



“The robot should be programmed for me”: User tests evaluating a telepresence robot for the social integration of older adults.

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Telepresence robots that allow communication between older adults and their remotely located social contacts can foster social integration. The present laboratory test study explores older adults' successful use of a telepresence robot (research question 1, RQ1), as well as their perceived enjoyment (RQ2), perceived ease of use (RQ3), perceived usefulness (RQ4), perceived social presence (RQ5), and intention to use (RQ6) a telepresence robot for robot-mediated communication (RMC). Semi-structured interviews, observations, and questionnaires were applied with a group of $N = 14$ older adults living in Germany. Participants completed a navigational task (as remote users) and an interpersonal communication task (as local users). Results show older adults used the telepresence robot successfully (RQ1) during the tasks. Furthermore, in interviews older adults described their perceived enjoyment (RQ2), perceived ease of use (RQ3), and perceived usefulness (RQ4) during RMC as generally high. Perceived social presence (RQ5) during RMC was generally described as high, with RMC being considered a viable substitute when face-to-face communication is not possible. Finally, only two participants (2/14) had no intention to use (RQ6) a telepresence robot in the long term. Future design recommendations are provided, such as adapting the telepresence robot's functions to older adults physical, psychological, and social conditions.

CCS CONCEPTS • Human-centered computing • Human computer interaction (HCI) • HCI design and evaluation methods • User studies

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1 INTRODUCTION

Ilse and Hannelore live in the same small village in Germany and have been friends for over 30 years. Their houses are located on the same street, they attend each other's family celebrations and share regular coffee afternoons. Despite their physical closeness, they also use technology (their smartphones) to communicate with each other. This mediated communication has grown more frequent over the years due to different life events such as Ilse's 4-week stay in a rehabilitation clinic and Hannelore's 3-week vacation through Asia. Although they are still mentally and physically fit, they recognize that aging may eventually constrain their mobility and social engagement. Both friends were invited to test a telepresence robot prototype specifically designed to support the social integration of older adults. They traveled together to the laboratory to share their first hands-on robotic experience. The tests sparked playful competition and positive feedback. After a brief training session, Ilse and Hannelore quickly became comfortable using the telepresence robot to complete simple communication tasks. As they experimented with the technology, they reflected on situations in which a telepresence robot could be particularly valuable (such as allowing the robot to follow them around the house so they could continue a conversation without interruption). Both friends expressed optimism about using such a robot to maintain social contact in the future, especially as other forms of communication may become more difficult with age. Notably, they described the sense of social presence during robot-mediated communication higher than what they typically experience through audio-only phone calls or smartphone-based video calls.

Life changes that usually come with aging (widowhood, retirement, health issues, etc.) put older adults at risk of suffering loneliness (i.e., the subjective feeling of being alone, unwanted, or misunderstood) and social isolation (i.e., an objectively low number of social contacts)[20]. Both, loneliness and isolation have been linked to quality of life, general health, cognitive function, and mortality, among others, and are currently considered public health concerns [21, 26].

Potential solutions aimed at fostering the social integration of older adults are therefore being developed and researched. There is evidence that innovative communication technologies – including telepresence robots – have the potential to reduce loneliness and social isolation in older people, mainly when used to enhance existing relationships [18, 20]. *Telepresence robots* are a subset of social robots that are designed to enable interpersonal communication over distance. They can connect older adults to their social networks, such as their relatives, friends, and healthcare providers by allowing them to engage in robot-mediated communication (RMC) while being in different physical locations [67]. RMC can be defined as people communicating with and through robots teleoperated by humans [58]. Telepresence robots consist of a remotely controllable mobile platform with video conferencing equipment that allows *remote users* to move the robot around a local environment and interact socially with *local users* (those sharing a physical space with the robot) through the robot [1].

Despite the potential benefits of innovative communication technologies in promoting social integration, older adults adopt these tools at lower rates than younger age groups [8]. Recognizing the complexity of exploring technology adoption in later life, researchers have proposed theoretical models specifically tailored to this demographic. Notably, the Almere model, that was specifically developed to test the acceptance of assistive social agents (such as telepresence robots) by older users. The model, which was used as framework for this study, expands on previous theories by taking into consideration variables related to functional evaluation like perceived usefulness and perceived ease of use, as well as variables that relate to social interaction [31]. In addition to examining technology adoption, the application of a human-centered design approach is essential when developing technologies for the aging population. Designing with consideration for the physical, cognitive, and psychological characteristics of older adults, as well as tailoring technologies to align with their daily routines and living conditions, has been shown to enhance technology acceptance within this demographic [5, 25]. Based on the above, this study was conducted with the aim of exploring the experiences and perceptions of older adults after using a telepresence robot prototype developed in the CO-HUMANICS (Co-Presence of Humans and Interactive Companions for Seniors) project (www.co-humanics.de). The prototype was specifically created to contribute to the social integration of older adults and its design

followed recommendations from a requirements analysis conducted within the project with a group of 30 older adults [17]. To evaluate users' experiences and perceptions, we included constructs from the Almere model of technology acceptance [31] (perceived enjoyment, perceived ease of use, perceived usefulness, and intention to use) and the Temple Presence Inventory (TPI) (social presence) [46] which have been previously applied to study technology acceptance in older populations. Although we had already collected data related to several of the aforementioned constructs in previous studies within the CO-HUMANICS project [2, 16, 17], this constitutes the first study in which data collection was done after participants engaged in robot-mediated communication. This is relevant since previous research suggests that individuals' beliefs and attitudes towards a new technology in the pre-usage stage are generally based on indirect experience and second-hand information. However, after an initial experience with the technology, individuals tend to adjust their judgments to reflect their user experience [12]. Furthermore, familiarization with robots can lead to users feeling more comfortable and trusting during their interaction with them and a positive correlation between technology exposure and acceptance has been identified [3].

Therefore, user studies—such as those involving participants like Ilse and Hannelore—are essential for gaining deeper insights into older adults' user experiences, which in turn may support increased technology adoption in this population. However, research addressing older adults' perceptions following direct interaction with technology remains limited [12]. Against this backdrop, the present study was undertaken to examine older adults' successful use of a telepresence robot, with a specific focus on perceived enjoyment, perceived ease of use, perceived usefulness, perceived social presence, and intention to use.

2 RELATED WORK

2.1 Older adults and technology

In recent decades, abundant research exploring and evaluating if and how modern communication technologies can contribute to the social inclusion of older people has been conducted [15]. Technology use among older adults is gradually becoming widespread, with the adoption of smart devices currently on the rise [70]. Considering that older adults are often less mobile and have smaller social networks than other age groups and that they place greater importance on social relationships [41] it is not surprising that they are adopting technology specifically for social purposes (such as email, WhatsApp, and Facebook) [34]. It has been found that communication technologies not only allow social contact over distance but also can provide opportunities for particularly deep, meaningful, and emotional communication, therefore contributing to older adults' social integration [15, 21, 39].

2.2 Telepresence Robots for Older Adults

According to previous research, telepresence robots are mostly being used in environments such as assisted living, long-term care, and healthcare facilities to provide support, promote healthy aging, and foster the social well-being of older adults [13, 56, 57]. In a systematic review by Chen et al. [13] seven studies researching social robot interventions conducted in healthcare facilities, retirement homes, and dementia units showed potential for reducing depression in older adults. An additional scoping review by Hung et al. [36] identified key facilitators (a feeling of physical presence, ease of use, mobility, and training) and barriers (cost, privacy issues, internet connectivity, and workflow) to the implementation of telepresence robots in aged cared settings. It was initially assumed in the assistive robotics research and development that older adults would no longer be able to perform daily life activities as they grew older and that they would experience an inevitable decline [23]. Therefore, earlier versions of robots built with older adults in mind mostly focused on compensating for potential health deterioration, thus supporting a deficit model of aging [7, 63]. However, researchers are now shifting towards social, supportive, and developmental models of aging that avoid the portrayal of older adults as a group of people with cognitive and physical declines within the context of robotics and technologies. Lee and Riek [42] engaged in a 6-month collaborative design process with community-dwelling older adults to better understand the coping strategies they have accumulated throughout their lives which can in turn motivate researchers to integrate the invisible aspects of older adults' aging experiences into the existing practices of designing robots for aging users. Our study contributes to this new model of successful aging, and

to the current research, by conducting interviews with older adults who live independently and have no mental or physical impairments in an effort to gain qualitative insights into their aging process. Against this backdrop, the present study was undertaken to examine older adults' successful use of a telepresence robot, focusing on perceived enjoyment, perceived ease of use, perceived usefulness, perceived social presence, and intention to use. Distinct from much of the existing literature, which has concentrated on individuals in healthcare or aged care settings, our study involves independently living older adults without physical or cognitive impairments, offering a novel perspective on telepresence technologies in non-clinical environments. Furthermore, by employing a telepresence robot specifically designed for older users (based on a prior human-centered requirements analysis) we provide original empirical data beyond that derived from commercially available systems, thereby contributing to research on tailored robotic solutions for aging populations.

The benefits of telepresence robots in the maintenance of older adults' social networks have been shown by previous research [67]. Several studies have tested telepresence robots as tools to help social inclusion of older adults with positive results [72]. In a study conducted by Niemelä et al. [52] it was shown that telepresence robots increase family members' presence to their elderly parents in residential care and thus positively affect the residents' wellbeing. Moyle et al. [49, 50] found that older adults with dementia experienced a sense of social presence, authenticity, and connection when using a telepresence robot to interact with family caregivers and healthcare professionals. Besides social connectedness, research has found that telepresence robots improved sleep quality, psycho-emotional health, reduced the number of unhealthy days, depressive symptoms, and enhanced the self-efficacy of older adults [73].

RMC for older adults can adopt different forms. Hiyama et al. [33] introduced a system using telepresence robots in remote IT education classes for older people and confirmed that RMC promoted interactions between students and assistants. Koceski and Koceska [40] tested a telepresence robot system that allowed older adults living in a nursing home to engage in RMC with doctors, nurses, family, and friends. Their results confirmed that participants identified significantly more benefits than concerns about using the robot and said they were willing to use a telepresence system in both social and medical contexts. Although most research on RMC discusses remote/local real-time communication, some studies have focused on social mediator robots (robots that serve as mediators by allowing humans to exchange asynchronous messages). Noguchi et al. [53] established that a mediator robot that delivers messages to family members in a way preferred by the older adults has the potential to suppress their anxiety about self-disclosure on loss experiences.

Extensive research on RMC, in all its forms, has examined the factors influencing user acceptance and explored strategies to improve it, often framing technology adoption within the context of technology acceptance models [30]. Baisch et al. [5] showed older technology users perceived a telepresence robot as a valuable device if they considered that the robot's features matched their particular psychosocial needs, e.g., social support and life satisfaction. Also, having the necessary resources to deal with the robot (material, psychological, etc.) raised the perception of the robot as a valuable tool to foster social support. Furthermore, a study by Frennert et al. [25] determined that the design of robots has to fit in the ecology of older adults, support their values, and seamlessly adapt to all members of their social network in order to facilitate adoption. On the other hand, differences between older people's expectations and roboticists' assumptions in the design process were found by Bradwell et al. [10]. While older adults requested functionalities such as interactivity, personalization, obeying commands, and responsiveness, roboticists overestimated the importance of the technical capabilities of the robots and often stereotyped older people as fragile and in need of assistance. Although previous research has emphasized the need to adapt telepresence robots for older users, most studies involving older adults have relied on commercially available robots. This study advances the field by conducting user tests with a telepresence robot specifically designed for older adults following a human-centered design approach [2, 17].

Despite the demonstrated benefits of telepresence robot use in older age, overall technology acceptance among older adults remains challenging [31, 59]. However, while older adults tend to use technology at lower rates than younger age groups, these rates are steadily increasing [34]. Moreover, older adults have shown a willingness to adopt technology when it supports their ability to live independently [11].

The reasons behind these adoption rates are varied. Empirical evidence indicates that digital exclusion in this population is often associated with several interrelated barriers, including inadequate access to internet or

broadband services in certain geographic regions, constrained financial resources, and challenges inherent in the remote delivery of digital interventions [9].

In addition, as noted by Chen and Schulz [10], both spatial and social constraints on social interaction, as well as individual-level factors such as interest in technology, motivation for use, cognitive functioning, visual acuity, and physical ability to manipulate devices (e.g., hand or finger mobility required for touchpad use), may influence the appropriateness and usability of technological solutions for older individuals. Experiential and perceptual factors -such as perceived relevance, utility, enjoyment, social influence, self-efficacy, and perceived ease of use- also play a critical role in shaping older adults' decisions to adopt new technologies [11]. Therefore, in an effort to raise the acceptance rate of robots, researchers employ human-centered approaches that invite older adults into the design, testing, and evaluation process [43].

3 PRESENT STUDY

The present study is part of the CO-HUMANICS (Co-Presence of Humans and Interactive Companions for Seniors) project (www.co-humanics.de), in which a telepresence robot for older adults will be developed. The primary aim of the robot is to support technology-enabled social co-presence, allowing people who are physically distant to be virtually present in a user's everyday environment. Conceived as a communication tool, the robot is intended to help reduce loneliness and social isolation in later life. More broadly, the project seeks to foster the social integration of older adults by creating technologies that adapt to their needs and lifestyles, facilitating enjoyable and effective communication with family and friends across distance.

As a first step in the project, a requirements analysis with a human-centered design approach was conducted to explore older people's attitudes towards, intentions to use, and requirements for a telepresence robot [2, 17]. Informed by said results, the prototype for the CO-HUMANICS telepresence robot was further developed. The aim of the present study is to assess older adults' successful use, perceptions, and intention to engage in RMC via a telepresence robot designed to foster social integration and enhance social presence between communication partners.

In previous research, technology adoption models such as the Almere model [31] have been frequently employed to study the use of technology by older adults [62]. Said model and other previous studies pose that *successful use*, *perceived enjoyment*, *perceived ease of use*, *perceived usefulness*, and *social presence* determine *intention to use* and are positive predictors of technology acceptance among older adults [31, 44, 48].

Successful use is the interaction with a communication technology that results in perceived added value to the individual user [27]. Participants in this study were first-time robot users. Therefore, it was particularly important to observe and assess whether they could operate the technology independently. This was essential to ensure that the data collected from other variables would be meaningful and relevant to the study. Had participants been unable to use the technology on their own, measuring other variables -whether quantitatively or qualitatively- would not have yielded reliable or useful insights.

Perceived enjoyment is defined as the feelings of joy and/or pleasure associated with the use of a determined technology [31]. The degree to which the user experiences fun when using a certain technology has an impact on how they value it and can increase their intention of continuing the use of the technology in the future [62].

Perceived ease of use is the degree to which one believes that using the system would be free of effort [31]. Older adults report that they would use technology if it was easier to use, more user-friendly, and more adequate for their needs [37].

Perceived usefulness is defined as the degree to which a person believes that the system would be assistive [31]. Previous studies emphasize the importance of perceived usefulness in technology adoption as a predictor of continued intention to use the technology [29, 71].

Social presence refers to the subjective experience of being present with a "real" person and having access to his or her thoughts and emotions [9]. Because social presence often predicts positive communication outcomes it is relevant in the study of technology-mediated communication [54].

Intention to use refers to older adults' disposition to make use of a technology over a longer period [31]. Although older adults have reported in previous research that they consider robots to be useful for other people, they frequently reject them for themselves [43].

The present study considers the aforementioned constructs in its research questions:

RQ1: How successfully can older adults use a telepresence robot in robot-mediated communication with respect to *robot navigation* (Task 1) and *interpersonal communication* (Task 2)?

Q2: How do older adults *perceive the enjoyment* of using a telepresence robot in robot-mediated communication?

RQ3: How do older adults *perceive the ease of use* of a telepresence robot in robot-mediated interpersonal communication?

RQ4: How do older adults *perceive the usefulness* of a telepresence robot in robot-mediated interpersonal communication?

RQ5: How do older adults *perceive the social presence* provided by a telepresence robot during robot-mediated communication?

RQ6: How do older adults express their *intention to use* a telepresence robot for robot-mediated communication?

In general, for their successful acceptance and implementation, innovative technologies must be perceived positively by the end users and co-using stakeholders [47]. The present study aims at exploring older adults' experiences and perceptions during RMC via a telepresence robot and to inform future design decisions.

4 METHODS

The study consisted of laboratory user tests of a telepresence robot aimed at enhancing social presence during RMC and fostering the social integration of older adults. Participants completed a navigational task (in the role of the remote user) and an interpersonal communication task (in the role of the local user) (see Figure 1).

The navigational task consisted of remotely steering the robot from a control room by using a keyboard and a desktop computer. Participants had to navigate the robot inside the laboratory to look for five hidden objects: a) cup, b) wrench, c) decorative figure shaped like a person, d) decorative figure shaped like an animal, and e) remote control. All objects were typical household items. A communication partner (research assistant) acted as the local user, gave hints related to the location of the hidden objects (when requested), and held a casual conversation with the participant during the search. Participants were informed that they could speak with their communication partner at any time. The task had a duration of 7 min and was adapted from [68].



Figure 1. (Left) Remote user navigating the robot from the control room by using a computer and keyboard (navigational task). (Right) Local user sharing a space with the robot while engaging in robot-mediated communication (interpersonal communication task). Images created for the CO-HUMANICS project and used with consent.

The interpersonal communication task involved playing the “Celebrity Name Guessing Game” with a communication partner (research assistant) acting as the remote user. The participant and the other player each took a card with information about a secret celebrity. Both players took turns posing and answering yes/no questions until they guessed their partner’s celebrity. During the game, the participant sat on a sofa in the laboratory and the robot remained static facing the participant. The task had a duration of 7 min and was adapted from [19].

The selection of tasks was based on the primary types of interactions that older adults are likely to experience during RMC using a telepresence robot. A real-life scenario analogous to the navigational task might involve an older adult remotely operating a robot located in a friend’s home, while the co-located friend moves around the space, showing various objects and engaging in conversation. Similarly, a real-life counterpart to

the conversational task could involve an older adult interacting with a telepresence robot mediating communication with a grandchild living abroad, as they play a guessing game together. Although older adults are often portrayed solely as local users in the context of RMC, our previous research revealed that participants frequently expressed a strong desire to take a more active role and have control over the robot, as a way to maintain their autonomy during RMC [17]. Based on these findings we chose to allow participants to embody both roles, that of the local user and the remote user.

Post-task questionnaires, as well as semi-structured interviews and task observations were conducted to obtain quantitative and qualitative data respectively to answer the study's research questions.

The tasks, questionnaires, and interviews (in German language), together with the observations were conducted by one researcher (first author) in Germany, in a university setting (living laboratory, control room, and a meeting room prepared for the study), in December 2023. The average duration of the interviews was 20 min. Additionally, a short pre-task training session (approx. 5 min) and technical support during the tasks were provided by the second and third authors. The sample size of $N = 14$ is in line with previous human-computer interaction user tests involving older adults [28, 60, 66]. Convenience sampling was used to recruit participants. Specifically, the research team contacted older people who previously participated in the requirements analysis for the CO-HUMANICS project [17].

A pre-test was conducted before data collection and a research assistant was trained to act as the communication partner of the participants in all tasks. The study is preregistered at <https://osf.io/yexn3> and all materials (including questionnaires, interview guides, transcripts, and instructional sheets) are accessible at <https://osf.io/rtxba/> both in German original language and English translations. The study was approved by the ethics committee of the Ilmenau Technical University, on November 21, 2023.

4.1 Participants

The study sample included $N = 14$ older adults between the ages of 61 and 75 years ($M_{\text{age}} = 68$, $SD_{\text{age}} = 4.4$, 57% women; see Table 1). Inclusion criteria for participants were: 60 years or older (based on the World Health Organization's definition for older adults; [69]) living independently, having no cognitive impairments, and being active communication technology users.

In line with the inclusion criteria, all participants engaged in technology-mediated communication in the 4 weeks prior to the user tests. Most of them (79%) with a frequency between several times a week to several times a day. Furthermore, all participants (100%) were smartphone and messaging applications users. Additionally, we used the Technology Readiness subscale of the Technology Commitment Scale [51] to assess participants' inclination toward and interest in exploring new technologies. This helped us ensure that participants aligned with our inclusion criteria. A very low score would have indicated a lack of interest in new technologies, suggesting that the participant did not meet the criteria for inclusion. The scale consisted of four items related to technology use (e.g., "I am very curious about new digital developments" and "I quickly take a liking to new digital developments") evaluated with a 5-point Likert scale ranging from "1 = *totally disagree*" to "5 = *totally agree*". Higher scores indicated a higher level of technology readiness. Items were averaged to obtain a total mean score. The scale showed strong reliability (Cronbach's $\alpha = .93$). The sample as a whole scored above average on technology readiness ($M = 3.1$, $SD = 1.1$). Therefore, the answers obtained from participants showed us they all had some interest in exploring new technologies.

4.2 Telepresence robot

The CO-HUMANICS telepresence robot (Figure 2) is based on the TORY platform of the German robotics company MetraLabs. As previously described in [22], the TORY platform's design simplifies the navigation in confined spaces and enables the platform to rotate in place. It has a circular footprint with a 50 cm diameter and rotation symmetry by placing the differential drive on the middle axis. The default setup of the platform features a 2D Sick S300 laser range scanner, with an opening angle of 270°, enabling efficient mapping and obstacle detection. It is mounted 10 cm above the ground plane and automatically limits the speed of the robot platform to 0.3m/s when obstacles are nearby as a safety feature. An additional bumper ring located at the bottom of the robot automatically stops its movement when triggered, further ensuring safety during operation. For the present study, the driving backwards function of the robot was disabled as a safety feature, due to the lack of an obstacle avoidance function during backwards navigation.

Table 1: Description of the study sample

No.	Age	Pseudonym	Gender	No. of people in household	Education	Face-to-face communication frequency ^a	Communication technology use	Communication application use	Interview duration (min)
1	61	Karl	m	2	High	Less than weekly	Smartphone	Instant messaging	19
2	62	Hannelore	w	2	Medium	Several times a week	Landline phone, smartphone	SMS, instant messaging	18
3	63	Ilse	w	3	Medium	Less than weekly	Landline phone, smartphone	Instant messaging, video conference	16
4	65	Gisela	w	2	High	(Almost) never	Landline phone, smartphone, tablet	Instant messaging, email	23
5	65	Renate	w	3	Medium	Daily	Landline phone, smartphone	Instant messaging, video conference	23
6	66	Gertrud	w	2	High	Daily	Landline phone, smartphone, tablet	SMS, instant messaging, video conference	23
7	67	Ingrid	w	1	High	Several times a day	Landline phone, smartphone, laptop/PC	SMS, instant messaging	21
8	67	Joachim	m	2	High	Several times a day	Landline phone, smartphone, tablet, laptop/PC	Instant messaging, video conference	17
9	68	Friedrich	m	2	High	Daily	Landline phone, laptop/PC	SMS, instant messaging, video conference	23
10	69	Wolfgang	m	1	High	Daily	Smartphone, laptop/PC	SMS, instant messaging	23
11	71	Brigitte	w	2	High	Several times a week	Landline phone, smartphone, tablet, laptop/PC	SMS, instant messaging, video conference	17
12	72	Ursula	w	2	High	Several times a week	Smartphone	Instant messaging	12
13	75	Rainer	m	2	High	Several times a week	Landline phone, smartphone, tablet, laptop/PC	SMS, instant messaging, video conference, social media	26
14	75	Hermann	m	2	Medium	Less than weekly	Landline phone, smartphone	SMS, instant messaging, video conference	12

Note. Abbreviation: No. (number). $N = 14$. Study participants are listed in ascending order by age. All names are aliases. a – in the past four week

Several customizations to the default setup were made prior to the user tests in line with the findings of the requirements analysis conducted as part of the CO-HUMANICS project [16]. An Intel RealSense D455 RGB-D stereo camera was used to monitor the floor in front of the robot to detect obstacles outside the laser plane. To enable mounting further sensors and actuators easily, a mounting profile was attached to the top of the robot, leading to a total height of 1.25m. A Microsoft Azure Kinect, based on time-of-flight (ToF) technology, was used as a second RGB-D camera to observe the local user and to obtain 3D information about the environment. The local user could interact with the robot from the same side through a 15.6" multi-touch display. For this study, the Microsoft Azure Kinect camera was used for the video during the video call.

To detect the environment in all directions, three RGB Valeo fisheye cameras with a horizontal opening angle of 195° were placed on the mounting profile with a 120° offset. To enhance the remote user's ability to communicate and enable a collaborative telepresence with the local user, a top-mounted LG HF60LS Largo 2.0 projector was connected to a FLIR PTU E46 pan tilt unit (PTU) on the robot. To minimize latency and maintain stable connections, all required computing capabilities are held onboard.

4.3 Materials

The following materials were developed for the present user tests study: (a) entry questionnaire, (b) navigational task instructional sheet, (c) interpersonal communication task instructional sheet, (d) semi-structured interview guide, and (e) post-task questionnaire. All materials, including full transcripts of the interviews, are available (in both the original German language version and English translations) at <https://osf.io/rtxba/>.

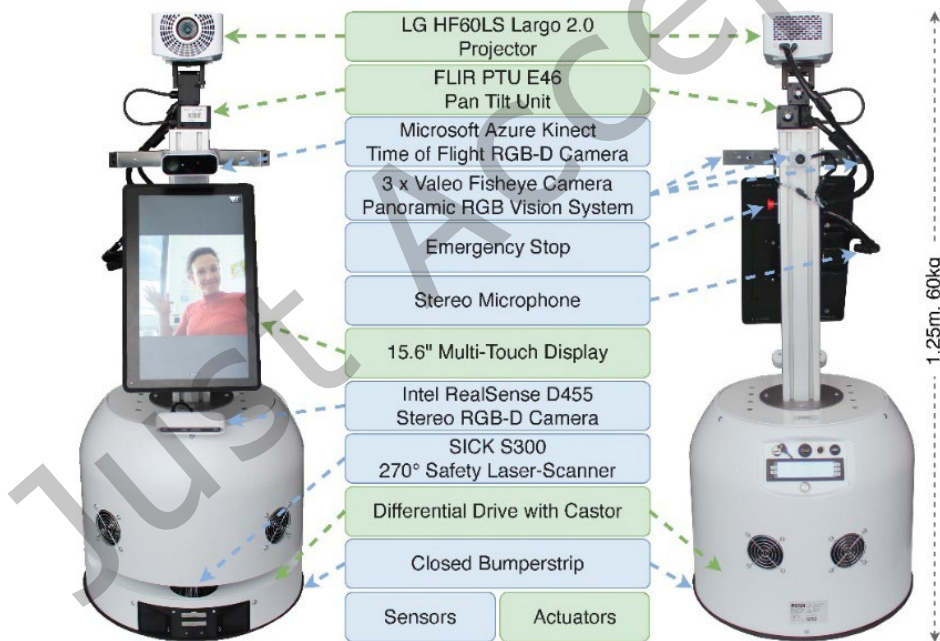


Figure 2. The CO-HUMANICS telepresence robot with its sensors (devices that collect information from the environment) and actuators (devices that perform actions). Originally published in Fishedick et al. (2023) used with permission of the authors.

4.3.1 Entry questionnaire

The entry questionnaire included information related to the older adults' age, gender, number of people living in the home, education, frequency of communication (face-to-face and technology-mediated), most used devices and applications, and technology readiness.

4.3.2 Navigational task instructional sheet

The navigational task instructional sheet included a short explanation and a set of rules for the task (e.g., “The following test is intended to find out how well you can control the robot from a distance”, “you and the robot will be in two different rooms”, “you will receive a list of five objects located throughout the laboratory”, “during the scavenger hunt, you and a communication partner will be connected via a robot”, etc.). Additionally, the instructional sheet contained a blueprint of the laboratory and color pictures of the hidden objects: (a) cup, b) wrench, c) decorative figure shaped like a person, d) decorative figure shaped like a tiger, and e) remote control.

4.3.3 Interpersonal communication task instructional sheet

The interpersonal communication task instructional sheet included a short explanation and a set of rules for the task (e.g., “The following test is intended to find out how well you can talk to another person via the robot”, “you will be connected to a person in another room using the robot”, “you will receive a series of printed sheets, each containing information about a celebrity (e.g. name, age, profession)”, “each player takes turns asking the other player questions about the celebrity on the other player’s sheet”, etc.). Additionally, the instructional sheet contained pictures and a short informational text about six different celebrities.

4.3.4 Semi-structured interview guide

The semi-structured interview was organized in five main blocks (one block for each measured construct), as well as a warm-up and a closing block. The topics and some example questions of the main blocks were: (a) perceived enjoyment: “What did you particularly enjoy about using the robot? Why?”, “How could the enjoyment of using the robot be further increased?”; (b) perceived ease of use: “How easy or difficult was it for you to use the telepresence robot? Why?”, “How could the operation of the robot be further simplified?”; (c) perceived usefulness: “How useful or useless do you find the telepresence robot? Why?”, “How could the usefulness of the robot be further increased?”; (d) social presence: “How close/distant did you feel to your communication partner when you communicated via the telepresence robot? Why?”, “Compare robot-mediated communication with mediated communication by telephone, smartphone or computer: what is different, what is similar?”; and (e) intention to use: “In which daily-life situations would you use a telepresence robot for communication?”, “What would further increase your willingness to use a telepresence robot in the future?”.

4.3.5 Post-task questionnaire

The post-task questionnaire included four constructs from the Almere model of technology acceptance [31]: perceived enjoyment, perceived ease of use, perceived usefulness, and intention to use and two constructs from the Temple Presence Inventory (TPI) [46]: Social presence - passive interpersonal and Social presence - active interpersonal.

Perceived enjoyment was measured with the corresponding subscale of the Almere model of technology acceptance. The scale consisted of 5 items (e.g., “I enjoy using the robot to talk to other people” and “I find the robot fascinating”) rated on a 5-point Likert-type scale ranging from 1 to 5 (*totally disagree* - *totally agree*). Scale reliability was strong (Cronbach’s $\alpha = .91$).

Perceived ease of use was measured with the corresponding subscale of the Almere model of technology acceptance. The scale consisted of 5 items (e.g., “I find the robot easy to use” and “I think I can use the robot without any help”) rated on a 5-point Likert-type scale ranging from 1 to 5 (*totally disagree* - *totally agree*). Scale reliability was acceptable (Cronbach’s $\alpha = .75$).

Perceived usefulness was measured with the corresponding subscale of the Almere model of technology acceptance. The scale consisted of 3 items (e.g., “I think the robot is useful to me” and “It would be convenient for me to have the robot”) rated on a 5-point Likert-type scale ranging from 1 to 5 (*totally disagree* - *totally agree*). Scale reliability was strong (Cronbach’s $\alpha = .91$).

Perceived social presence during interpersonal RMC, specifically when acting as the remote user (active role), was measured with the active interpersonal social presence subscale of the Temple Presence Inventory (TPI) adapted for a telepresence robot. The subscale consists of 5 items (e.g., “How well were you able to control the robot during the scavenger hunt?” and “How well could you see the living lab during the scavenger hunt?”)

rated on a 5-point Likert-type scale ranging from 1 to 5 (*not good – very good*). Scale reliability was good (Cronbach's $\alpha = .88$).

Perceived social presence during interpersonal RMC, specifically when acting as the local user (passive role), was measured with the passive interpersonal social presence subscale of the Temple Presence Inventory (TPI) adapted for a telepresence robot. The subscale consists of 4 items (e.g., "How well could you see the different facial expressions of your game partner during the guessing game?" and "How well could you see the different body movements of your partner during the guessing game?") rated on a 5-point Likert-type scale ranging from 1 to 5 (*not good – very good*). Scale reliability was good (Cronbach's $\alpha = .84$).

Intention to use was measured with the corresponding subscale of the Almere model of technology acceptance. The scale consisted of 4 items (e.g., "I would like to use a robot like this again in the future" and "I would like to have a robot like this at home in the future") rated on a 5-point Likert-type scale ranging from 1 to 5 (*totally disagree – totally agree*). Scale reliability was strong (Cronbach's $\alpha = .93$).

4.4 Data collection and analysis

Participants were greeted by the main researcher with a specialization in media and communication (first author) and were introduced to the robotics researchers (second and third authors). They were taken to a small conference room prepared for the study where a short description and aim of the study were given and a written consent form was read and signed by each of them. Then, the entry questionnaire was provided and filled out personally by each older adult. Additionally, the instructional sheets for the tasks were handed out in printed form, read out loud, and explained in detail.

Before beginning the tasks, older adults were informed of the possibility of taking breaks when needed and were offered snacks and beverages. Participants were encouraged to speak freely before, during, and after the tasks. Any additional questions were answered at this point.

Each older adult was then taken to the control room (a small laboratory where a desktop computer and a keyboard used to control the robot were located) for a brief training session. One roboticist explained the function of the control keyboard keys to the participants and instructed them on how to move the robot in all directions. During the session, a small task was completed by the older adults: they navigated the robot to two specific locations (ca. 5 min).

During the navigational task, older adults acted as remote users by controlling the robot independently while searching for five hidden objects in the laboratory. The selected items were common household objects (see section 4.3.2.) and were placed on different types of furniture (on a shelf, on a table, over the couch, etc.). All objects and locations were identical for all participants. One older adult and one roboticist sat in the control room for the duration of the task. Older adults could ask the roboticist questions regarding robot navigation when needed. Furthermore, when participants required help locating a specific object in the laboratory, they could ask their communication partner (a research assistant acting as local user) for "clues". Older adults were notified when the time for the task had run out (7 min). After the navigational task, participants were directed to the laboratory for the next task.

During the interpersonal communication task, participants acted as local users in the laboratory and sat on a couch facing the robot. A communication partner (research assistant) acted as the remote user in the control room. Both the older adult and the communication partner received 3 celebrity sheets each and then decided among themselves who would take the first turn. Participants then proceeded to pose yes/no questions to each other about the celebrities on the other person's sheet. When the answer to a question was "no", the participant who posed the question lost their turn. When one of the players guessed a celebrity correctly, a new celebrity sheet came into play. Older adults were notified when the time for the task had run out (7 min). Observational notes were taken during both tasks by the main researcher.

Semi-structured interviews were conducted immediately after the tasks using the prepared guide and took about 20 min on average (range 12 – 26 min; see Table 1). Additional questions and topics were explored based on the participants' answers. After the interview, participants filled out the post-task questionnaire and were asked for feedback on the study. The feedback indicated that participants felt comfortable during the tests and free to express their opinions.

Video/audio files of the tasks were backed up and audio files of the interviews were backed up, anonymized, and transcribed by a native German speaker with the help of specialized software. Quotes used in the present study were translated into English with the help of the software DeepL and later revised (and corrected when necessary) by the first author.

The questionnaire data were analyzed using a Bayesian one-sample t test in R Studio (2023.06.01). We used the data of 12 participants, as 2 participants did not complete all questionnaires. We hypothesized that older adults would evaluate their interactions with the telepresence robot positively. Specifically, we expected participants' ratings on perceived enjoyment, ease of use, usefulness, social presence (active and passive interpersonal), and intention to use a telepresence robot to be significantly higher than the neutral midpoint of 3 on the 5-point Likert scales [H_0 : The mean rating for each variable equals the scale midpoint ($\mu = 3$). H_1 : The mean rating for each variable is greater than the scale midpoint ($\mu > 3$)].

Qualitative data from the interviews was analyzed following the methodology described by Rädiker and Kuckartz [61]. First, categories were created based on the research questions of the study and the interview guide (deductive approach). Data related to these categories was coded and grouped by topic. The initial categories into which the data was grouped were a) successful use, b) perceived enjoyment, c) perceived ease of use, e) perceived usefulness, f) perceived social presence, and g) intention to use. Next, a second round of coding was conducted, and new subcategories were created based on additional themes found in the data (inductive approach). Finally, a third round of coding was conducted, to refine the categories and sub-categories.

Data from the observations was used to contrast quantitative and qualitative data.

5 RESULTS

In the following section, the research questions of the study will be answered. An overview of the main results is presented in Table 2. The focus areas listed in the table represent deductive categories derived from the research questions, while the main findings summarize the most relevant subcategories identified inductively within each primary category.

Table 2: Overview of focus areas and results of the present study

Focus areas	Definitions	Main findings
Successful use	Interaction with a communication technology that results in perceived added value to the individual user [27]	All participants were able to successfully navigate the telepresence robot (navigational task) and engage in RMC (interpersonal communication task) The most common issues that older adults successfully addressed were: (a) Physical: adjusting to the control keyboard keys, eyesight issues, etc. (b) Psychological: ability to multitask, perception of space, etc.
Perceived enjoyment	Feelings of joy and/or pleasure associated with the use of a determined technology [31]	Participants described their experience with a telepresence robot as enjoyable Reasons for perceived enjoyment: the telepresence robot's effective performance, effective RMC, using the robot in a playful context Improvement recommendations: voice commands, telepresence robot as a communication partner, object grasping, and appearance
Perceived ease of use	Degree to which one believes that using the system would be free of effort [31]	Participants found the telepresence robot was easy to use Reasons for ease of use: previous experience with technology and task simplicity Difficulties: fear of causing damages, inability of the robot to move backwards and move/tilt the camera Improvement recommendations: simplified and customizable control device and adjustable camera with zoom function

Perceived usefulness	Degree to which a person believes that the system would be assistive [31]	Participants deemed the robot useful Scenarios in which robot would be most useful: remote visual check/search, as a companion, and as communication device Improvement recommendations: the incorporation of a smart assistant, physical assistance, medical assistance, and customized entertainment functions
Perceived social presence	Subjective experience of being present with a “real” person and having access to his or her thoughts and emotions [9]	Participants described the perceived social presence during RMC as generally high Perceived social presence during RMC was higher or similar to perceived social presence during other mediated forms of communication (landline, smartphone, laptop, etc.) RMC was considered a viable substitute for face-to-face communication
Intention to use	Disposition to make use of a technology over a longer period [31].	Only two participants said they would have no interest in adopting a telepresence robot in the future The main reasons were that participants did not see a need for it, or the perceived usefulness of the telepresence robot was not high enough The remaining 12 participants were open to adopting a telepresence robot to a greater or lesser extent

Note. Main findings are grouped according to the study’s research questions and investigated constructs

5.1 Successful use (RQ1)

All participants were able to navigate the telepresence robot and engage in robot-mediated communication (RMC) with a high degree of success (RQ1), which was assessed through interview data and observational data documented during the navigational and interpersonal communication tasks.

When asked for their impressions after completing both tasks, participants mostly described successful experiences. Some older adults agreed that using the control keyboard keys (while acting as the remote user) took some adjustment. However, after the first minutes of navigation, controlling the robot became easier and more intuitive for them. According to 62-year-old Hannelore, *“The more you press the buttons, the more confident you become”*. Additionally, as almost half of the participants were regular laptop/PC users (43%) their previous skills facilitated robot navigation for them. *“If you use a normal laptop, you also use a keyboard and mouse”*, said 65-year-old Gisela after describing using the control keyboard keys as easy.

Most participants described navigating the robot as straightforward and said they felt comfortable using the controls after the initial short training. According to 61-year-old Karl, *“It was just a matter of driving back and forth... and choosing the direction was no problem”*.

For some participants, physical and psychological characteristics —such as eyesight, the ability to multitask, and perception of space— had an effect on the telepresence robot’s successful use.

“I said to myself ‘Now you have to concentrate on [navigating] the robot and on the things it has to do’ and that distracted me...You have to connect the two. You have to remember both...that was actually the difficulty”. (Rainer, 75 years old)

Renate, who is 65 years old, said the telepresence robot moved too fast for her to see what appeared on her screen, *“That’s why I always guided it, so that it would slow down a bit, because it was too fast for my eyes”*. For one participant, the telepresence robot’s location in the laboratory was difficult to assess.

“I had a bit of a problem: where is it now [the telepresence robot]? Am I already at the [selected] location? It was really important to be able to look in all directions to see where it was”. (Gertrude, 66 years old)

Observations confirmed these statements, since several participants were frequently seen “squinting” or coming closer to the computer screen while trying to locate objects in the laboratory. Furthermore, Gertrude could be seen having difficulties locating the robot in the laboratory and repeatedly asking for help from the roboticists during the navigational task.

Related to RMC —specifically when acting as local users— participants described no difficulties. These findings are in line with the observations conducted throughout the interpersonal communication task, in which participants required almost no support or guidance from the roboticists.

As expressed by 67-year-old Ingrid, *“If you’re used to videoconferencing then it’s not really a problem. It was completely normal. Good visibility too. It was easy to hear”*. Gisela confirmed that for her, RMC was successful, *“There were no fluctuations in the audio, and I have to say that the sound was really great, just as if you were really sitting opposite each other”*. Rainer agreed by saying, *“The camera was positioned so that you could see his [the communication partner’s] full face and also his mouth movements. [Communication] was definitely good”*.

Finally, general observations during the tasks confirmed that older adults were able to navigate the robot to different locations throughout the laboratory and all of them were able to locate at least one hidden object during the navigational task (7 minutes). Additionally, participants engaged in RMC by successfully asking and answering questions uninterruptedly during the interpersonal communication task (7 minutes).

5.2 Perceived enjoyment (RQ2)

The perceived enjoyment questionnaire data yielded a Bayes factor of $BF_{10} = 5.27$ showing moderate evidence in favor of the hypothesis ($M = 3.43$; $SD = 0.49$; see Table 3). To better understand the responses from the questionnaire, participants were asked to describe their perceived enjoyment when using a telepresence robot.

Most participants agreed that the telepresence robot’s effective performance contributed to their perceived enjoyment. Ursula really liked that the telepresence robot *“reacted immediately. When you address it via the keyboard, you immediately see a response”*. Renate expressed a similar opinion, saying she enjoyed *“that he [the telepresence robot] went where I wanted, and I didn’t have to argue with him that he should go left and not right”*. Friedrich, 68-year-old, summarized the experience by saying *“[The telepresence robot] is relatively easy to use and it responds immediately, so it’s fun”*. According to Ingrid, what she enjoyed the most was effective RMC because *“it is really an opportunity to talk to and to see the other person”*.

Participants also enjoyed using the telepresence robot in a playful context, *“The search game was great to test it [the telepresence robot]”*, said 63-year-old Ilse. For Karl *“It was a fun situation where you could search back and forth. I really enjoyed using it [the telepresence robot]”*. These statements were confirmed by observational data in which participants were seen smiling and laughing at different moments during the navigational and interpersonal communication tasks.

Older adults were also asked to give recommendations to increase their perceived enjoyment while using a telepresence robot. Four main themes emerged from the interview data: voice commands, telepresence robot as a communication partner, object grasping, and appearance.

According to users, controlling the robot through voice commands would make navigation more enjoyable. Hannelore said, *“I think it would be better to say: ‘Look in the cupboard’”*. While Brigitte, who is 71 years old, agreed that she would prefer it if *“you simply tell it [the telepresence robot] what to do without having to use a keyboard”*.

The possibility of having the robot as a communication partner was also mentioned by several participants.

“[Having] a conversation [with the telepresence robot] would certainly improve communication and make it more fun, [since] at the moment ...the robot doesn’t speak”. (Wolfgang, 69 years old)

Object grasping capabilities were also suggested by participants. According to Renate, perceived enjoyment would increase if the telepresence robot *“not only finds things, but it also takes or brings them somewhere else”*.

Lastly, an improvement in the telepresence robot’s appearance was recommended by several older adults. *“It looks very technical. It could have a slightly more pleasant exterior”*, mentioned 67-year-old Joachim. While Ursula stated that she would enjoy using the robot more if *“the face showed... some human traits”*.

5.3 Perceived ease of use (RQ3)

Perceived ease of use was rated especially positively, with strong support for the hypothesis ($BF_{10} = 392.48$, $M = 3.95$; $SD = 0.53$; see Table 3). This can be also seen in participants’ feedback during the interview where they highlighted aspects related to ease of use and familiarity with the controls when teleoperating the robot.

Table 3: Summary of quantitative results for the evaluated technology-related constructs

	BF_{10}	M	SD	Cronbach's α
Perceived enjoyment ^a	5.27	3.43	0.49	.91
Perceived ease of use ^a	392.48	3.95	0.53	.75
Perceived usefulness ^a	0.65	3.44	1.08	.91
Perceived active interpersonal social presence ^b	14570.23	4.5	0.54	.88
Perceived passive interpersonal social presence ^b	279.53	4.18	0.69	.84
Intention to use ^a	1.08	3.58	1.08	.93

Note. $N = 12$. M = mean, SD = standard deviation, BF = Bayes Factor. ^a subscale of the Almere model of technology acceptance (Heerink et al. 2010). The scale consisted of 5 items rated on a 5-point Likert-type scale ranging from 1 to 5 (*totally disagree* - *totally agree*). ^b The Temple Presence Inventory (TPI) (Lombard et al. 2009) was adapted for a telepresence robot. The subscale consists of 4 items rated on a 5-point Likert-type scale ranging from 1 to 5 (*not good* - *very good*).

According to interview data, participants who found the telepresence robot easy to use mentioned two main influencing factors: their previous experiences with computers and task simplicity. Older adults who were familiar with computers in particular and communication technology in general described the robot as very easy to use. Wolfgang said using the telepresence robot “*is not difficult for me because I’ve been around computers all my life. It’s totally easy*”. Renate also mentioned her previous experience made navigating the telepresence robot simpler “*I already have experience with computers. With the computer I know [how to move] right or left*”. Additionally, participants thought the tasks at hand were not complicated and therefore had no problems completing them with the robot. According to Karl, using the telepresence robot “*was easy because there were no complex, complicated things that it had to do. I didn’t have to grab anything*”. Other participants’ opinions agreed with this view.

“*Basically, you just have to click, then click again, then it [the telepresence robot] goes there, and then I more or less just have to turn it. So, the four or five commands it has are completely ok*”. (Gisela, 65 years old)

On the other hand, participants considered that some aspects of robot navigation were difficult at first but improved with repeated use. An initial fear of damaging the telepresence robot—or the objects in the laboratory—during navigation was a common theme. “*I always had the feeling that I had to stop it immediately, otherwise it would hit the table*”, said Gisela. “*I always thought: ‘Oh, press the stop button quickly so that nothing falls off’*”. At first, Ilse also worried that she could cause damage but “*it became clear after the conversation [with the roboticists] that it’s not possible [to cause damage]*”.

An additional difficulty described by participants was the robot’s inability to move backwards [as opposed to having to rotate and then move forward] and to tilt / lower / raise the front facing camera (Azure Kinect).

“*The movement obviously is somewhat limited, and it is not completely fluid. You can’t move [the camera] up or down, so [the telepresence robot] can’t move its head. And you can only turn the body left and right*”. (Hermann, 75 years old)

Additionally, Wolfgang said “*As a human, you are used to looking around, up and down, in all directions. The robot can’t do all that*”. Brigitte commented that not being able to move the robot backwards made navigation more difficult for her “*I would have liked to have a button to simply move backwards*”. Accordingly, observations showed that some older adults tried to increase their field of view by moving their heads up, down, or sideways in response to the robot’s inability to complete said movements.

During the interviews, participants were asked to give recommendations to improve the telepresence robot’s perceived ease of use. The most common suggestions were a simplified control device and an adjustable camera with zoom function. Older adults described an intuitive and comfortable control device, preferably in the form of a joystick. Additionally, the option to customize the device by adding control keys, a touchpad, and/or voice commands—based on individual requirements—was also recommended. According to Wolfgang “*a joystick would be a step forward. Or if this were a touchscreen, I could move the image upwards with my hand, or down*”.

and to the side". Joachim said he would like to have a joystick, "or something similar to a game console". For Hannelore, "The non-plus ultra would be voice control, in my opinion".

"[It would be easier to control] with speech, that you can say 'go a little to the left', for those who may not be familiar with these arrows [control keyboard keys]. Then they can speak the way they might have spoken to their husband or wife in the past. Also, [control keys] should be large and colorful. For example, right is red, left is green, and pressing in the middle is stop". (Renate, 65 years old)

Based on her experience working with people with special needs, Gisela agreed by saying that, "control keyboard keys are better for mentally disabled people with spasticity".

Speaking about the camera, Ilse wished the telepresence robot was able to look "up and down...[because] it can't do it. Now it can only look at eye-level". For his part, Rainer mentioned that a larger field of view would also be a welcome upgrade, "make [the camera] wide-angle".

5.4 Perceived usefulness (RQ4)

We collected information about the telepresence robot's perceived usefulness. Our questionnaire results show that ratings did not significantly exceed the midpoint, and the Bayes factor favored the null ($BF_{10} = 0.65$, $M = 3.44$; $SD = 1.08$; see Table 3). However, participants emphasized usefulness in three main instances: remote visual check/search, companionship, and as a communication device.

After testing the telepresence robot, Joachim commented that it could be valuable in the context of older people because "you can have an impression of the condition of the other person". Karl thought back to life with his late mother, who lived far away from him, "there were one or two occasions when she didn't call me back, then I would have activated the device [telepresence robot] to have a look". Furthermore, Hannelore said the telepresence robot could be "very useful in geriatric care to check that everything is in order and to have a look [into the facilities]".

Having the telepresence robot as a companion was also considered helpful.

"[The telepresence robot] is very, very useful in this respect [companionship] because currently older people's daily life can be lonely. You could see it [the telepresence robot] as a companion". (Rainer, 75 years old)

The telepresence robot as a communication device was also highly valued. "If I am lonely, I could say 'now I want you to call my daughter or my son'", Rainer commented. However, participants said the telepresence robot did not seem especially useful for them solely as a communication device. According to Brigitte, "I already have my other devices that I communicate with. I don't necessarily need the robot". Karl agreed by saying "with the devices I have at my disposal [laptop and smartphone] ...I can do everything quite well". Therefore, when discussing usefulness, all participants agreed that additional functions were required.

Among older adults' suggestions to raise perceived usefulness were the incorporation of the following functions: smart assistant, physical assistance, medical assistance, and customized entertainment.

The smart assistant proposed by participants had several functions. Ingrid mentioned the telepresence robot should be able to give reminders: "Did you turn off the light?" or "Did you turn off the stove?". "Look again, please go back to the kitchen". For Wolfgang, integrating a smart assistant (like those commercially available) would give the robot an "added value". While for Rainer, assistance in daily life activities would also be welcomed. He described a scenario where the telepresence robot could be useful:

"[I could ask] 'where can I get a gift for my grandchild? My grandson is seven years old, he is interested in books, in space, in technology, and so on' and then he [the telepresence robot] could give me an answer and select something". (Rainer, 75 years old)

Physical assistance was also a function that, according to participants, would improve the telepresence robot's usefulness. "When you are older, you are less mobile. Then I would have someone in the room who is mobile...and could reach things. That would be a huge relief", said Ilse.

Regarding medical assistance, Brigitte commented that "In an emergency, if there really is something wrong, you could press a red button, and your daughter or whoever, can ask 'Mom, what's wrong?'". Ingrid also

recommended an emergency function, “The robot speaks to the person...and if there is no reaction, an emergency signal would somehow be transmitted”.

A customized entertainment function was also proposed by participants. Gisela wished that the device also “worked like an audiobook, where you say... ‘read me this and that’. I think that would be a nice thing”. Ilse could also envision a telepresence robot “that has games. I think that would also be good for seniors, if he [the telepresence robot] is practically their playing partner. I think that would be great”.

Hannelore commented that the entertainment function of the telepresence robot should be customized with specific content, “Current politics...nature, the weather. I think that the robot should be programmed for me”. Other participants agreed.

“[The telepresence robot’s usefulness] depends on what abilities the senior has. There is no universal answer for all types of seniors, it is different for each individual. The functions [of the telepresence robot] need to be adapted in each case”. (Wolfgang, 69 years old)

5.5 Social presence (RQ5)

We collected information using questionnaires about the perceived social presence in two instances: 1) when teleoperating the robot/acting as the remote partner and 2) when acting as the local partner co-located with the robot. For each instance, we used different dimensions of the TPI, i.e., when participants teleoperated the telepresence robot/remote partner, we used the active social presence dimension and when participants acted as the local partner, we used the passive social presence dimension. On both instances, participants reported very high scores. Active interpersonal social presence ($M = 4.50$, $SD = 0.54$) was significantly above the midpoint, with decisive support for the hypothesis ($BF_{10} = 14,570.23$). Similarly, passive interpersonal social presence ($M = 4.18$, $SD = 0.69$) was significantly above the midpoint, providing very strong evidence for the hypothesis ($BF_{10} = 279.53$) (see Table 3).

According to Joachim, he felt “really close” to his communication partner “because we were able to talk to each other without delay and we both saw each other. I think that made us feel quite close”. When asked how close she felt to her communication partner when using the telepresence robot, Ursula said she felt as if “there was no distance between us”.

Participating older adults were also asked to compare perceived social presence between RMC and other types of mediated communication and face-to-face communication. In general, perceived social presence during RMC was higher or similar to perceived social presence during other mediated forms of communication (landline, smartphone, tablet, and computer).

“[RMC felt] obviously closer than a phone call”. She added that “You can use WhatsApp in your smartphone. But it is such a small screen. And I think as an older person you need a larger picture, so to speak, so this (RMC) is better”. (Ingrid, 67 years old)

According to Karl, his feelings of closeness were raised because the camera on the telepresence robot “was at a distance that felt natural. Just like how you sit opposite each other. So, I actually found that quite nice”.

For Gisele, feelings of closeness during RMC were no different to the ones perceived during other mediated communication, “for me it’s the same as using my tablet”. Likewise, Brigitte did not notice a difference, “it is like doing it over Skype...it looks exactly the same. You don’t notice if it is a robot or a computer”.

On the other hand, perceived social presence during RMC was not comparable to face-to-face communication according to participants. Ilse stated that “It is and will always be a computer. It is a robot. It has a nice, large display [...] but it won’t be able to replace face-to-face contact”. Other participants have a similar opinion.

“I’m a big fan of face-to-face communication. For many years now, we’ve had to do a lot online, almost by necessity, even in a professional context. It is practical, but it is no substitute for actually having someone in front of you”. (Karl, 61 years old)

However, despite not being comparable to face-to-face communication, older adults recognize RMC is a viable option in terms of maintaining social contact when face-to-face contact is not possible.

"It is not that much different [than face-to-face communication] except that I can't touch him [the communication partner] or pat him on the shoulder [and say] 'You did well!' But apart from that, it is okay in terms of understanding, communicating, sound, and so on". (Brigitte, 71 years old)

According to Joachim, *"It is similar [to face-to-face communication] in that you have one-on-one communication, i.e. close communication, without any delay in image or sound. On the other hand, of course, there is always a machine in the middle".*

When consulted about recommendations to raise feelings of closeness during RMC, most older adults agreed that the technology had reached the highest level possible. Renate summed it up by saying, *"He [the communication partner] would only feel closer if he was standing next to me".*

5.6 Intention to use (RQ6)

Finally, for intention to use, the questionnaire data shows only anecdotal evidence in favor of the hypothesis ($BF_{10} = 1.08$, $M = 3.58$, $SD = 1.08$). However, when asked directly, out of fourteen, only two participants said they had no interest in adopting a telepresence robot while the remaining 12 participants were open to the possibility to a greater or lesser extent, depending on their hypothetical future life circumstances. The main reasons for not wanting to adopt a telepresence robot were that older adults did not see a need for it, or its perceived usefulness was not high enough.

Brigitte said she would have no problem with adopting a telepresence robot in the future, *"I'm open. I'm open to things like that [using a telepresence robot]. If it works well, then I think it's a good thing".*

Ursula saw the adoption of a telepresence robot as highly probable and mentioned she is up for it. For her, technology acceptance is inevitable.

"You can already see it in everyday life. A lot of things are only possible via smartphone, so you really have to say to yourself, I'm going to adapt to it, it's the future and I have to familiarize myself with it a bit and then I'll be able to deal with it. But you have to open yourself up to it". (Ursula, 72 years old)

Rainer also said he would adopt a telepresence robot, but he set some conditions *"If it is inexpensive and doesn't cost twenty thousand [Euros] and is perhaps paid for by health insurance, I would gladly take it".*

Some older adults said they would probably not adopt the telepresence robot at the moment but would reconsider their decision if their life situation changed.

Wolfgang admitted that *"The likelihood of me using one is rather low, but it would depend on what disability I had. I'm open to it in principle, but it would have to be adapted [the telepresence robot] to my situation".*

"[Adopting a telepresence robot] could be a way of staying in contact with the outside world or with a significant other. Of course, you would also have to be able to switch between having a relative or doctor or friends and acquaintances as communication partners. I wouldn't be averse to that". (Joachim, 67 years old)

When asked how they would envision using a telepresence robot in the future, participants presented several scenarios (Table 4).

Finally, participants were asked to briefly evaluate their experience during the user tests and to describe the robot with adjectives. Almost all older adults described their experience in positive terms and said they enjoyed the opportunity to try innovative technologies first-hand. Additionally, they liked the playfulness of the tasks and found them adequate for an initial evaluation of RMC. These comments were supported by the observational data, which shows older adults were mostly relaxed and had an open attitude during the tasks. The mentioned adjectives describing the telepresence robot are shown in Table 5.

Table 4: Future Robot-Mediated Communication Scenarios Created by Participants

Participant	Future scenario
Ingrid	"If [the robot] had an emergency button and I lived alone somewhere, I could always be asked 'Is everything fine with you?'"
	"I could say 'I want to listen to a radio play' and [the telepresence robot would be] something that might replace my sensory organs [like failing eyesight]"
Gisela	"I wonder if it will be able to, in the future, start the washing machine in the basement"
Joachim	"Ordering something could be automated, without having to go to any stores. You could do it more directly [through the telepresence robot]"
Rainer	"For example, if I want to watch a movie or to watch the news. The robot could have a connection to a projector and control it so that I can watch the movie in a really big [format], as if I were there"
Renate	"I would speak [with the telepresence robot]. Or when I am home all the time and not working anymore, the robot would also be a companion for me"
	"When I'm cooking or something, he [the telepresence robot] can look something up for me [online] or make a call"
Karl	"[If my kids said] 'We worry about you and don't know how we could check up on you. It would be nice if you could just go to the robot and say hello, so we can see what you're up to'. I could imagine doing it [using the robot for that purpose]"

Note. Not all participants talked about future scenarios. Those that were given during the interviews are presented here.

Table 5: Adjectives used by participants to describe the telepresence robot

Positive adjectives describing the telepresence robot	Negative adjectives describing the telepresence robot
Agile	Clumsy
Communicative	Impersonal
Determined	Machine-like
Easy to Control	Stiff
Fast	
Flexible	
Intuitive	
Movable	
Obedient	
Practical	
Smart	
Uncomplicated	
Useful	

Note. Participants could mention one or more adjectives. All adjectives in the table were mentioned once.

6 DISCUSSION

The present study aimed to explore participating older adult's ($N = 14$) successful use, perceived enjoyment, perceived ease of use, perceived usefulness, perceived social presence, and intention to use a telepresence robot for RMC. User tests were conducted in a laboratory setting and qualitative and quantitative data was collected through semi-structured interviews, questionnaires, and observations. This study presents the first user testing of the telepresence robot developed for older adults within the framework of the CO-HUMANICS project. By adopting a human-centered approach, we respond to calls from the research community for participatory design practices that actively involve users from the early stages and throughout the development of social robots. In particular, we address the need for research that focuses on older adults as end-users of such technologies [25]. This focus is especially important given that social isolation and loneliness remain pressing challenges in later life, and telepresence robots are envisioned as tools that may mitigate these issues by supporting social connectedness.

In general, findings based on the quantitative data show that older adults evaluated their interactions with the telepresence robot positively, particularly in terms of enjoyment, ease of use, and social presence, while their perceptions of usefulness and intention to use were more variable and less conclusive. Findings based on the qualitative data are discussed in the following sections.

6.1 Successful use

Qualitative data showed all participants were able to use the telepresence robot successfully (RQ1). When acting as remote users, participants expressed there was an initial adaptation period during which they learned how to use the control keyboard keys. After this period, they became more confident and robot navigation became intuitive to them. Many participating older adults were of the opinion that their previous skills in operating computers and smartphones helped them navigate the telepresence robot more successfully. These findings are in line with previous research showing that technology literacy is the core foundation from which comfort with and expectations of the technology evolve and that having knowledge and experience with day-to-day communication technologies (smartphones, tablets, etc.) is the precursor for future technology mediated programming among older adults [4]. This successful use of the telepresence robot is paramount considering that it has been reported that if older adults perceive themselves as competent to handle the robot, they deem it as capable of fulfilling their social needs, which in turn improves technology acceptance levels [5]. Given the demonstrated effectiveness of telepresence robots in alleviating loneliness and social isolation—primarily by enhancing connectedness between older adults and their family members or caregivers, as highlighted in the review by Shishehgar et al. [66]—the successful use of telepresence robots may represent a critical initial step toward promoting the broader social integration of older adults. Few difficulties navigating the robot persisted throughout the tests and all of them were related to the participant’s physical and/or psychological state (i.e., ability to multitask, eyesight, space perception, etc.). When acting as local users, all participants were able to successfully engage in RMC communication from the initial moments. These results are especially relevant when considering that complex system navigation could be a source of device abandonment [6]. No support was required from participants during the task and no difficulties were reported.

6.2 Perceived enjoyment

Participants described their experience using a telepresence robot for RMC as enjoyable (RQ2). Among the aspects that raised participants perceived enjoyment were the telepresence robot’s effective performance, ease of use, interpersonal communication capabilities, and playful context in which the robot was operated. This is in line with a previous systematic review on the topic of telepresence robots for older people, which showed that older adults experienced positive emotions, such as enjoyment and excitement, when using telepresence robots [73]. Similarly, Isabet et al. [38] concluded in their narrative review study that healthy older adults found the telepresence robot interesting and reported perceived enjoyment during their interactions with it, while older adults with cognitive disorders also appreciated their interactions with the robot. Therefore, more than just a desirable feature, enjoyment can be relevant to sustained use, which in turn is necessary for the robot to fulfill its broader purpose of helping older adults maintain frequent and meaningful contact with family and friends, thereby buffering against loneliness. Additionally, the playful nature of the interaction was noted as a contributing factor to perceived enjoyment. Older adults expressed that further improvements could be carried out in order to make RMC more enjoyable: adding voice commands, designing the telepresence robot as a communication partner (and not just as a communication mediation device), object grasping capabilities, and a more pleasant appearance.

6.3 Perceived ease of use

Participating older adults described some features of the robot as easy to use (RQ3). The two most mentioned reasons for this perception were participants’ previous experience with technology (computer and smartphone) and the simplicity of completing the task at hand. This is in line with previous research showing that participants perceived the robot as easy to use after interacting with it [14]. As previously stated in the narrative review on mobile telepresence robots and older adults conducted by Isabet et al. [38] ease of use is among the determinant factors for the acceptance of telepresence robots. Older adults, as well as family members, professionals, and others acting as remote users would benefit from a simplified user experience. However, some aspects negatively affected the perceived ease of use. During their initial navigation of the telepresence robot, participants feared damaging it or the objects in the laboratory. They also had issues with the telepresence robot’s inability to move backwards and to tilt / lower / raise the front facing camera (Azure

Kinect). Participants contributed some recommendations for future improvements that would raise the perceived ease of use. The most mentioned suggestions were the development of a user-friendly control device (in the form of a joystick, for example) and an adjustable camera with zoom functions (to broaden the field of view).

6.4 Perceived usefulness

Participants deemed the telepresence robot as useful (RQ4) in 3 scenarios: as a tool for remote visual check/search, as a companion for older adults, and as a technological device that allows communication with locally remote people. The perceived usefulness of the robot in specific scenarios is particularly significant, as broader research has identified perceived usefulness as a strong, long-term predictor of technology use intention. This finding is further supported by prior studies that have demonstrated a similar relationship in telepresence contexts [45]. In the context of loneliness and social isolation, usefulness is also tied to how well the robot can serve as a bridge to meaningful relationships, reinforcing the idea that perceived usefulness extends beyond functionality to include its social impact. Additionally, participants contributed recommendations that would improve their perceived usefulness of a telepresence robot. According to them, incorporating the following functions: smart assistant, physical assistance (grasp, move or carry objects, for example), medical assistance (emergency button that connects to medical personnel), and customized entertainment (audiobooks, music player, movie projector, etc.) would make the telepresence robot more useful. This is in line with previous research that shows that new technological tools are considered useful if they are perceived to facilitate daily life and enable the social, physical, mental and psychological improvement of the older adults [32].

6.5 Social presence

Older adults described characteristics related to social presence during RMC (RQ5). They expressed experiencing feelings of closeness to their communication partner during the tasks and most deemed the level of perceived social presence during RMC as higher than perceived social presence during other forms of mediated communication (landline, smartphone, tablet, and computer). Such results confirm previous findings showing that social presence is higher when communicating via a telepresence robot compared to other communication devices and/or applications [64]. As previously reported by Hung et al. [36] telepresence robots provide pleasure and a sense of connection when compared to other technologies, which constitutes a facilitator of telepresence robot adoption. Furthermore, when acting as local users, perceived social presence was higher than when acting as remote users. Given that feelings of presence and closeness are directly linked to reduced perceptions of loneliness, this dimension is central to the value of telepresence robots for older adults. Designing for social presence is therefore not only an acceptance factor but also a pathway to fostering emotional well-being.

6.6 Intention to use

Most older adults (12/14) said they would be interested in using a telepresence robot in the future (RQ6) under specific conditions. Those older adults with no intention to use a telepresence robot (2/14) argued that they don't need it or that its usefulness is not high enough for them to adopt one. These findings are in line with previous studies [2, 17] and confirm that robots for older adults need to be specifically tailored to people who may be reluctant to use robots because of the great jump in technology they represent [65]. Furthermore, these results support research that shows that customizing robots to cater to older adults' requirements results in them being more content when using them [55]. On the other hand, the willingness of participants to use a telepresence robot in the future depends on several factors. Some participants mentioned that if the technology becomes mainstream, they could adopt it, while others said that if their life situation changed (deteriorating health, widowhood, mobility issues, etc.) they could use it to maintain their social networks. This is in line with previous research that shows that older adults who suffer from a lack of socialization due to physical problems can alleviate this condition through the adoption of communication technologies [57]. Autonomy is also a critical factor influencing the intention to use telepresence robots. Our previous research indicated that older adults consider the preservation of autonomy essential for adopting such technology, particularly through the

ability to control certain robot functions rather than remaining passive users [3, 17]. Furthermore, research by Hung et al. [35] reported on how telepresence robots can support a sense of autonomy by eliminating the burden of depending on a third person to assist in initiating RMC. This emphasis on autonomy was reinforced during our user tests, where participants consistently highlighted it as a key factor influencing their openness to adopting telepresence robots in the future. Importantly, willingness to use such systems is meaningful not just at the level of individual acceptance, but also at the societal level: if older adults adopt these technologies, they may be better equipped to sustain their social networks and avoid the negative health outcomes often associated with loneliness and isolation.

This study incorporates elements of the Almere model of technology acceptance to examine older adults' perceptions following their use of a telepresence robot. Nonetheless, we acknowledge that technology acceptance is a multifaceted process influenced by factors beyond those captured by the model. As noted by Frennert et al. [24], additional determinants in later-life technology adoption may include older adults' self-knowledge and cumulative experiences with technological innovations, which shape their decisions regarding which technologies to adopt. Other influential factors include the perceived imbalance between the effort required to use a robot and the anticipated benefits, the immediate financial cost, and the cognitive and physical demands associated with mastering the technology.

Finally, our findings also highlight the importance of considering factors such as perceived enjoyment, ease of use, usefulness, and social presence in the design of telepresence robots. These dimensions have long been recognized as central in technology acceptance research, yet traditional technology acceptance models often overlook the social aspects of interaction with technologies [31]. For older users in particular, motivations for acceptance or rejection may depend not only on functional performance but also on how socially engaging and enjoyable the technology feels. Future research would therefore benefit from adopting an acceptance lens that integrates these social and experiential factors, both when designing new systems and when evaluating their use in real-world contexts. Such an approach would help ensure that telepresence robots are not only usable and useful, but also meaningful and engaging for their intended users.

7 STRENGTHS AND LIMITATIONS

The present study contributes valuable insights into older adults' successful use, perceived enjoyment, perceived ease of use, perceived usefulness, perceived social presence, and intention to use a telepresence robot for RMC. All the aforementioned constructs have been proven to determine technology acceptance among potential future technology users. Moreover, based on participants' hands-on experience with a telepresence robot, potential difficulties during robot usage were determined. These difficulties can inform future design decisions in the context of the CO-HUMANICS project and beyond.

However, the present study is not without limitations. Firstly, the sample for the present study is small ($N = 14$) and consists of older adults who are active, living in Germany, and have an interest in technology. Also, it was an inclusion criterion that participants were mentally healthy and lived independently. All these characteristics limit the generalizability of the results of the user tests to other groups of older adults. Furthermore, participants of the study all had previous experience in using communication devices and applications (such as computers, smartphones, instant messaging applications, videoconferencing applications, etc.). Having previous technological skills may have affected older users' experiences during RMC.

Moreover, technology acceptance in this study was examined using the Almere technology acceptance model. However, this model does not account for all potential influencing factors. Incorporating additional theoretical frameworks or constructs could have impacted this study's discussion. Additionally, the training received by older adults and the completed tasks were one-time instances and had a short duration. Further training and using the telepresence robot for longer periods could change the results obtained from the study.

Finally, participants were already familiar with the CO-HUMANICS project and could therefore have given positively biased answers to please the researchers. Future research can focus on prolonged use of a telepresence robot to complete more complex tasks over a longer period.

8 RECOMMENDATIONS FOR FUTURE ROBOT DESIGN

Based on the collected data, specific design suggestions for the further development of telepresence robots for older adults were made.

Following older adults' recommendations for *successful use*, a telepresence robot should be adaptable to their physical and psychological needs. Specifically, factors such as eyesight, hand dexterity, hearing, ability to concentrate, space perception, etc. should be considered in the design of control functions and capabilities (navigational speed, camera view, etc.). Moreover, *perceived enjoyment* during robot usage would be improved by programming the telepresence robot as a communication partner. Older adults expressed that the telepresence robot has potential to be more than a device for mediated communication. For instance, being able to engage in simple conversations and to answer questions from the user are functions that would be enjoyed by older adults. In addition, participants would welcome a friendly-looking robot with some human or animal-like characteristics. Similarly, a simplified control device, that can be adapted to each user, would improve *perceived ease of use*. Participants who are familiar with video game consoles and similar technologies envisioned a joystick with some additional buttons (big and colorful). Furthermore, participants confirmed that the short training session with the roboticists made controlling the robot easier for them. Therefore, in the future, one (or several) training sessions should be made available to older adults before they engage in RMC. To further enhance usefulness, and to raise the telepresence robot's *perceived usefulness*, the following functions could be incorporated: smart assistant, medical assistant, and entertainment. For example, an integrated smart assistant that provides general information on demand would be appreciated by older adults (weather, opening times of businesses, traffic, reminders, etc.). Likewise, a medical assistant in the form of an emergency button that connects with medical personnel/emergency contacts would also be considered useful by older adults. Finally, entertainment functions that allow older adults to play games, watch movies, listen to music, etc. with remotely located friends and family would raise the telepresence robot's perceived usefulness. At the same time, *social presence* was generally perceived as high during RMC. Consequently, the high quality of sound and video as well as the adequate size and resolution of the screen should be ensured to maintain this positive perception. Beyond these aspects, several participants in our study proposed practical scenarios that illustrate how they might utilize a telepresence robot in the future. These envisioned situations highlight the specific functions that older adults are likely to find most valuable. In particular, participants emphasized the importance of features such as an emergency button and wellness check-ins, as well as the robot's role in providing entertainment and serving as a smart assistant or communication partner. Taken together, these insights reinforce the relevance of these functionalities in supporting aging in place and enhancing daily life.

Finally, the brief training session conducted in our study prior to task completion proved effective in enabling older adults to use the technology independently. This suggests that future technological solutions should incorporate opportunities for older adults to receive training before implementation in their living environments. To facilitate successful adoption, support materials such as printed manuals, online or in-person training sessions, and educational programs for family members and caregivers could be developed.

In summary, a telepresence robot aimed at the social integration of older adults should be able to adapt to older adults' physical, psychological, and social requirements to be successfully adopted in the long term.

9 CONCLUSION

The present study explored older adults' successful use, experiences, and perceptions of RMC via a telepresence robot designed to foster social integration and enhance social presence between communication partners. The study's results produced valuable insights for technology designers and developers. Specifically, it was shown that older adults were able to successfully use a telepresence robot (both as the remote and the local user) and that individual physical and psychological characteristics can have an impact on said successful use. Moreover, participants enjoyed communicating via the telepresence robot and reported being able to use it without major problems. Importantly, previous technology-related skills had a positive impact in the telepresence robots' perceived ease of use and should therefore be leveraged in future designs. At the same time, the usefulness of a telepresence robot as a communication device was recognized by participants. However, they were of the opinion that additional functions could transform a telepresence robot from merely a communication mediating device to a communication partner capable of providing information, support, and companionship.

Nevertheless, older adults considered robot-mediated communication a viable alternative only when face-to-face communication is not possible to keep in touch with their social network. Finally, older adults showed great interest in shaping the future of robot development by sharing their insights and experiences with the authors. In the future, studies should embrace human-centered design approaches where participants' voices are heard and included in the development of innovative technologies.

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DeepL (an artificial intelligence-based translation tool) was used to translate the quotes included in the present study from German to English.

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