interface (UI) and the controlling system functionality. In contrast, local family members shared idea sketches related to the robot's physical appearance and functionalities. Through these post-interview sessions, we collected valuable data regarding the opportunities and challenges of utilizing the Double 2 telepresence robot in long-distance family communication.

3.3 Measure

To investigate the key dimensions of telepresence robots in family communication, we employed various social presence measures in pre- and post-survey sessions. The internal consistency of the survey items within each dimension was assessed using Cronbach's Alpha coefficients.

Firstly, participants were asked to respond to five Likert scale questions, such as *"I felt a strong sense of connection and presence with the other person while communicating through the current CMC (or telepresence robot)."* and *"I felt that the other person was actively engaged and listening to me as if we were in the same physical space while communicating through the current CMC (or telepresence robot)."* These questions were used to create a reliable scale for measuring the **'awareness'** (Cronbach's alpha = .945), and the responses were averaged to generate an overall measure.

Secondly, eight 5-point Likert scale items were employed, including statements like *"Using the current CMC (or telepresence robot), I experience a feeling of face-to-face communication as the physical distance between us seems to diminish."* and *"Through the*

current CMC (or telepresence robot), I felt psychologically close to the other person." These questions formed a reliable scale for measuring **'proximity'** (Cronbach's alpha = .820).

Thirdly, we examined participants' perceptions of privacy and comfort while using the current CMC (or telepresence robot). Two 5-point Likert scale questions, such as *"The current CMC (or telepresence robot) ensures personal/private communication."* and *"The current CMC (or telepresence robot) allows for comfortable and private conversations, promoting a sense of trust."* were used to create a reliable scale for measuring ***'privacy'*** (Cronbach's alpha = .620).

Fourthly, participants were asked to self-report their experiences of family interaction using four 5-point Likert scale questions, including statements like *"The current CMC (or telepresence robot) enables immediate communication, effectively enhancing family interaction."* and *"We feel at ease and communicate seamlessly using the current CMC (or telepresence robot), fostering enhanced family interaction."* These questions formed a reliable scale for measuring ***'engagement'*** (Cronbach's alpha = .831).

Fifthly, we aimed to explore the extent to which participants perceived the current CMC (or telepresence robot) as facilitating efficient communication. Four 5-point Likert scale questions were used, including statements like *"The CMC technology (or telepresence robot) currently in use enables meaningful conversations."* and *"Understanding the conveyed message from the other party becomes effortless through the CMC technology (or telepresence robot) currently in use."* These questions formed a reliable scale for measuring ***'Emotional Communication'*** (Cronbach's alpha = .865).

Finally, the survey aimed to measure the perceived level of social presence before and after using telepresence robots compared to current computer-mediated communication (CMC) tools. The selection of survey items followed established criteria for reporting social presence (Tu, 2002; Kreijns, 2008; Makransky, 2016) and targeted five

key dimensions: awareness (5 items; Cronbach's alpha = .945), proximity (8 items; Cronbach's alpha = .820), privacy concern (2 items; Cronbach's alpha = .620), interactivity (4 items; Cronbach's alpha = .831), and emotional communication (4 items; Cronbach's alpha = .865).

3.4 Data Collection and Analysis

The data collection process involved audio-recording all interviews with participants' consent. Subsequently, the recordings were transcribed, and their names were replaced with aliases to ensure confidentiality (e.g., Amy's Family, Belle's Family). Additionally, participants recorded videos of their interactions with telepresence robots, which were shared with the researchers before the post-interview. The researchers carefully observed the recorded videos, noting intriguing insights and observations. These findings were then used to delve deeper into participants' intentions and emotions during post-interviews and the subsequent thematic coding stage.

The researchers employed a comprehensive approach to analyze family interactions, encompassing various methods. This included conducting interviews and reviewing recorded videos to gain deeper insights into the dynamics of family communication. During the pre- and post-interview sessions, researchers closely observed how families interacted and responded, enabling them to capture valuable data on communication patterns and emotional reactions. The analysis focused on aspects such as people's interactions, the impact of distance on communication, the emotional responses exhibited, and the overall atmosphere during the interactions. The recorded videos also allowed the researcher to observe movements within the home spaces, providing additional context to better understand the family's communication dynamics. This multi-faceted analysis aimed to paint a comprehensive picture of how families communicate and

connected in both physical proximity and long-distance scenarios, aiding in the investigation of the effects of telepresence robots on long-distance family communication.

Thematic analysis was conducted to extract significant themes and findings from observation and interview data. Based on the analysis of observation data, focusing on participants' experiences of shared activities, we identified categories related to interactivity, family relationship maintenance, social presence, proxemics, privacy, and communication modality based on main themes from interview analysis. Subsequently, thematic coding was performed to establish connections between codes and define the main themes outlined in the findings section. The five themes that emerged were: Awareness, Proximity, Privacy Concern, Interactivity, and Message Conyenance. Throughout the analysis, the researcher engaged in discussions regarding the codes and themes, considering various aspects to ensure the results and discussions were comprehensive and valuable. They also examined the existing literature on telepresence robots in home settings. We also examined strategies for maintaining long-distance intimate relationships, proxemics, telepresence, social presence, and computer-mediated communication. This examination helped refine the coding of themes and findings. All stories and quotes from the participants were included in the analysis to support the explanations addressing the research questions.

Moreover, we analyzed the pre- and post-survey data as supplementary information to support understanding key themes related to telepresence robots' positive impact on family communication. To examine the impact of telepresence robots on family communication, particularly in comparison to computer-mediated communication (CMC) tools such as video calls, audio calls, and text messaging, we performed paired t-tests using SPSS 29.0. We divided the data into five categories: awareness, proximity, privacy concern, interactivity, and message conveyance. Since the experiment was conducted in an asymmetrical setting with two groups—a local family and a remote family—we

anticipated differences between these groups. Therefore, we separately analyzed survey data for each group.

Chapter 4. Results

In order to answer our research question, we categorize our findings into three interconnected parts: (1) types of shared activities performed with telepresence robots in home environments, (2) key dimensions of telepresence robots in family communication to support intimate family relationships, and (3) design suggestions from participants to improve telepresence robot facilitation in family communication.

4.1 Activity Types of Utilizing Telepresence Robots in Home Environment

Our observational study aimed to investigate the progress of participants in utilizing telepresence robots over a two-week period. This was done starting with their initial usage and gradually transitioning to familiarity with telepresence. Throughout the study, we identified four types of activities that the participants engaged in. These activities included (1) exploring their homes, (2) sharing daily routines and interacting in different areas of their homes, (3) participating in physical activities, and (4) taking part in special family and home events. Additionally, participants often mainly focused on conversations after parking the robot near their remote counterparts. The findings indicated that telepresence robots effectively facilitate advanced interactions between two family groups. Consequently, we conducted a thorough analysis to examine the key dimensions that contribute to the support of intimate family relationships based on these shared activities.

Activity Types	**Summary of Details**
Exploring home space	● Visiting their room together ● Touring the new home together ● Discovering changes in the home (e.g., furniture, plants, frames) together ● Seeing outside the night view from home space together

Sharing daily routines and interacting in various home spaces	*Living room* ● Watching TV together ● Listening to music together ● Joining a family tea-time *Kitchen* ● Joining family mealtime ● Interacting with housework time such as cooking, washing dishes *Other spaces (e.g., hallway, bedroom, front door, dressing room)* ● Greeting family members at the front door ● Come across a family member in the hallway ● Having a chat with family members in the bedroom before sleeping ● Helping sister dress up for important meetings and sharing new clothes ● Helping elderly parents immediately by their side when they face technical issues or need help from their children ● Supporting prenatal education with a pregnant daughter and interacting with the fetus
Joining physical activities	● Playing games with kids (e.g., hide-and-seek game, chasey) ● Yoga and stretching together ● Interacting with pets (e.g., seeking, commanding, following)
Participating in special family and home events	● Joining holiday events (e.g., Lunar New Year) ● Celebrating birthday together ● Participating in ancestral rites ● Sharing interior remodeling processes ● Joining the clean-up

Table 2. Categorized shared activity types and a summary of details

Name Aliases	Amy's Family	Belle's Family	Celine's Family	David's Family	Ellen's Family	Faith's Family	Gina's Family	Hailey's Family
Average Call Duration (mins)	45.53	30.12	55.30	14.55	20.40	18.30	20.50	32.64
Total Use for 2 Weeks (mins)	155	120	164	85	75	140	110	100
A number of times used	5	4	5	6	5	8	5	4
- Exploring home	3(60%)	2(50%)	3(60%)	2(30%)	4(80%)	4(50%)	2(40%)	2(50%)
- Sharing daily routines in various home spaces	5(100%)	4(100%)	5(100%)	6(100%)	5(100%)	4(50%)	5(100%)	4(100%)
- Joining physical activities	3(60%)	1(25%)		1(16%)		1(12.5%)		2(50%)
- Participating in special	2(40%)	1(25%)	3(60%)	1(16%)	1(20%)			

	family and home events		
-	Taking care of certain family members	2(50%)	2(40%)

Table 3. Usage Data include the number of times used, average call duration, total two-week use, and shared activities with a number of participating times.

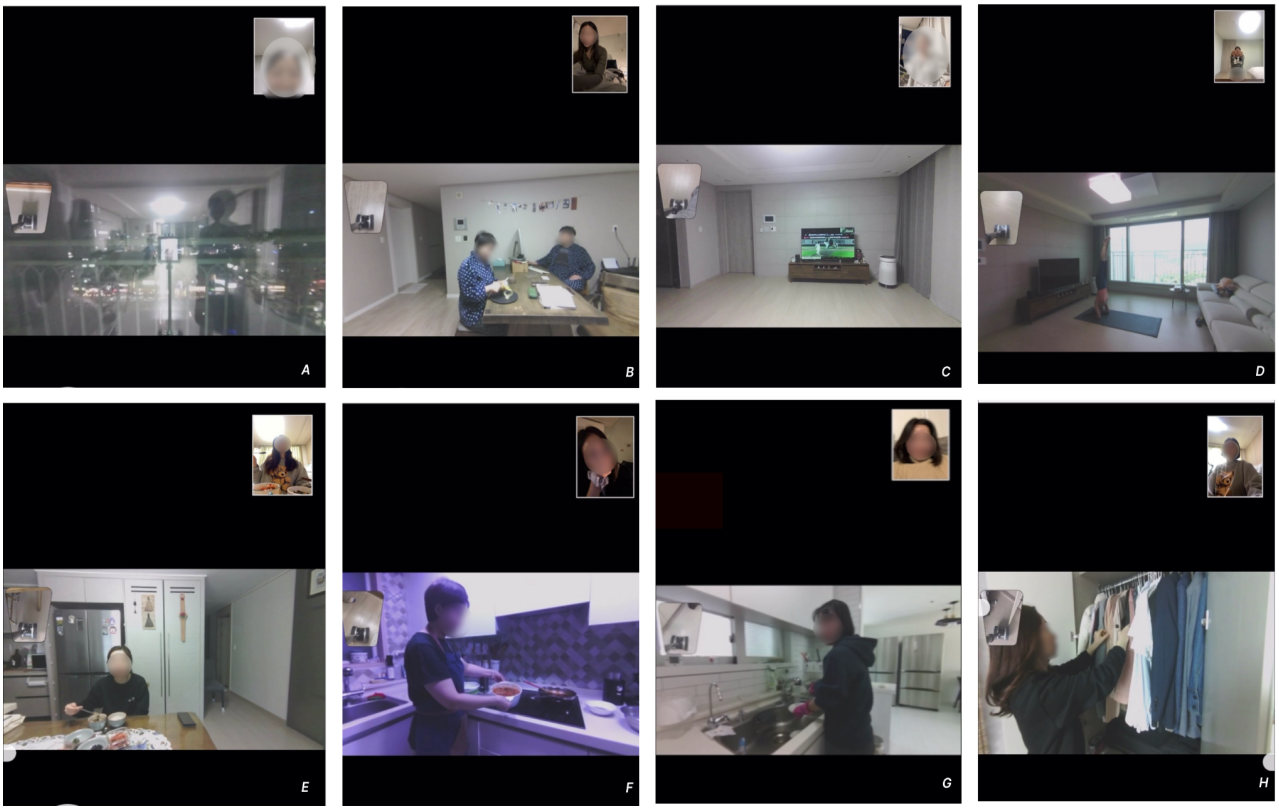

Figure 5. Examples of shared activities from participants using a telepresence robot(A: seeing outside night view together, B: joining tea-time, C: watching a baseball game together, D: doing yoga together, E: eating lunch together, F: interacting on cooking time, G: interacting on dish washing time, H: interacting in dress room)

4.1.1 Exploring Home

Initially, when connected through the telepresence robot, remote family members, who controlled the robots, explored their homes. They also got closer to their parents and siblings. For example, Gina (controller) expressed excitement: *"When I connected to my parents through the robot, I was so thrilled to see my home and the parents I missed a lot. I moved around the entire home for a while and saw the outside view with my mom."* Sometimes, family members lived apart from the family home for a long time and could

not visit due to the COVID-19 pandemic. This situation presented an ideal opportunity for remote family members to tour their family's new home and explore their room for the first time. Local family members accompanied their remote family members, using the telepresence robot to showcase their new home. For instance, Amy's sister (local family) said, *"We moved home two years ago, and my sister could not visit our new home due to the pandemic."* Despite sending her numerous photos and videos, it was a completely different experience to show her the new home by moving together through the robot." Additionally, as remote family members explored the home environment themselves using the telepresence robot, they discovered any changes such as renovated furniture, plants, and framed photographs in the home. This shared exploration fostered meaningful experiences and triggered nostalgic conversations. For instance, Gina's sister (controller) stated, *"I moved around the living room and examined all the framed photos with my father. We reminisced about our memories."* Furthermore, Belle highlighted the unique aspect of physically approaching and observing blooming plants with her mother. She expressed, *"Having the ability to move around and witness things in collaboration with my parents, rather than simply receiving photos or watching through a video call, made it a truly different experience."*

4.1.2 Sharing daily routines and interacting within various home spaces

Over time, family members became familiar with and comfortable communicating and engaging in activities through the telepresence robot. It took some time for remote family members to adjust to controlling the robot. At the same time, local family members also had to adapt to having the robot in their homes and interacting with their remote relatives through it. Starting from the second session of using the robot, each family actively participated in various activities in various home spaces. This showcased their unique characteristics and daily routines. Additionally, the telepresence robot allowed participants to partake in most family activities remotely, thus preserving established

family routines from when they lived together. For example, Ellen's mother from the local family expressed, *"We maintained our family tradition of teatime after lunch while enjoying TV shows together on Sunday afternoons. It genuinely felt like our interactions were authentic, and we no longer relied on phone communication."*

Our findings revealed that all participants spent most of their time in shared spaces, particularly the living room and kitchen areas. The shared spaces served as a central hub for family members to engage in activities together. It was observed that families spent leisure time bonding through activities like watching TV, listening to music, and having coffee in the living room, particularly on weekends. Remote family members positioned their robots near the sofa, actively joining in family routines. This included selecting TV channels and songs through the AI speaker by moving closer to it. Ellen's mother (local family) expressed happiness about their daughter joining them in the living room, making them feel present. Furthermore, she said, "We watched a baseball game in the living room and sang fight songs together to root for our team synchronously through the robot."

Remote family members are also able to participate in everyday activities like meals and housework in the kitchen space. The kitchen area plays a significant role in fostering connection and interaction among family members. Participants engaged in interactivity, such as meal preparation and household chores, where remote family members actively participated through the telepresence robot. This enabled them to join in conversations, provide assistance, and feel involved in their family members' daily routines. For example, remote family members who lived alone joined family mealtimes. They placed their telepresence robot on the kitchen table and shared a meal. Ellen (controller) described their experience, stating, *"I parked the robot on the kitchen table and had dinner together, synchronizing the time with my family. I could see all of our family members in one frame, so I felt like I was there."* This arrangement allowed remote family members to participate virtually in the shared dining experience and feel a sense of

togetherness despite being physically separated. Using the telepresence robot, they could engage in conversations, see everyone present, and maintain a connection during mealtimes.

Moreover, participants demonstrated other shared activities in the kitchen. These activities were where remote family members interacted with their family members while performing household chores like washing dishes and cooking. Being able to navigate the entire home, remote family members approached their family members and engaged in conversation during these tasks. Faith's mother (local family) mentioned, *"When I cooked dinner, my son would come to me and inquire about the menu or ask for recipes. Since the robot could move independently, I did not need to hold my phone. It was very convenient to talk with him while I did housework and focus more on our conversation."*

Our participants also shared activities in more diverse spaces such as the front door, hallway, bedroom, and dressing room. Remote family members could move to the family members themselves to greet them when they arrive home by moving to the front door. For example, Amy's sister (local family) shared their experience of heading to the front door to welcome their mother back from the gym and coming across her sister in the hallway on her way to the front door, feeling like *"I really like being there beside my sister and mother."* They reported that these interactions further enhanced family connection and togetherness. Also, our participants spent much time in the dressing room and bedroom with their mothers and sisters. They used this opportunity to share their recent clothing purchases and assist their younger sister in dressing up for important meetings or dates. Amy's sister (local family) shared their experience, saying, *"My sister and I used to spend much time together in the dressing room when we lived together, and now we could reunite and engage in this activity again."* Moreover, our participants said that they chat a lot in the bedroom before sleeping as they live together. For example, *"I talked with my sister*

and mother for 3 hours in the bedroom." It always happened when we lived together" (Celine, controller).

Additionally, our study revealed that participants often helped certain family members, such as elderly parents and pregnant daughters everywhere at home. This was done in their interactions with the telepresence robots. In some instances, elderly parents sought assistance from their children when facing technical difficulties or vision problems associated with aging. For instance, Gina's father (local family) said, *"I asked my daughter to read the small font in a manual book. My daughter approached me, and I showed it to the robot's camera so she could read it for me."* Moreover, pregnant participants found significant support from their parents through telepresence robots. They sought information about pregnancy and the baby, participated in prenatal education, and maintained a strong connection between the baby and her grandparents. Belle (controller) shared her experience with telepresence robots during pregnancy. She stated, *"I could share my rapidly changing body with her, and my mother kept checking my condition and giving advice. Furthermore, I would show my baby bump on the robot screen, and my parents would talk to the baby in the womb."*

Figure 6. Examples of playing hide-and-seek games using a telepresence robot (A-1,2,3 show how a local family seeks the robot, and B shows how remote family members seek the family member at home)

4.1.3 Joining physical activities

We found that some participants actively engaged in physical activity, such as playing games, exercising, and interacting with pets. Participants shared their experiences playing hide-and-seek with their twin nieces using the telepresence robot. Amy's sister (local family) expressed, *"My twin nieces are eight years old, and they enjoy spending time with me. We tried playing hide-and-seek using the robot, where I would hide somewhere in the house, and my nieces would control the robot to explore the entire home and find me. It was a fascinating experience."*

Furthermore, participants continued their exercise routines by following yoga and stretching videos on YouTube. Hailey (controller) stated,*"We used to do yoga together every night when we lived together, and now we can continue doing it together through the telepresence robot."* Some remote family members also actively participated in physical activities with their pets in the family house. They reported interacting with their pets by moving around to find them. The mobility of the telepresence robot made them feel like they were playing with their pets in the same place. In another instance, David shared their experience, saying, *"I looked around the whole house to find my cat, and I found him underneath my bed. It feels like we are connected and can feel each other."* Therefore, two features of telepresence robots like physicality and autonomy allow them to join physical activities with distant families.

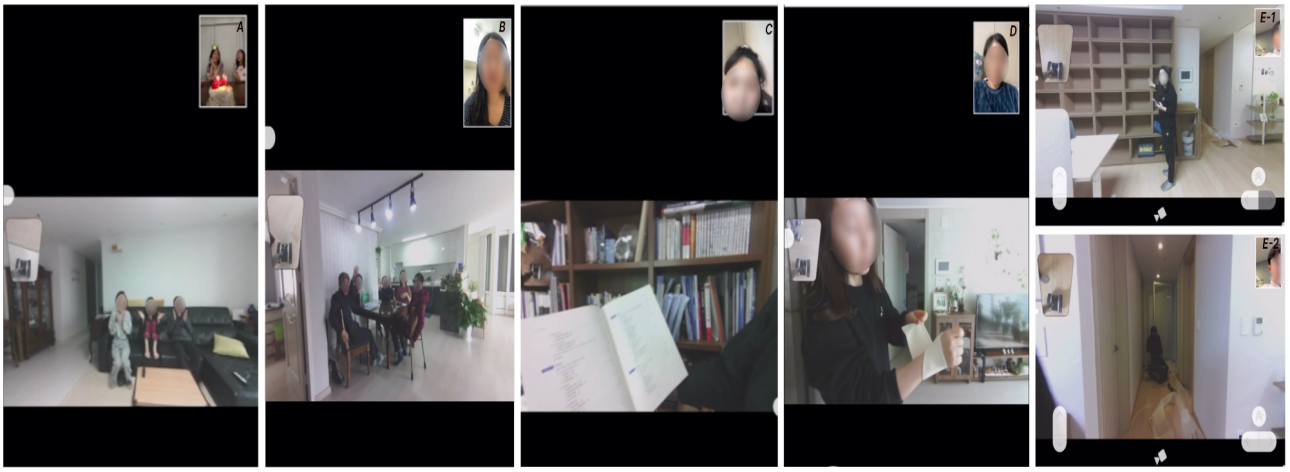

Figure 7. Examples of shared activities from participants using a telepresence robot in the

home environment in particular contexts (A: celebrating a remote family's birthday, B: participating in a family meeting, C: reading small fonts in a book for an elderly father, D: Showing usage of wrist guard for pregnant daughter, E: sharing interior remodeling situations in the home)

4.1.4 Participating in special family and home events

In addition to regular activities, families also utilized the telepresence robot for special cases and events. One notable use was during family events, where remote family members could participate actively. For example, on Lunar New Year's Day, remote family members could greet the whole family by bowing politely through the telepresence robot. It allowed them to be physically present during ancestral rites and create special memories. The participant stated, *"My daughter's family bowed politely to us through the robot and connected with us during ancestral rites."* This year, it became a special memory for us that our daughter's family could join and be physically present with us." (Celline's mother, local family). In another case, family members celebrated a remote family's birthday through a robot. The participants expressed their feelings, saying, *"I could celebrate my birthday with my parents and sister through a robot during dinner time. I could see how our family members enjoyed it, and I thought we were together"* (Amy, controller).

Additionally, remote families participated in regular family meetings, creating unity. Local family members reported feeling like the remote family member had taken their seat during the meeting. Celine's sister (local family) shared their perspective, stating, *"For my mom's birthday, our sisters had a family meeting at the living room desk, and my sister in a distant place could join through the robot. We felt like our sisters were united."*

Some participants also used the telepresence robot to join home events, such as home remodeling and clean-up. One family, Celline's Family, undertook significant interior work in their living room and transformed a bedroom into a dressing room. The remote family member witnessed the entire process by moving around the house with the robot. Theyactively participated in making decisions alongside their families. A participant from

Celline's Family expressed their experience, stating, *"I could see the whole process of interior work in the family home and also could join in making some decisions with my family members."* (Celline's sister, local family). Furthermore, local family members said they repurposed their sister's room as a dressing room. As a result of the remote family member's help, they were able to safely clear out the belongings that had been left in the room for some time. Local family members shared their perspectives, stating, *"We decided to change my sister's room into a dressing room, so she helped us clear out the stuff she had left in her room for a long time. She moved around with me in her room and looked* around for what we could throw away. She also wanted me to send her to Canada." (Celline's sister, local family).

Consequently, our research outcomes provide valuable insights into how families can effectively employ telepresence robots to enhance interactivity and address the challenges of long-distance separation from their family and home. Building upon these insights, we progressed to the subsequent phase of our study, which involved conducting a thorough analysis of telepresence robot usage. This analysis aimed to examine the pivotal factors that contribute to maintaining relationships within family contexts.

4.2 Key Dimensions of the Telepresence Robot in Family Communication

An observational study and in-depth interviews revealed a wide range of shared activities (4.1) and examined the ways in which these activities are influenced by five key dimensions of telepresence robots. These key dimensions are as follows: (1) Increased Awareness in an Asymmetrical Setting, (2) Proximity Control: Influencing Interaction Dynamics, (3) Privacy Consideration in Telepresence Robot Usage, (4) Enhanced Interaction Quality in Social Contexts, and (5) Supporting Communication Richness. Overall, all five factors reinforce social presence by promoting more engaging interactions among family members, surpassing the capabilities of CMC tools.

To support our qualitative analysis, we also collected pre- and post-survey data that aligns with the five key dimensions we examined. We used five specific items to measure the sense of social presence before and after utilizing the telepresence robot: (1) Awareness, (2) Proximity, (3) Privacy Concern, (4) Interactivity, and (5) Effective Message Conyenance. Four of these factors, excluding private communication methods, exhibited significant improvement after integrating telepresence robots into family communication, surpassing the capabilities of current CMC tools. In terms of privacy, local participants believed that the telepresence robot provided a level of privacy comparable to current CMC tools, while remote participants regarded it as a more private means of discussing family matters.

Key Dimensions	**Summary**
Increased Awareness in an Asymmetrical Setting	In an asymmetrical setting, local and remote families experienced different awareness. Local families felt like they were together with their remote families due to the robot's physical embodiment. Furthermore, remote families felt like they were in their family home with a highly immersive and high-quality telepresence robot.
Proximity Control: Influencing Interaction Dynamics	In this case, the local family allowed the telepresence robot to move around within its own personal space and bodily territory. Remote family members could have complete control over their proximity to their family members in every space in the home.
Privacy Consideration in Telepresence Robot Usage	There are minimal privacy issues using telepresence robots in family settings. They could accept moving around freely and sharing everything that happens at home.
Enhanced Interaction Quality in Social Contexts	Family members could deliver rich expressions to each other by using non-verbal cues such as facial expressions, body gestures, and touch. They could express affection or displeasure more directly without using many words.
Supporting Communication Richness	Communication through a robot promotes communication efficiency by giving more cues and exciting points to continue conversations. Families also have more extended conversations and focus on advanced technology communication.

Table 4. Summary of each key dimension in the Telepresence Robot in Family Communication

4.2.1 Increased Awareness in an Asymmetrical Setting

During the pre-interviews, the majority of participants expressed dissatisfaction with current computer-mediated communication (CMC) tools, citing a lack of strong presence and connection with their family members. Therefore, we found that their desire to experience a sense of being in the same place or with their loved ones motivated their interest in the telepresence robot. Our findings highlight the unique physicality and mobility of the telepresence robot, which distinguish it from existing CMC tools and contribute to enhanced awareness and a strong sense of presence among family members in remote situations (Local Family: pre-M(SD) = 3.31(.72), post-M(SD) = 4.45(.69), p = .009; Remote Family: pre-M(SD) = 2.98(.85), post-M(SD) = 4.24(.63), p = 0.00003). Participants also emphasized the impact of the telepresence robot's physical embodiment on their cognitive awareness, particularly in terms of social presence.

In addition, our study occurs in an asymmetrical setting where telepresence robots are physically present only in the parents' home. In contrast, other family members are classified as remote members who can only control the robot from a distance. As a result, we observed that the two groups experienced different types of presence based on their circumstances. However, it is worth noting that all participants did not express any significant issues with this asymmetry.

Some family members who had access to the robot expressed interest in controlling it. They wanted to explore their children's homes, especially those abroad. However, the majority of family members expressed satisfaction with the current setup. Many remote family members mentioned living in a studio or one-bedroom apartment with limited telepresence robot space. Additionally, most elderly parents, less familiar with advanced technology, exhibited low confidence in controlling the robot and expressed contentment with the current situation.

Local family members interacted directly with the telepresence robot, which served as a tangible representation of their remote family members. They emphasized the importance of the physically embodied robot agent, the large screen displaying their family members' faces, and haptic feedback in fostering a sense of togetherness. Through physical interaction with the robot, local family members could discern their remote family members' intentions. This included desired destinations or people they wanted to talk to. For example, David's father (local family) shared, *"During a conversation with my son through the telepresence robot, he suddenly turned the robot's body towards a different direction and followed the cat. I realized he was talking to me while also wanting to find the cat. That is my son. It truly felt like being with my son."*

Similarly, Amy's sister (local family) expressed a similar sentiment: *"When I discussed my new clothes with my sister, she suddenly moved to the dressing room to see them. I naturally followed her. It reminded me of the times we lived together."* Notably, we found that local family members associated with the telepresence robot, especially the screen displaying their family members' faces, with their remote family members, with recognition exceeding 80%. They also mentioned that their recognition was altered when the screen changed to display different remote family members. For instance, Amy's father (local family) stated, *"As my daughter's face was shown on the robot's iPad screen, I could recognize the robot almost 90% the same as my daughter. Interestingly, when the screen switched to my grandchild, I recognized it as my grandchild."* Another participant expressed the significance of physicality, saying, *"I think it was imperative to have something physical. When my pregnant daughter showed her baby bump, I hugged the robot, and the hug was for my daughter and the baby"* (Belle's mother, local family). Our participants said that awareness of the telepresence robot made them feel a strong co-presence, like being together with their remote families.

On the small side, participants described a sense of control over the telepresence robot, which contributed to immersive experiences. They appreciated the ability to maneuver the robot with a wide camera angle and utilize the loudspeaker, as it enhanced their immersion in the remote environment. Remote family members felt they were physically present in their homes while interacting with their family members through the robot. This immersive nature of the telepresence robot fostered a strong sense of presence. For instance, Belle (controller) shared that *"she could move around her home and connect with the family members she wanted to interact with."* She mentioned how seeing what her family members were doing made her feel like she was physically there, engaging with her parents in person. Another participant shared an encounter in the hallway with their sibling while remotely exploring the house. They highlighted that smoothly passing each other was like being together in person.

Additionally, Ellen (controller) described how she joined a family meeting in her family home through the robot. She expressed that *"I could see seven family members on the screen and join the conversation naturally. It made me feel like I was physically present."* The loud speaker and large screen let her recognize who was speaking and engage in meaningful conversations. Remote family members emphasized that the telepresence robot gave them more opportunities to participate in various family activities in their homes, creating a solid sense of telepresence. They also noted how these experiences helped alleviate homesickness by fostering a sense of presence and enabling interaction with their family members.

4.2.2 Controlling Proxemics: Influencing Interaction Dynamics

Our research findings indicate that participants could control their proximity to one another, enabling intimate interactions within their personal space and body territory, similar to in-person interactions. As participants had various interactions in all home spaces and physically interacted by controlling proximity, their psychological proximity to

each other also increased (Local Family: pre-M(SD) = 2.97(.84), post-M(SD) = 4.30(.69), p = .001 and Remote Family: pre-M(SD) = 2.43(.95), post-M(SD) = 4.22(.63), p = 0.00002). Family members actively adjusted their distance by moving closer or farther apart to engage with specific family members or spaces. Participants mentioned instances where the telepresence robot physically bumped into their bodies, which was perceived as playful and affectionate. For instance, Amy's sister (local family) stated, *"When my twin nieces controlled the robot and interacted closely with us, it created a warm and affectionate atmosphere."*

Furthermore, participants expressed how the telepresence robot empowered them to control their proxemics, a feature absent from previous computer-mediated communication tools. This capability allowed them to approach each family member physically, visit different rooms in the house, and engage in conversations. Gina (controller) emphasized, *"The freedom to move around the entire home and interact with family members in different rooms fostered a sense of togetherness and facilitated the natural sharing of family experiences."*

4.2.3 Privacy Considerations in Telepresence Robot Usage

During the interviews, participants expressed minimal concerns about privacy within the family. Local families perceived the privacy considerations associated with the telepresence robot to be similar to those of other computer-mediated communication (CMC) tools (pre-M(SD) = 3.82(.49), post-M(SD) = 4.11(.51), p = .909). However, remote families believed that the telepresence robot offered a higher level of privacy than other CMC tools, allowing for intimate and confidential conversations without privacy concerns (pre-M(SD) = 3.95(.68), post-M(SD) = 4.00(.95), p = .037). These contrasting perceptions of privacy between remote and local families highlight the influence of contextual factors on privacy perception in telepresence robot usage.

Both sides of families expressed a desire to freely share all spaces without specific permission from each other. Local families willingly granted remote family members access to the telepresence robot during calls. This facilitated interactions throughout the entire home, including the living room, kitchen, and every other space in their household. As Celine, the controller, pointed out, *"We have lived together for more than 20 years, so there is no need to protect privacy for our family members."*

4.2.4 Enhancing Family Interaction Quality in Social Contexts

During the pre-interviews, it was evident that all families preferred synchronous communication methods over asynchronous ones, emphasizing the significance of immediate interaction in their family dynamics. They mainly used audio and video calls, allowing real-time communication. Additionally, they utilized text messaging, notably through family group chats, to share photos and videos, enhancing their conversations' comprehension. Faith mentioned that *"the telepresence robot provided the most enriched communication experience, enabling us to express our emotions more vividly."* Our findings revealed that various features of telepresence robots contributed to an enhanced quality of interaction in social contexts (local family: pre-M(SD) = 3.89(.24), post-M(SD) = 4.43(.58), $p = .006$) and remote family: (pre-M(SD) = 3.82(.71), post-M(SD) = 4.35(.50), $p = .028$).

First, immediate feedback played a significant role. Participants received immediate responses during conversations, allowing for seamless and dynamic exchanges and creating a sense of presence and engagement. The telepresence robot also facilitated the conveyance of nuanced information, enabling family members to communicate in more detailed and specific ways. Participants reported that they could express themselves more comprehensively, enhancing the quality of their communication. David’s father (local family) mentioned that they could understand remote family members' information and emotions due to their behavior in controlling the robot, such as moving quickly or using

more movement to convey their intentions. Gina's sister (controller) also mentioned that they could understand *"other parties' nuances of their words by seeing their complete reactions with intuitive body gestures and the home atmosphere shared through the widescreen angle."*

These factors helped overcome language barriers and brought families closer together, even if they had previously communicated less due to the language barrier. For example, Celine's sister (local family) mentioned that their niece, who only spoke English and knew a few Korean words, found communicating challenging without their sister's translation. However, using the robot, the niece expressed her feelings directly through robot movements, and the participant used more gestures. Despite using fewer spoken words, they felt more connected. Gina (controller) shared that her foreign husband, who only spoke English, and the family members in Korea spoke only Korean and could convey information and feelings by moving the robot's body. They could understand the nuances of each other's words, even if the exact meaning was unclear. The telepresence robot allowed even slight differences in meaning to be conveyed and easily understood, bridging the gap between different languages. All participants expressed satisfaction with the robot's ability to facilitate nuanced communication, enabling a deeper understanding of information and emotions in their family interactions.

Furthermore, we observed that telepresence robot-mediated communication facilitated the ability to refer to shared experiences and objects, contributing to a deeper understanding and connection among family members. Through the telepresence robot, participants could reference specific individuals, locations, or items that held significance within their shared context. It helped simplify the situation and foster a more meaningful conversation. For instance, Amy (controller) pointed out changes in their living room using the robot's camera, employing abstract expressions and deictic terms. Amy's sister (local family) perfectly grasped the references and continued the conversation seamlessly.

Non-verbal cues, such as gestures, body language, and facial expressions, were also conveyed through the telepresence robot, enriching the overall communication experience. Participants used abstract expressions like *'there,' 'it,' 'those,'* and *'over there'* to refer to shared sights and objects, enhancing comprehension and engagement during conversations. We found that these implicit cues, in correlation with individual controls, helped family members naturally convey their emotions. By catching each other's facial expressions with eye-contact and atmosphere, they were more likely to show affection or displeasure towards each other. Local family members mentioned how they could see remote family members' faces on the big screen, facilitating a better understanding of their emotions through facial expressions. Remote family members, on the other hand, could express their feelings through facial expressions and physical interactions, such as getting closer to show affection or moving further away to express dissatisfaction. For example, Ellen (controller) mentioned *"using the robot to tap their mother's body to call for reconciliation after a quarrel, conveying their desire for reconciliation without using words."* Ellen's mother also mentioned *"feeling that the robot's touch signaled a call for reconciliation, and they subsequently expressed affection by apologizing."* Overall, we found that joint references with non-verbal cues controlled by individuals allowed families to engage in rich communication in simple and intuitive ways. The telepresence robot facilitates the use of implicit cues, enhancing expressiveness and depth of interactions.

4.2.5 Supporting Communication Richness

All of these factors significantly impact the quality of communication among family members. They influenced various aspects such as the choice of conversational topics, the duration of conversations, and the level of concentration during interactions. The telepresence robot facilitated more meaningful and focused conversations, allowing participants to engage in a broader range of topics and express themselves more effectively (Local Family: pre-M(SD) = 3.81(.48), post-M(SD) = 4.54(.54), p = .018 and Remote

Family: pre-M(SD) = 3.72(.68), post-M(SD) = 4.39(.54), p = .009). Participants reported that sharing a broad and immersive visual perspective through the robot could sustain conversations and explore unexpected topics longer than previous communication methods. For instance, David's mother (local family) mentioned: *"how their son, while controlling the robot, noticed they had run out of rice at home."* This observation led to a conversation about rice brands, and they continuously discussed the topic. It exemplifies how the telepresence robot facilitates in-depth conversations beyond simple exchanges.

Furthermore, Amy's father also highlighted *"the increased concentration of children during remote communication sessions."* The telepresence robot was perceived as an entertaining tool for connecting with remote families, such as grandparents and aunts/uncles, and the children became more engaged in the conversations. Participants shared that their grandchildren, who previously had difficulty maintaining focus during video calls, wanted to continue the calls. Instead, they enjoyed interacting with their relatives through a robot. This shift in children's behavior was attributed to the gamified nature of the robot and its various functions, which made the communication experience more engaging and interactive. Therefore, the telepresence robot's ability to provide a broad visual perspective and offer additional interactive features enhanced family communications engagement and quality. Participants experienced more focused and prolonged conversations, and children, in particular, exhibited increased concentration and enjoyment during remote interactions.

		N	Pre-Mean(SD)	Post-Mean(SD)	t	p
Awareness	Local Family	17	3.31(.72)	4.45(.69)	-3.116	**.009
	Remote Family	12	2.98(.85)	4.24(.63)	-4.520	***<.001
Proximity	Local Family	17	2.97(.84)	4.30(.69)	-4.295	**.001

	Remote Family	12	2.43(.95)	4.22(.63)	-5.890	***<.001
Privacy Concern	Local Family	17	3.95(.68)	4.00(.95)	-.117	.909
	Remote Family	12	3.82(.49)	4.11(.51)	-2.279	*.037
Interactivity	Local Family	17	3.89(.24)	4.43(.58)	-3.398	**.006
	Remote Family	12	3.82(.71)	4.35(.50)	-2.411	*.028
Message Conveyance	Local Family	17	3.81(.48)	4.54(.54)	-2.784	*.018
	Remote Family	12	3.72(.68)	4.39(.54)	-2.959	**.009

Table 5. Paired t-test of feeling social presence before and after usage of telepresence robots compared to other CMC tools (e.g., video call, audio call, text-messaging) based on Awareness, Proximity, Privacy Concern, Interactivity, and Message Conyenance.

4.3 Design Suggestions from Participants

As we found key dimensions of telepresence robots used in the family context, our participants were also asked to suggest potential improvements based on their user experiences. Accordingly, participants provided valuable insights and suggestions during the post-interview idea sketching session. These suggestions aimed to improve the telepresence robot experience and address specific areas of concern for family communication. Here are some of the participants' suggestions at the system and physical levels:

4.3.1 Physical Level Suggestions

Improved appearance: While the telepresence robot already enhanced feelings of awareness, especially social presence, participants provided suggestions for further enhancing the robot's appearance more like humans to strengthen the sense of awareness.

First, they suggested designing the robot to resemble a human by incorporating a hanger to dress it up. Ellen's mother (controller) proposed adding a hanger to the robot's appearance. This would allow them to dress it up more like their daughter and increase their awareness of the robot. Participants also desired adjustable height options to accommodate interactions with babies or pets and the ability to control the robot's head angle for nodding and turning. David's father mentioned that *"having more adjustable height and head angle control would benefit maintaining eye contact in different postures, such as sitting or standing."* Furthermore, participants expressed the importance of including arms and hands on the telepresence robot to assist with physical tasks. For example, Faith's mother expressed the desire for the robot to have *"more human-like functions with delicately controlled arms and hands, allowing for more nuanced interactions and reducing the sense of repulsion associated with the robot."*

Improved mobility and navigation with expanded control options: While participants freely controlled proximity, they suggested improving the robot's mobility and navigation capabilities emerged as a key recommendation. They suggested specific improvements, such as incorporating wheels designed for navigating two-story houses, implementing obstacle avoidance technology to maneuver around furniture and decorations, and improving maneuverability in narrow spaces. Additionally, participants recommended incorporating gesture-based controls or voice commands to provide a more intuitive and personalized user experience. These enhancements would allow the robot to move seamlessly and navigate homes effectively. Amy mentioned the diverse structures of homes, like multi-story houses, with various furniture and decorations, and emphasized *"the need for versatile wheel tools and control options, such as auto avoidance technology and gesture controls, to address different situations and emergencies."*

Integration with smart home devices and adding housework functions: Participants recognized the potential benefits of integrating the telepresence robot with

smart home devices and systems. They suggested features such as remote control of lights, thermostats, and other smart devices through the robot's interface. This integration would offer convenience and functionality, enabling users to interact with their home environment more effectively. Furthermore, some participants also proposed the addition of housework functions to the telepresence robot, such as vacuuming and wet mopping capabilities. They mentioned the idea of *"interchangeable wheel tools for different tasks."* By incorporating these housework functions, participants believed that *"the telepresence robot could provide a more immersive experience and resemble living with remote family members."* They also mentioned that *"the robot's ability to help with cleaning tasks and explore the house could make the robot more worthy and create win-win situations, such as assisting parents with cleaning while allowing remote family members to move around and engage with their home environment."*

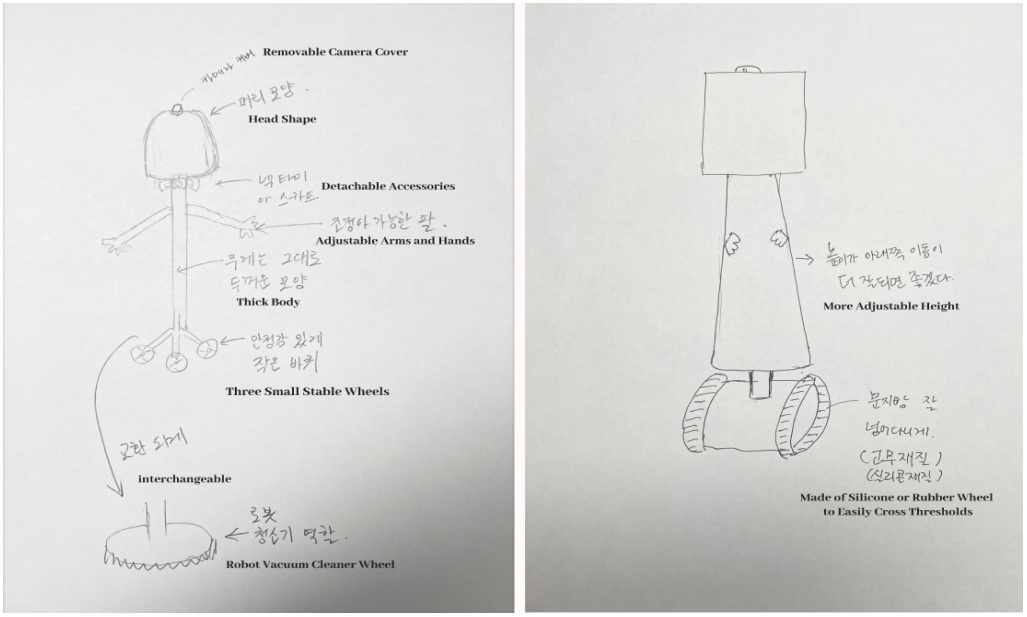

Figure 8. During the post-interviews, local family members created sketches suggesting designs of telepresence robots for family communication in home environments based on their two weeks of deployment experiences.

4.3.2 System Level Suggestions

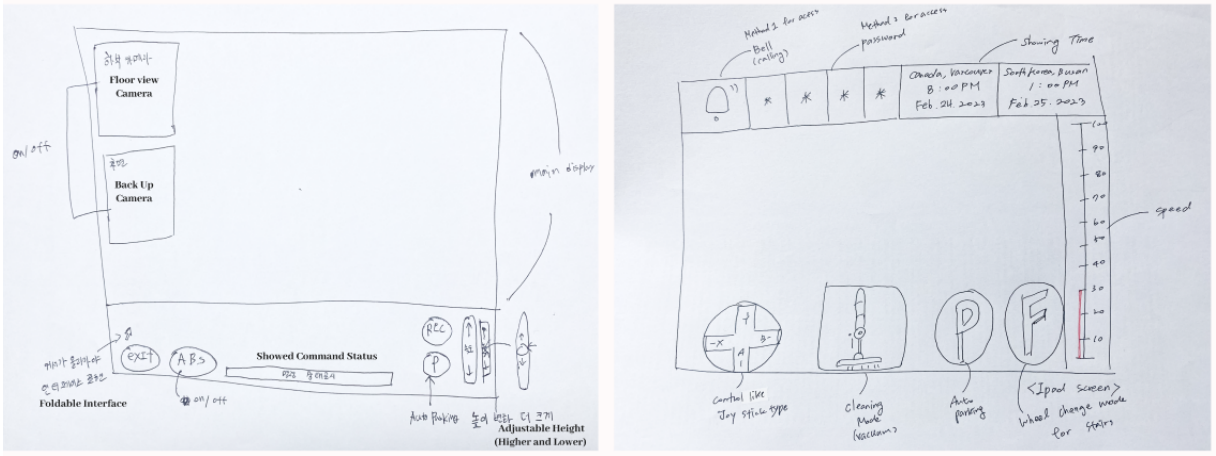

Figure 9. During the post-interviews, remote family members created sketches suggesting designs of telepresence robots app UI for family communication in home environments based on their two weeks of deployment experiences.

Streamlined Access Process: While privacy issues were not a significant concern for all participating families, participants expressed concerns about the system's security, particularly the possibility of the robot's camera being hacked. Their privacy concerns revolved around external threats rather than family privacy. Some participants suggested using a removable camera cover to prevent cam phishing and protect their family's privacy from leakage outside. For example, Celine's family members stated, *"I feel worried about hacking or cam phishing, which frequently happens with smartphones' front cameras or PC webcams. Like many people who put stickers to block their webcams, having a removable camera cover would be great."*

In addition to security concerns, participants expressed a desire for streamlined access settings. This would enable more convenient and unrestricted use of telepresence robots without explicit permission from local family members. Suggestions included implementing features such as a 'do not disturb' mode and the ability to schedule specific times for uninterrupted access. Additionally, some participants proposed a simplified access system comparable to unlocking the front door of a physical home using a password. These recommendations aim to improve the convenience and user-friendliness

of granting access to the telepresence robot, especially for elderly family members residing in the family home. Gina's sister mentioned, *"My elderly parents struggled to turn on the robot and open the app, so I think it would be better to have free access or minimal verification steps for family members."*

User-friendly interface and setup: Participants emphasized the need for the telepresence robot to have an interface that is easy to use and a straightforward setup process. Some participants suggested, *"incorporating intuitive controls and providing clear instructions to adapt it."* Especially elderly parents shared experiences about struggling to turn on and connect the call through an application with unclear instructions in the setup process and a less intuitive UI system. Therefore, they suggested more social systems for all generations, from kids to older adults, to help them adopt new technology with limited technical expertise.

At the UI level, participants proposed several enhancements. They suggested displaying time difference and speed on the upper side of the user interface (UI) screen, enabling users to understand each other's situations better and facilitating communication. Another suggestion was to allow multiple remote users to interact simultaneously. This would enable family members who live separately to share the same scenes and engage in collective interactions. Furthermore, Faith's siblings suggested additional features for the user interface, such as *"displaying time differences and speed, to enhance control and understanding between local and remote family members."*

Improved battery life and charging options: Participants stressed the importance of improving the telepresence robot's battery life and charging options. They expressed the need for longer battery life to extend robot operating time between recharges. They recommended advancements in battery technology to achieve this goal. Furthermore, many participants suggested exploring alternative charging methods to enhance convenience and accessibility. Specifically, they mentioned, *"wireless charging and docking stations as*

potential solutions." These alternative charging methods would streamline the charging process, eliminating the need for manual plugging and unplugging of the robot. Participants shared their experiences of the telepresence robot running out of battery during conversations or moving around, even when fully powered. This situation raised concerns about increased household electricity bills and the inconvenience of not having the robot ready. As a result, participants stressed the importance of addressing battery life and charging issues. This is to develop a more efficient and cost-effective telepresence robot that can support longer communication sessions and be readily available for home use.

Chapter 5. Discussion

Our study aimed to gain insights into the role of telepresence robots in facilitating family communication. It also examined the key dimensions that support intimate interactions within the home context. By exploring the challenges and opportunities associated with telepresence robots in family communication, our goal was to provide a comprehensive understanding of their potential.

Overall, our findings indicate that participants expressed high satisfaction with telepresence robots. This made them fulfill the relationship maintenance strategy factors and provided a positive experience. Moreover, they recognized them as advanced technology capable of replacing traditional video calls in the home context. Based on these results, we present a summary and discussion of the opportunities telepresence robots offer. Additionally, we provide design implications to address challenges encountered during our family communication study.

5.1 Opportunities of the Telepresence Robot in Family Communication

5.1.1 Amplifying Physical Interaction with Mobility: Embracing Physicality for Intimate Family Connections

First, the value of physicality was a significant finding in our study, as participants expressed high satisfaction with telepresence robots connecting long-distance families in remote locations. Participants could address the lack of physical presence that often hinders long-distance communication by having a physical robot at home and controlling a remote robot. This aspect of physicality aligns with relationship maintenance artifacts,

which aim to maintain intimate relationships by mediating a sense of close intimacy through physiological parameters and gestures (Hassenzahl et al., 2012).

While wearable devices have been explored in long-distance communication to support physical interaction, previous literature has primarily focused on their ability to transmit non-verbal cues and information rather than facilitate emotional and in-depth communication. In contrast, telepresence robots offer an advantage by enabling emotional engagement and physical interaction in synchronous communication. Telepresence robots' unrestricted mobility further enhances the sense of being physically present, leading to more natural and comfortable interactions. Remote family members reported the ability to move the physical robot closer to family members and explore spaces within the family home. This mobility provides a sense of autonomy for family members controlling the robot, allowing them to interact with their remote counterparts comfortably and without restrictions.

Overall, our findings underscore the opportunities presented by physicalness, particularly in the context of mobility, for facilitating intimate family interactions in long-distance communication. By providing a physical presence and enabling touch and physical interaction, telepresence robots offer unique possibilities for maintaining relationships and fostering emotional connections. The free mobility of these robots enhances the sense of physicalness and enables natural and unrestricted interactions. These insights have important implications for the design of telepresence robots in family communication, emphasizing the significance of physicalness as a crucial factor to be considered in future developments.

5.1.2 Expanded Interactivity and Engagement: Creating Memorable Experiences Through Dynamic Interactions

Second, our study investigated the capabilities of telepresence robots in facilitating various shared activities in the home space. Shared activities are essential to reinforce

relationships by creating memorable experiences with their routines (Stafford & Canary, 1991; Wood & Inman, 1993; Hassenzahl et al., 2012). While previous literature has primarily focused on the use of telepresence robots for specific purposes in public places (Markoff, 2010; Lee & Takayama, 2011; Newhart & Olson, 2017) and couples' communication centered around interacting at a home and mundane activities (Yang & Neustadter, 2018), our findings highlighted the diverse range of interactivities observed in family communication using telepresence robots.

Unlike in other contexts, family communication with telepresence robots provides a platform for interacting with multiple family members. The high mobility of these robots allowed dynamic interactions throughout the living space, free from privacy or proximity concerns. Our participants exhibited different types of interaction depending on the family members involved. They viewed the robot as a communication tool and entertainment device with gamification functionality. Families utilizing telepresence robots found enjoyment in their everyday lives by interacting with the robot. They also engaged in seek-and-hide games and fostered meaningful interactions during special events or circumstances, such as family gatherings or providing care to parents or during pregnancy. These interactions added an additional dimension to family dynamics and enhanced family communication quality.

It is significant to note that the level of interactivity in family communication using telepresence robots is infinite. Thiscan vary depending on the unique characteristics of each family. As technology continues to evolve, telepresence robots hold the potential to enhance family interactions further and serve as entertainment tools within the family context. Therefore, telepresence robots offer families the exciting opportunity to engage in various interactive experiences. By enabling dynamic interactions among family members, promoting gamification, and accommodating special contexts, these robots enrich family communication. Further exploration and development in this area can unlock new

possibilities for telepresence robots to be valuable tools in facilitating entertaining and meaningful interactions within the family unit.

5.1.3 Exploring Awareness Dynamics: Supporting Telepresence and Social Presence Feelings

Third, we uncovered distinct types of awareness experienced by families using telepresence robots and their remote counterparts. Awareness, a key element in mediating intimate relationships through technology, encompasses the ability to sense the mood, display presence, and maintain knowledge about one's environment and surroundings (Wisneski et al., 1998). Our findings shed light on the unique awareness dynamics observed in this context.

Remote family members, interacting with the telepresence robot from a distance, reported experiencing telepresence.They felt like they were actively engaging with family members in their family home. The telepresence robot's high immersive quality played a significant role in creating this feeling. This allowed them to transcend the screen limitations and immerse themselves in shared space. On the other hand, local families experienced a different form of awareness known as social presence. They reported feeling a sense of co-presence as if they were physically together with their remote family members in the same space. Therefore, our findings heightened awareness, fostered a deeper connection, and facilitated more meaningful interactions. The asymmetrical awareness experienced by both sides of the family emphasized the potential of telepresence robots to foster a sense of togetherness and facilitate emotionally meaningful interactions.

5.1.4 Enriching Communication Through Non-verbal Expressions: Enhancing Expressivity with Non-verbal Cues

Fourth, our study revealed the immense value of telepresence robots in enhancing expressivity and enabling more comfortable and meaningful interactions. It is essential to

express feelings in an enriched way using symbols in order to support relationship maintenance (Hassenzahl et al., 2012). Through the natural utilization of non-verbal cues, telepresence robots offer a level of communication richness that surpasses existing computer-mediated communication (CMC) tools. While video calls are considered the richest media channel available and provide the closest approximation to face-to-face communication among CMC tools (Corry et al., 2007), telepresence robots elevate communication modality to an even higher level. Our participants recognized these robots as advanced technologies that evolved from video calls and conferences. Telepresence robots maximize robot-mediated communication expressivity by being equipped with wide-angle cameras, loudspeakers, and mobility. In addition, they effectively support key characteristics of collocated synchronous interactions, including rapid feedback, nuanced information, coreference, individual control, and implicit cues (Olson & Olson, 2000). By leveraging these features, we found that telepresence robots enable individuals to overcome language barriers and convey various emotions, including affection and displeasure. This is both verbally and non-verbally. This capability significantly reduces the psychological impact of distance and fosters a greater sense of expressivity in communication.

Furthermore, telepresence robots offer a distinct advantage in creating a feeling of co-presence, often lacking in video conferencing. Our study revealed that families utilizing telepresence robots experienced social presence similar to being physically present with their remote family members. The direct interaction with the robot, which displayed the faces of their remote family members on a large screen and moved around them naturally, contributed to a heightened sense of togetherness. This finding suggests that telepresence robots have the potential to provide the highest level of communication modality among current CMC tools, offering individuals an experience that closely resembles face-to-face interaction within the same physical environment. Therefore, telepresence robots present

exciting opportunities to elevate communication modality and create immersive and engaging family interactions. These robots can transform how families connect and bridge spatial divides by incorporating advanced features, facilitating non-verbal communication, and fostering a sense of co-presence. These insights offer practical implications for the design and development of future telepresence technologies, aiming to create more authentic and fulfilling communication experiences for distant families.

5.1.5 Expanding Privacy Boundaries: Redefining Privacy Dynamics in Family Communication

Fifth, we investigated the privacy barriers that arise when families use telepresence robots for communication. Existing research has emphasized privacy concerns in the context of telepresence robots used for one-to-one communication, where issues of compromised privacy can arise, particularly in private living spaces (Yang & Neustadter, 2018). However, our study findings suggest that families who have resided in a family home for over 20 years experience lower privacy barriers when utilizing telepresence robots.

Participants expressed that their closest intimate relationships were within the family unit, resulting in fewer privacy concerns than in other relationships. The acceptance of a telepresence robot in their home, which is considered an intimate space, was willingly embraced by all participants. The notion of body territories played a role in their perception, as they felt comfortable having the robot present in their personal spaces. Remote family members had unrestricted access to move around and explore all areas of the home while connected through the telepresence robot. They also expressed confidence in the robot as a private communication method for their family. They believed that it would facilitate private conversations on a similar or even better level than current computer-mediated communication (CMC) tools. As a result, they expressed a desire for

simplified access processes and direct availability. This was without permission from family members who had the robot physically present.

5.2 Design Implications of Telepresence Robot in Family Context

Based on our findings, we propose design guidelines for a telepresence robot to improve it as a family home communication tool. While telepresence robots are typically designed for specific purposes in public spaces, we have identified areas where they can be enhanced to foster intimate connections and facilitate interactions in private settings, especially in a family context.

Implication	Guideline
Strengthening a human-like appearance and functions	● Customize the robot's appearance with hangers and dress-up features. ● Provide adjustable height and head angle settings for dynamic interactions. ● Add arms and hands for improving robot capability
Integration with smart home devices and housework systems	● Connect the robot to smart home devices for remote control. ● Equip it with interchangeable wheels for housework tasks like vacuuming and mopping.
Improve mobility and navigation capabilities	● Enhance navigation for various home layouts and obstacles. ● Incorporate Voice UI and gesture control for user autonomy.
Managing access settings and security	● Offer flexible access options like ‘always-on’ or ‘do not disturb’ modes. ● Use detachable camera covers to protect family privacy from external threats.
Supporting the interactions of multiple people and generations	● Enable simultaneous interaction with split-screen views. ● Develop an intuitive UI with clear instructions, time differences, and speed gauges.
Addressing battery life and charging options	● Optimize power management for extended battery life. ● Explore wireless charging for convenience and availability.

Table 6: A summary of design implication with guidelines

5.2.1 Strengthening a human-like appearance and functions

Based on our findings (4.3.1), further study should consider several design improvements in robot appearances to strengthen the sense of awareness and

personalization in telepresence robots. Incorporating hanger options into the robot for customization is one approach that allows users to customize the robot's appearance. This allows users to be better aware of their remote family members. Additionally, we could consider the option of interchangeable covers or accessories, enabling users to easily change the robot's appearance with different colors, patterns, or materials. This customization feature fosters a deeper personal connection, as users can tailor the robot's appearance to suit their preferences.

Another suggestion is to provide users with a broad range of adjustable height and head angle options. These functions allow users to customize the robot's position based on their needs and have flexibility with seamless transitions between different postures to enhance user comfort and personalization. Furthermore, we propose the integration of human-like arms and hands to enhance the telepresence robot's capabilities. By incorporating sensors and actuators, the robot can acquire the ability to grasp objects, manipulate tools, or perform simple actions. This integration provides a more human-like interaction experience, allowing users to engage more effectively in physical tasks and housework functions.

5.2.2. Integration with smart home devices and housework systems

For further improvements, we suggest integrating telepresence robots with smart home devices and systems. This includes controlling home appliances remotely and incorporating physical housework functions into telepresence robots. By establishing compatibility between the telepresence robot and various smart home devices, remote families can control and interact with their home devices through the robot's interface. This is without additional setup or configuration. Moreover, telepresence robots can also physically perform housework functions with detachable and replaceable attachments for vacuuming or wet mopping. In finding 4.3.1, our participants suggested housework functions to deepen immersion in remote places. This was to make the robot price worthy

of being a home tool. Therefore, this flexibility can make telepresence a more valuable tool covering multiple uses, such as communication methods and home devices.

5.2.3. Improving mobility and navigation capabilities

In future designs, we should focus on controlling the robot in various aspects of the home context, such as different home structures and surroundings. In our findings (4.3.1), our participants suggested functions like path planning and obstacle recognition for multi-story houses. We propose ideas for enhancing the robot's navigation system by developing algorithms and considering factors such as home structures with floor layouts and objects to help the robot navigate efficiently and safely. Additionally, telepresence robots can be equipped with various sensors such as depth cameras, proximity sensors, or laser range finders for obstacle detection and avoidance. Real-time feedback from these sensors allows the robot to adjust its path accordingly, avoiding collisions with furniture and decorations. Moreover, it can help users quickly and effectively control the robot by reducing trial and error, such as bumping into objects or getting lost on an onboarding step.

In addition, we suggest developing accurate voice recognition systems that interpret user commands or gesture recognition systems that track and understand hand movements, enabling users to control the telepresence robot effortlessly using their preferred interaction method. As there was relatively low autonomy of hands or body for remote families controlling the robot, these intuitive control options enhance both sides of users' engagement and make the robot more accessible to all users.

5.2.4 Managing access setting and security

In our findings (4.2.3), participants reported that family members did not perceive any privacy issues when using the telepresence robot. We recommend simplifying access settings to create a user-friendly system well-suited for the family context. These applications should provide options for configuring free access time settings, such as an

'always-on' or 'do not disturb' mode, allowing users to customize the availability and interaction patterns of the robot according to their preferences and privacy needs. By implementing these streamlined access settings, we can facilitate a more natural and seamless experience while respecting users' privacy preferences.

Furthermore, a telepresence robot in a family setting allows communication without unnecessary complexities, fostering a sense of natural and seamless interaction. However, it is essential to address security concerns raised by some participants, particularly regarding the potential hacking of the robot's camera by external parties. To mitigate these concerns, we suggest equipping telepresence robots with detachable camera covers as a security measure to safeguard user privacy from external threats. We emphasize the importance of considering privacy settings in family communication, as privacy considerations and security methods can differ from those in other intimate relationships and public settings.

5.2.5. Supporting interactions of multiple people and generations

As we found in 4.3.2, a family comprises multiple individuals and involves intergenerational interactions, ranging from young kids to older adults. Some families participating in our study have more than one family member living apart from the family home. Therefore, they strongly suggested enabling simultaneous interaction for multiple remote users through a multi-user interface. This interface should accommodate multiple users joining a telepresence session simultaneously with split-screen views or individual windows, allowing each user to have their dedicated space for interaction. As multiple remote family members can access communication via telepresence robots simultaneously, it can support the reunification of the entire family.

Additionally, we suggest improvements to the user interface (UI) system to make it friendly for all generations by sharing information more intuitively. In future designs, the UI system of telepresence robots can provide additional functionalities, such as clear

instructions for all buttons in the interface, and help family members understand each other's local situations while displaying time differences on screen with light/dark mode. Many participants also suggested displaying a speed control gauge to track their movements, especially when kids are controlling it. We believe it is essential to make the telepresence robot a social system for all generations within the family.

5.2.6. Addressing battery life and charging options

In future research, we should improve the power management system of telepresence robots by implementing energy-efficient components, such as low-power processors and display panels, to position them as home devices. In finding 4.3.2, we discovered that telepresence robots require more frequent charging than other home appliances, resulting in burdensome electric bills for households. Therefore, operators should explore advanced battery technologies for wireless charging capabilities. This will extend the robot's operating time and reduce recharging frequency. Additionally, our participants expressed the need for convenient charging options, such as wireless charging. In future developments, users should be able to conveniently charge the robot by ensuring proper alignment for efficient charging. This will minimize downtime and maximize its availability for interaction and use.

Chapter 6. Limitations and Future Work

While our findings provide insights into facilitating long-distance family communication through telepresence robots and identify opportunities and challenges, our study has three fundamental limitations that should be addressed in future research. Firstly, our participants were recruited using snowball sampling and had direct connections with the researchers. Future work should employ more diverse sampling methods to enhance our findings' generalizability, including individuals from different nationalities and environments. Secondly, our study spanned only two weeks, during which no restrictions or usage rules were imposed. Extending the duration of future studies and implementing specific usage guidelines can yield more valuable and comprehensive findings regarding the telepresence robot's impact over an extended period of time. Lastly, our deployment of the telepresence robot in the family home caused an asymmetry problem, as it provided a specific perspective from both local and remote families. It would be beneficial to deploy the telepresence robot in households on both ends or alternate the roles between local and remote families every two weeks. This would enable us to gain a more comprehensive understanding and discover additional confirmed insights. By addressing these limitations in future research, we can further enhance our understanding of how telepresence robots facilitate long-distance family communication and gain more robust and diverse insights.

Chapter 7. Conclusion

In this study, our objective was to explore the potential insights of telepresence robots in facilitating long-distance family communication by examining critical factors that contribute to relationship maintenance within the family context. Through a comprehensive analysis of observation data and pre- and post-interviews conducted with eight families, we examined five key dimensions that significantly influence the effectiveness of telepresence robots in supporting family communication: increased awareness in an asymmetry setting, controlling proxemics, privacy considerations in telepresence robot usage, enhancing interaction quality in social contexts, and supporting communication richness Our findings reveal that telepresence robots offer abundant opportunities for supporting long-distance family relationships, encompassed by the identified five key dimensions. Additionally, our participants' valuable design suggestions shed light on their challenges using telepresence robots. Taking these challenges into account, we discussed design implications aligned with the identified opportunities. Our work extends to researchers, designers, and operators working in the field of Human-Computer Interaction (HCI), particularly within the telepresence robot industry. Our findings serve as a valxfhouable guide for developing enhanced telepresence robot designs specifically tailored to the unique demands of the family context, ultimately leading to enriched family communication experiences.

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Appendix

Items (Number of items)	Survey Questions(*pre and post*)	Cronbach's Alpha
Awareness(5)	While communicating through the existing CMC (or telepresence robot), I was able to recognize the presence of the other person and express emotions. I was able to establish smooth eye contact and accurately recognize the expressions and emotions of the other person through the existing CMC (or telepresence robot). I was able to recognize the other person's expressions and emotions by communicating through the existing CMC (or telepresence robot). When communicating through the existing CMC (or telepresence robot), I felt that the other person was actively engaged, listening to me as if we were in the same physical space. While communicating through the existing CMC (or telepresence robot), I felt a strong sense of connection and presence with the other person.	*.945*
Proximity(8)	When communicating through the current CMC (or telepresence robot), I feel a strong sense of closeness to the other person, especially when I am physically close to the device. Using the current CMC (or telepresence robot), I experience a feeling of face-to-face communication as the physical distance between us seems to diminish. Through the current CMC (or telepresence robot), I am able to engage in shared physical activities with the other person. While communicating through the current CMC (or telepresence robot), I perceive a similarity to face-to-face communication. *For the local family* During communication via the current CMC (or telepresence robot), I feel as though the other person is right beside me, creating a presence similar to a real person. When communicating through the current CMC (or telepresence robot), I strongly sense the presence of the other person. *For remote family* While using the current CMC (or telepresence robot), I can perceive the other person's proximity as if they are physically near me. I believe that by communicating through the current CMC (or telepresence robot), the other person will be able to perceive my	*.820*

	presence.	
Privacy Concern(2)	The current CMC(or telepresence robot) ensures personal/private communication. The current CMC(or telepresence robot) allows for comfortable and private conversations, promoting a sense of trust.	*.620*
Interactivity(4)	The current CMC (or telepresence robot) enables immediate communication, effectively enhancing family interaction. We feel at ease and communicate seamlessly using the current CMC (or telepresence robot), fostering enhanced family interaction. Communication through the current CMC (or telepresence robot) helps bridge the psychological distance, facilitating closer family connections. The current CMC (or telepresence robot) has a positive impact on the formation of intimacy within the family, promoting enhanced interaction.	*.831*
Emotional Communication(4)	The CMC technology (or telepresence robot) currently in use enables meaningful conversations. It is effortless to convey one's intended message using the CMC technology (or telepresence robot) currently in use. The current CMC technology (or telepresence robot) allows for vividly expressing emotions and thoughts between communicators. Understanding the conveyed message from the other party becomes effortless through the CMC technology (or telepresence robot) currently in use.	*.865*

국문 초록

작업, 교육, 결혼 등의 다양한 이유로 본가로부터 떨어져 장거리에 거주하게 된 자녀들이 많습니다. 이로 인해 물리적 거리 극복하고 가족 간의 친밀한 관계를 유지하기 위해 효과적인 소통 방식의 필요성이 대두되었으며 많은 가족들은 장거리 가족 간의 친밀감 유지를 위해 컴퓨터 매개 커뮤니케이션(CMC) 도구를 활용한 소통을 해오고 있습니다. 특히 대면 소통과 가장 비슷한 높은 소통 효과를 주는 영상 통화가 널리 사용되고 있음에도 불구하고 친밀한 관계를 유지하는 전략 중에서 중요한 요인으로 작용하는 물리적 상호작용, 공유 활동, 감정 표현 및 사회적 실재감 같은 요소들은 충족되기 어렵습니다. 따라서 본 연구는 원격 가족 소통을 돕는 텔레프레즌스 로봇의 잠재력을 탐구합니다. 2주 동안, 본가에 거주하는 로컬 가족 구성원 17명(예, 부모님 및 형제자매)과 본가로부터 떠나 장거리에 거주하는 원격 가족 구성원 12명(예, 자녀 및 자녀의 배우자 및 자녀)으로 이루어진 8가족이 본 연구에 참여했습니다. 먼저, 본 연구는 가정 환경에서 텔레프레즌스 로봇을 사용하여 참가자들이 다양한 상호작용을 통한 공유 활동에 참여하는 모습을 관찰하였습니다. 또한 우리는 가족 관계 유지를 지원하는 텔레프레즌스 로봇의 핵심 요소를 조사하였습니다. 이 연구 결과는 장거리 가족 소통을 위한 텔레프레즌스 로봇의 개선점과 기회에 대한 논의에 기여합니다. 또한, 가족 소통을 원활하게 돕기 위한 주요 디자인 가이드라인을 제시합니다.

주요어: 인간과 컴퓨터의 상호작용, 컴퓨터 지원 협력 작업, 가족 커뮤니케이션, 관계 유지, 사회적 실재감, 텔레프레즌스 로봇

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