Computers in Human Behavior 98 (2019) 122–133

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Full length article

# Home robotic devices for older adults: Opportunities and concerns

Inbal Deutsch[a], Hadas Erel[a], Michal Paz[a], Guy Hoffman[b], Oren Zuckerman[a,*]

[a]Interdisciplinary Center (IDC) Herzliya, Israel
[b]Cornell University, Ithaca, NY, USA

ARTICLE INFO

*Keywords:*
Older adults
Robots
Attitudes
Aging
Design guidelines
Human-robot interaction

ABSTRACT

Robotic devices for older adults are becoming a reality. New robots are being introduced for the growing subpopulation of healthy older adults, with an emphasis on supporting the positive aspects of aging. In order to inform the design and implementation of such robots, the relevant needs and concerns of this population should be studied, mapped, and translated into recommendations. We present a qualitative study of thirty cognitively-intact older adults, evaluating their attitudes and emotional reactions towards different types of home robotic devices. Interview analysis of participants reactions to videos of six devices uncovered four user needs that can be threatened by the introduction of home robots: the need for independence, the need for control, the fear of being replaced, and the need for authenticity. Furthermore, results reveal that cognitively-intact older adults are willing to adopt robotic devices into their homes, contingent upon their preferences and concerns being addressed. We provide recommendations regarding how researchers and designers of home robots can better address the user needs of healthy older adults by leveraging aspects of the robot's function, speech, appearance, size, proactivity, and mobility.

## 1. Introduction

Becoming an older adult comes with both positive and negative changes. Nowadays, many older adults experience "healthy" or "successful" aging (Havighurst, 1963; Rowe & Kahn, 1987). They typically have more time to pursue their own interests and are known to score higher on measures of self-acceptance and positive affect (Hudson, Orviska, & Hunady, 2017; Misselhorn, Pompe, & Stapleton, 2013). However, aging also brings about challenges such as sensory, cognitive, and physical decline and is associated with higher levels of loneliness and depression (Adams, Sanders, & Auth, 2004; Jeste et al., 2013). Global demographic trends show the world population is rapidly aging. Currently, individuals aged 60 and older make up 12.3% of the global population; this number is thought to increase to 22% by 2050 (World Health Organization, 2016). As a result, "being an older adult" is becoming a stage of life that may last several decades, stressing the importance of a successful aging experience.

Technology has the potential to assist with the challenges of aging, as well as with enhancing older adults' everyday wellbeing. As a result, digital products are being specifically designed for older adults, including websites, mobile apps, wearables, and smart home devices (Mast et al., 2010; McCreadie & Tinker, 2005; Scanaill et al., 2006). One such technology is home robotic devices, which is believed to have the potential to support physical, cognitive, and social aspects of the older adult's life (Dario, Guglielmelli, Laschi, & Teti, 1999). Some have suggested home robots as possible support for the shortage of caregivers and health-care providers (Super, 2002), as well as a way to comply with older adults' desire to remain in their own homes and to dispel loneliness (Robinson, MacDonald, & Broadbent, 2014).

Within the human-robot interaction community, researchers have been addressing the challenges faced by older adults in various ways. Most previous studies focused on the decline in cognitive and physical abilities. Recently, due to the growing population of healthy and active older adults, researchers have also begun to focus on successful aging as an additional framework for designing robots for this subpopulation. These studies argue that robotic design criteria should expand to address different aspects of successful aging, such as autonomy and resilience (Lee, Tan, & Šabanović, 2016; Lee & Riek, 2018). In the HCI community, these aspects are commonly referred to as user needs, identified by interviewing or observing relevant users and analyzing their statements regarding their goals, concerns, wishes, and preferences (Kujala, Kauppinen, & Rekola, 2001). HCI researchers commonly use such user needs as design considerations for the creation of new technological products. Healthy older adults and healthy young adults are different populations with different user needs (Lee & Riek, 2018), and different factors influence their attitudes toward robots. As a

* Corresponding author. Media Innovation Lab, Interdisciplinary Center (IDC), 46150, Herzliya, Israel.
*E-mail address:* orenz@idc.ac.il (O. Zuckerman).

https://doi.org/10.1016/j.chb.2019.04.002
Received 14 June 2018; Received in revised form 1 April 2019; Accepted 5 April 2019
Available online 05 April 2019
0747-5632/ 

result, older adults may reject robots that younger adults may find useful. Several reasons may account for these differences. First, many assistive robots are designed under the “deficit model of aging” framework, which focuses on disabilities, and may lead to rejection by healthy older adults who do not want to be associated with the negative aspects of aging (Lee et al., 2016). Second, older adults were found to be more sensitive to robot appearances, a sensitivity that was shown to influence robot acceptance (Riek, 2017). Third, older adults were shown to be less experienced with robotic technologies in comparison to younger adults, this difference accounted for the age-related variance in robot acceptance (Ezer, Fisk, & Rogers, 2009), and may also lead to concerns regarding difficulties in operating the robot (Riek, 2017; Robinson et al., 2014). Lastly, different cost-benefit considerations and higher selectivity is associated with older age and was also shown to influence acceptance (Frennert et al., 2013).

While often considered a single demographic, older adults are not a homogeneous population and have a variety of needs and desires (Broekens, Heerink, & Rosendal, 2009; Lee et al., 2016). As a result, the functions of robotic devices for the elderly also vary widely. One common categorization in this domain is the distinction between physically assistive robotic devices and socially assistive robots (Broekens et al., 2009). Assistive Robotic Devices generally aid in physical activities such as household maintenance, cooking, monitoring health, and similar functions. In addition, these devices can provide help for those who need continuous attention and aid in performing basic functions such as eating, bathing, toileting and getting dressed. Examples of these robots include smart wheelchairs, artificial limbs, PR2 cooking robot, and more. (Broekens et al., 2009; Graf, Hans, & Schraft, 2004; Mast et al., 2010). In contrast, Socially Assistive Robots are designed as social entities and involve some level of social interaction with the older adult (Broekens et al., 2009). This category is further divided into service robots and companion robots (Broekens et al., 2009). Socially Assistive Service Robots primarily aid in activities such as event reminders, medicine reminders, and offering suggestions for activities (Breazeal, 2003; Mast et al., 2012). Examples include ElliQ, Nursebot, Care-o-bot, and others (Breazeal, 2003). Socially Assistive Companion Robots do not assist in daily activities, rather their entire function is social interaction. These robots are designed to provide companionship for the older adult in order to dispel loneliness and reduce stress (Robinson et al., 2014). Such devices are sometimes designed with a resemblance to animals, toys, or even pets, and include Paro (seal), Huggable (teddy bear), and Aibo (dog; Dautenhahn, 2004).

The challenge of integrating robotic technology into the lives of older adults is still far from trivial. Older adults' attitudes toward robotic devices vary greatly, affecting acceptance rates (Hirsch et al., 2000; Tapus, Tapus, & Mataric, 2007). With recent advancements in the development of home robots, there is an opportunity to study how healthy older adults react to different types of home robots, extending the body of knowledge in the field, and informing designers on the challenges and opportunities relevant to this specific subpopulation. In this paper, we set out to better understand the design factors influencing cognitively-intact older adults' attitudes toward a variety of near-future home robots. We use qualitative methods to analyze older adults' attitudes and reactions toward six robotic devices, mapping emerging themes and providing design recommendations for designers, researchers, and practitioners.

## 2. Related work

Prior literature on older adults' attitudes towards robotic devices typically focused on clinical populations. Recently, studies have been conducted on the population of cognitively-intact older adults, who mostly reside at home (Lee & Riek, 2018), and we set to extend this approach. Previous work studied older adults' general attitudes toward home robots, usually by asking participants to express their opinions when thinking about the topic abstractly, imagining a device, or interacting with a specific robot. Recent studies further set out to identify robot design characteristics that are necessary for healthy older adults (Lee & Riek, 2018; Wu, Fassert, & Rigaud, 2012). These human-robot interaction studies typically utilize several research methods: (1) mapping of user needs based on direct observation and interviews (Heerink, Kröse, Evers, & Wielinga, 2010; Martelaro & Ju, 2019; Mutlu & Forlizzi, 2008; Pantofaru & Takayama, 2011; Patnaik & Becker, 1999); (2) Participatory design studies where users are involved in the design process (Lee et al., 2017); (3) Evaluation of user reaction to low fidelity prototypes, sketches, and 3D animations (Gomez, Szapiro, Galindo, & Nakamura, 2018; Hoffman, Zuckerman, Hirschberger, Luria, & Shani Sherman, 2015; Hoffman & Ju, 2014; Lee et al., 2009; Luria, Hoffman, Megidish, Zuckerman, & Park, 2016; Obaid et al., 2015; Ribeiro & Paiva, 2012); (4) Evaluation of user reaction to simulations of a robot's social interaction using video examples and Wizard of Oz simulation techniques (Hoffman, 2016; Martelaro, 2016; Martelaro & Ju, 2017; Sequeira et al., 2016; Wang, Sibi, Mok, & Ju, 2017); and (5) Evaluation of a user's direct interaction with a working robot (Cesta et al., 2007). Prior work that studied robotic devices for healthy older adults have utilized some of these methods to evaluate both acceptance factors and attitudes related to the robot's function and appearance. These studies' results are listed below.

### 2.1. Acceptance and attitude studies

Healthy older adults' attitudes toward robotic devices include concerns regarding robots’ function and appearance (Fang & Chang, 2016; Mitzner et al., 2010).

#### 2.1.1. Acceptance and attitude studies concerning the robot's function

When healthy older adults were asked what home-based tasks a robot should perform, they preferred robotic assistance for specific tasks related to chores, manipulating objects, and information management, but not for personal care and leisure activities (Smarr et al., 2014). Older adults who participated in the design process of a robotic device stressed the importance of the robot's function over appearance. These preferences were found to influence acceptance (Frennert, Östlund, & Eftring, 2012). Older adults who interacted with a robot approved of the interaction as long as the robot was not trying to be a friend (Frennert et al., 2013), giving preference to functionalities such as appliances of assisting in specific tasks (Dautenhahn et al., 2005), as long as it did not fully replace human care (Moon, Danielson, & Van der Loos, 2012). Overall, prior work showed that cognitively-intact older adults are not opposed to the idea of robotic devices at home, however, they are wary of using one themselves (Heerink et al., 2010; Young, Hawkins, Sharlin, & Igarashi, 2009). Our work extends prior work by performing a comprehensive analysis of a wide range of factors, with different types of robotic devices, identifying repeating themes and providing design recommendations.

#### 2.1.2. Acceptance and attitude studies concerning the robot's appearance

Hirsch et al. (2000), showed that when the physical appearance of a device implied any disability, it evoked feelings of embarrassment, leading to rejection of the device. Cesta et al. (2007), showed that a device's appearance plays a major role in acceptance, as older adults rejected a robot that had human features such as a face. More recent studies indicated that older adults' preferences are not conclusive, with some showing no preference or higher preference was found for human-like or pet-like appearance (Caleb-Solly, Dogramadzi, Ellender, Fear, & Heuvel, 2014; Prakash, Kemp, & Rogers, 2014). Physical appearance was so important to them that they would not use a device if the design implied any disability. Due to feeling embarrassed, they stated that they preferred to give up their independence and social interactions over using such a device (Hirsch et al., 2000). Older adults were also conclusive with regards to the robot's size; they expected robots to be small and discrete (Prakash et al., 2014).

Overall, prior studies imply that appearance influences acceptance (Riek, 2017), with clear preferences towards smaller size (Cesta et al., 2007; Giuliani et al., 2005), and appearance that does not imply disability (Hirsch et al., 2000). However, results regarding anthropomorphism are inconclusive (Broadbent, Stafford, & MacDonald, 2009). Our work extends prior work with an in-depth evaluation of older adults concerns and attitudes regarding a variety of robots, manifesting different design aspects including, but not limited to, appearance.

In sum, prior work reveals that design matters and can influence older adults' attitudes and acceptance (Broadbent et al., 2009). However, clear design recommendations are still lacking, specifically for healthy older adults ( Frennert & Östlund, 2014; Lee et al., 2016). Our aim is to provide a comprehensive mapping of healthy older adults' attitudes and concerns when presented with a range of robots, each manifesting a different design approach. With the recent advances in home robotics, older adults' attitudes and preferences should be carefully understood and considered.

## 3. Methodology

In this study, we comprehensively map attitudes and concerns collected from in-depth interviews of healthy older adults towards a range of robots design factors. We employ qualitative research methods that are considered ideal for exploratory studies (Sofaer, 1999), supporting an inductive process leading to emerging themes without a prior hypothesis. While it is possible to use quantitative methods to measure attitudes, qualitative methods can provide a richer description of complex phenomena (Sofaer, 1999). Qualitative research allows for the identification of nuances in the data, such as doubts and concerns that can enhance understanding of the "how" and "why" underlying participant's attitudes, as well as integrate the thoughts, attitudes, and emotional reactions into a useful and comprehensive representation of the data. Among the various qualitative methods, we specifically chose to conduct interviews, as they allow for flexibility during data collection while remaining grounded in a particular framework (Barr, 2018).

We conducted 30 in-depth interviews with cognitively-intact older adults in their own homes, evaluating their reactions to videos of six near-future home robotic devices. We systematically and comprehensively analyzed their reactions, revealing common themes and identifying user needs that influence their positive and negative attitudes. These lead to design recommendations for robot designers that target this specific population. The study was approved by the ethics committee of the research institute, with reference number 170326.

A video study methodology was chosen as it is common in human-robot interaction studies and was shown to be an effective research tool when the goal was to understand user's perceptions of robotic technologies (Lehmann, Saez-Pons, Syrdal, & Dautenhahn, 2015; Takayama, Dooley, & Ju, 2011; Woods et al., 2006). This method was also utilized in recent studies (Lee & Riek, 2018; Zaga, de Vries, Li, Truong, & Evers, 2017). Despite known limitations (Schilbach et al., 2013), video studies have advantages, including a consistent experience across participants and the presentation of relevant functions while avoiding usability challenges (Bretan & Weinberg, 2014; Ho, MacDorman, & Pramono, 2008; Wu et al., 2012). In this study, the use of videos made it possible for a large number of older adults to relate to a range of near-future robotic devices (see also Lee et al., 2016; Lee & Riek, 2018; Smarr et al., 2014), some of which can only be shown in videos because they do not yet exist as commercial products. The safe and error-free experience of viewing a variety of robot videos can promote a quick comprehension of the device's features and allow for a simple evaluation of older adults' attitudes and concerns. To verify comprehension, we ran a pilot test and made sure older adults comprehended the device's appearance and function, and were comfortable with expressing their opinions.

### 3.1. Participant demographics

The study was conducted with 30 participants between the ages of 67 and 90 (M = 78.5, SD = 7.29; 10 male, 20 female). The male to female ratio is consistent with the deviation found in the country's ratio, which stands at 0.69 (Central Bureau of Statistics, 2017). We performed purposeful sampling that targeted cognitively intact, healthy older adults who live at home. To ensure the sampling of participants was representative of a variety of healthy older adults living at home, we recruited older adults from two sources: a database of older-aged volunteers who have previously participated in scientific studies on campus (53.3%), and a home-support program for older adults (46.7%). All participants lived in either an apartment (83%) or private home (17%). 60% of the participants were completely independent (received no assistance), 20% were mainly independent (i.e received food catering for convenience), 7% were slightly dependent (received assistance up to once a week), and 13% were somewhat dependent (received assistance more than once a week). The independence ratio slightly deviates from the country's ratio for older adults which stands at 67% independent, 16% partially dependent, and 17% highly dependent (Mashav-JCD, 2015). This variability allowed for a representative sample of different types of cognitively-intact older adults who live at home, therefore reaching the requirement for saturation.

#### 3.1.1. Participant inclusion criteria

The older adult's population is extremely heterogeneous (Lowsky, Olshansky, Bhattacharya, & Goldman, 2013). It was, therefore, necessary to focus on a specific subpopulation with common characteristics. We focused on cognitively-intact older adults (see cognitive assessment subsection below) with the intent to gain insights on nonclinical subpopulations. As our focus was on the benefits of technologies and robotic devices for domestic use (Hutson et al., 2011), we further restricted our inclusion criteria to older adults who lived at home. Moreover, a minimum age was set to 67 as this is the retirement age in the authors' country. To summarize, this study included 67+ year-old, cognitively-intact older adults who live at home and are relatively healthy, active and independent.

*3.1.1.1. Cognitive assessment.* Participants that were recruited from the campus database (53.3%) have undergone a formal cognitive assessment. Participants from the home-care program (46.7%) had not undergone a formal assessment, but were recruited through the home-care program administration only if they met certain criteria (physical and cognitive health). In addition, an informal cognitive assessment was performed with all participants during the beginning of the interview. We did not perform a formal cognitive assessment to avoid stereotype threat (Barber, Mather, & Gatz, 2015), that could affect participants' reactions to the videos. The informal assessment included questions from the mini-mental and Montreal Cognitive Assessment. For example, participants were asked to informally describe their routine, confirming orientation to time when discussing particular days, times, etc. Orientation to space was confirmed when discussing location, such as where they used to live, where they live now, etc. Questions from the mini-mental that confirmed registration, attention, recall, language, and repetition were also integrated into the conversation through questions about family, friends, knowledge, use of current technology, and difficulties encountered during everyday lives. Cognitive state was assessed and re-confirmed by an additional researcher while reviewing interview transcripts. Two participants were disqualified from the study due to their assessed cognitive state during the informal interview conversation (showing difficulties in recall, as well as repetition of information and stories); two additional cognitively-intact participants were further recruited. As a result, the final 30 participants were confirmed as cognitively intact older adults that are suitable for the study.

| Aspects \ Device | PR2 | Nao | Paro | ElliQ | Google Home | Cozmo |
|---|---|---|---|---|---|---|
| Appearance | Creature | Creature | Creature | Object | Object | Object |
| Function | Assistive | Service | Companion | Service | Assistive | Companion |
| Moblity | Mobile | Mobile | Stationary | Stationary | Stationary | Mobile |
| Proactivity | Reactive | Proactive | Reactive | Proactive | Reactive | Proactive |

**Fig. 1.** Devices used in the study, balanced across the four aspects.

### 3.2. Procedure

The interviews were conducted in the living room of each of the older adults' homes. To ensure consistency, two researchers began by conducting four interviews together before interviewing the rest of the participants individually. Each researcher spent two interviews as the interviewer and two as an observer. Some participant's native language was English while others spoke the country's local language; the interviewer (one of which was also a native English speaker) made sure to interview each participant in their preferred language. The study was audio-recorded and later transcribed. After completing the informed consent process, the study began with a relaxed hour-long conversation about the participant's daily routine. This conversation assessed their cognitive state, as described above, and assured that the study began in a communicative atmosphere that did not immediately dive into the potentially unknown territory of robotic devices. The participants were then told they will be shown six video clips of different devices. They were informed that the purpose of the study was to learn about their general attitudes and preferences; that there is no correct or incorrect answer, but that we are interested in their genuine opinion and reflection. Additionally, they were informed that none of the devices shown in the videos were made in the interviewer's lab and thus no bias of the interviewer towards a specific robot could be assumed.

Each video clip was individually shown, one by one, on the interviewer's tablet device (a black, 9.7 inch Samsung tablet), with a break for discussion in between videos. Using a tablet allowed participants to hold it themselves and adapt the view distance and angle to their preference. The participants were given a printed photograph of each device currently being discussed in order to aid in recall and to have a physical representation to point at and elicit responses with. The order of the videos was randomized between participants to avoid order effects (counterbalanced). After viewing each video, a 5–10 min semi-structured interview was conducted regarding the device just seen. Participants answered both general and specific questions, such as: “What did you think of this device?“, “If you were to receive this device for free, as a gift, would you like to use it? Why or why not?“, “What did you think of the device's size?“, “What did you think of the device's appearance?“. When the participant was done discussing the current device, the next video was played on the tablet, followed by a similar 5–10 min interview. This procedure was repeated for all six videos.

### 3.3. Robot inclusion criteria

To allow for a comprehensive evaluation of older adults' attitudes and concerns, we introduced participants to six robots manifesting variations along four design aspects. These aspects were reported as meaningful in previous studies. They were never studied together but were used in different studies, each with a specific robot (Cesta et al., 2007; Syrdal, Dautenhahn, Koay, Walters, & Ho, 2013); or in studies conducted with clinical populations (Wu et al., 2012). The four aspects are: Function (assistive/service/companion), Appearance (creature/object), Mobility (mobile/stationary), and Proactivity (proactive/reactive). We used these aspects as selection criteria to verify that participants received a balanced introduction to the range of design aspects applied in existing robots. These aspects were not used to define specific research questions and were not directly communicated to participants, but only used for the robots’ selection by the researchers.

The devices considered were representative of major trends in human-robot interaction research and commercial robotic products at the time of this study. We only included devices that were at least in a working prototype phase, or that have been announced to be released to the market in the near future. After reviewing many videos relevant to these criteria, six videos were chosen, each showing a different device. The four design aspects were balanced across all videos, so that participants were exposed to different applications of each aspect in various settings. For example, the Paro robotic device was classified as creature/stationary/reactive/companion, while the PR2 robot was classified as creature/mobile/reactive/assistive. To ensure a balance selection for all aspects, we included a non-robotic smart device (Google Home) to properly represent the category of object/stationary/reactive/assistive. The six devices were: PR2, Nao, ElliQ, Cozmo, Paro, and the Google Home. Fig. 1 demonstrates the six devices and their respective design aspects.

### 3.4. Robot and video descriptions

The length of each video ranged from 45 to 66 s (5 min and 34 s total). The human actors in the videos were both older and younger adults, with similar appearance and behaviors to that of the participants.

Personal Robot 2 - Willow Garage's PR2 is a human-sized robot used by universities as a research platform. It is considered a prototypical example of a general home assistant robot (Willow Garage, Inc., n.d.). The video shows PR2 in a cooking demonstration, making popcorn in a kitchen stovetop setting. In the video, PR2 opens drawers, holds cookware, turns on the stove, closes lids, and stirs food.

Nao - SoftBank Robotics' Nao is a general purpose commercial anthropomorphic robot (Shamsuddin et al., 2011). The video shows Nao recognizing the user's face as they enter, actively responding to the individual, and acting as a desktop work assistant for the individual.

Paro - NAIST's Paro is a robotic baby seal which is designed to interact with people, reacting to touch, light, audio, temperature, and posture changes (Kidd et al., 2006). The video shows Paro moving its head, blinking, and reacting to its environment. The user pets Paro and talks to it warmly while the robot makes “purring” noises.

ElliQ - Intuition Robotics' ElliQ is a near-future commercial robot that has two parts: a screen and a ‘robotic character’ (Intuition Robotics, Ltd, n.d.). The video shows ElliQ motivating the user to be active and engaged with family members, reminding the user to take her medicine, arranging rides for her, reminding her of appointments, and suggesting activities such as playing bridge, listening to TED talks, and taking a walk.

Google Home - Google Home was selected to serve as the non-robotic object-like device. It is a commercially-available smart device serving as a home assistant with a voice-activated speaker (Google, Inc, n.d.). The video shows the device at home, controlling the lights in the house, answering various questions from users and connecting between family members.

Cozmo - Anki's Cozmo is a small commercially-available entertainment robot that can play games with users (Anki, Inc, n.d.). The video shows the device recognizing the user and being happy to see him, initiating a simple physical game with the user using two cubes, showing positive emotions when winning and negative emotions when losing.

### 3.5. Qualitative analysis process and themes

We used the affinity diagram and thematic coding methods to uncover older adults' preferences and concerns based on the data gathered in the 30 interviews. These qualitative analysis methodologies enable identification of emerging themes in the data that may reveal design considerations that are critical to this population. Prior to performing analysis, we verified that the responses of the four participants who underwent interviews with two researchers (one interviewer and one observer) did not differ substantially from the responses of the other 26 participants. We extracted 496 quotes from the audio recording transcripts. Each quote expressed an attitude, emotional reaction, or value judgment about one of the devices shown in the videos or about robotic devices in general. The affinity diagram methodology (Beyer & Holtzblatt, 1997) was initially used to analyze the quotes in a bottom-up process to identify and organize common attitudes and concerns stated by the older adults. Once groups and initial themes were formed, the thematic analysis methodology (Gibbs, 2007, pp. 38–56) was used to strengthen and finalize the theme definitions. Affinity diagramming is a hierarchical technique used to organize and group large quantities of responses and insights in a visual manner based on their natural relationships (Hartson & Pyla, 2012). This technique is used by interaction designers and HCI researchers (Huang & Truong, 2008; Rutkowska, Lamas, Visser, Wodyk, & Bańka, 2017), and has been used before in the context of older adults (Payyanadan et al., 2017). Affinity diagrams are best used when there is unknown or incomplete knowledge of the area of analysis, allowing for the definition of key groups and categories without losing individual variance (Beyer & Holtzblatt, 1997). By pulling together data with similarities and common themes, the affinity diagram helps consolidate contextual data and move from individual preferences to common patterns across all participants (Hartson & Pyla, 2012). It is inductive, meaning it is a purely bottom-up process and the categories emerge from the data, not from a predefined taxonomy. Using this method allowed for the identification of topics that are of importance to healthy older adults and are not consistently considered when designing for this population.

Four researchers created the bottom-up affinity diagram (see Fig. 2). All the quotes were equally divided between the researchers, and an initial read-through was individually done in order to become familiarized with the data. Team members then took turns reading a quote out loud and placing it on the wall. Quotes that shared similar meaning were clustered closer together. Preliminary clusters of quotes evolved into 16 initial groups. The initial groups were discussed and debated, evaluating their effect on the overall group formation. On several occasions, discussions led to the division of a group into better-defined groups. If needed, quotes were moved to reflect better association to a certain group, until consensus was reached about the groups. Groups were then clustered further into higher-level categories. At this stage, the researchers leveraged thematic analysis (Gibbs, 2007, pp. 38–56), using the 16 groups and initial categories, to determine the final themes. Throughout the process, disagreements were discussed until a consensus was met. If a consensus was not easily reached, all quotes

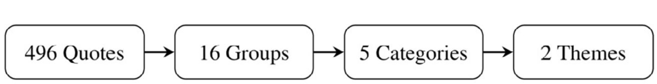


**Fig. 2.** Qualitative analysis process occurring in the affinity diagram.

from the relevant categories were reviewed again, and an additional researcher was invited to provide another perspective. This bottom-up process led to two high-level themes, five categories, and 16 groups, presented in Fig. 3 and Fig. 4.

The two themes that emerged from the qualitative analysis process were: (I) About the Robot, including statements specifically addressing features of the robotic device in three categories: Behavior, Appearance, and Function, encompassing eight groups with many including subcategories of “for” and “against”; and (II) About Me, focusing on the relationship between the device and participant's own values, life, and preferences, including two categories: User Needs and Openness to Device, encompassing eight groups. In the following sections, we present the themes, comprised of five categories and 16 groups, with representative quotes. Four researchers reviewed and discussed all the quotes within each group until a consensus was reached regarding a selected set of quotes that represent the range of participants' reactions. In this section, we included a smaller set of quotes that are clearly understood in a stand-alone fashion and do not present redundancy.

## 4. Theme I: About the robot

The first high-level theme emerged from categories that involved concerns and preferences towards the robotic device. These categories relate to the robot's behavior, appearance, and function (see: Fig. 3). While behavior and appearance involved attitudes regarding specific robot features, function involved the main task the robot can fulfill (assistive or social function). Each category includes quotation groups that emerged from the responses, with some of the groups further divided into “for” and “against”.

### 4.1. Behavior

This category emerged from groups that dealt with the way the robotic device behaved during the interaction. It is comprised of three quotation groups: Proactivity, Mobility, and Speech.

#### 4.1.1. Proactivity

Of the 25 quotes mentioning proactivity, only 9 were in favor of a proactive device, with 16 against proactivity. Participants rejected proactive robots because they preferred to continue performing activities themselves and did not want the robot to do it instead of them.

> Who needs this? What will I do? It will leave me without activity. I think it will lead to a degeneration of people (P24, Female, 77).

Two participants specifically stated that they did not like how the robot took initiative.

> I like it when I have to tell it what to do, not when it's proactive. It doesn't need to remind me. I want to remind it (P27, Female, 79).

Of those who were in favor of proactivity, three participants said they preferred proactive robots because it would give them the ability to consult with the device. Other reasons that arose were wanting a device that can suggest and remind them of things.

> I like that ElliQ wouldn't have to wait for me to say something to it before it reacts (P19, Male, 75).

In sum, our findings suggest that more participants were against the proactivity aspect of the robot's design than for it.

#### 4.1.2. Mobility

Of the 26 quotes discussing the device's mobility, 9 were in favor of mobility, with 17 against it. Participants explanations for not wanting a moving device included that a moving robot is irritating and that it would “get in the way” or “frustrate them”. Three participants felt that a robot moving meant a loss of control, both in their abilities and in the interaction with the device.

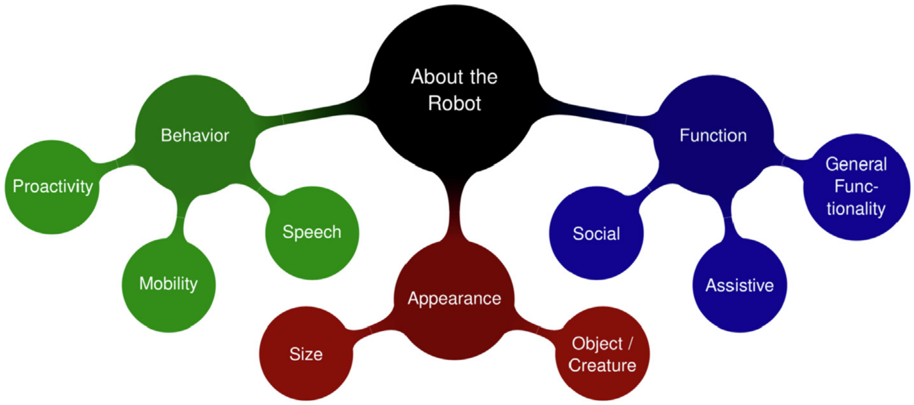


**Fig. 3.** Theme I, "About the Robot", and its three categories (Behavior, Appearance, and Function), made up of eight groups. This theme includes all of the quotes that comprised the concerns and preferences towards the robotic device.

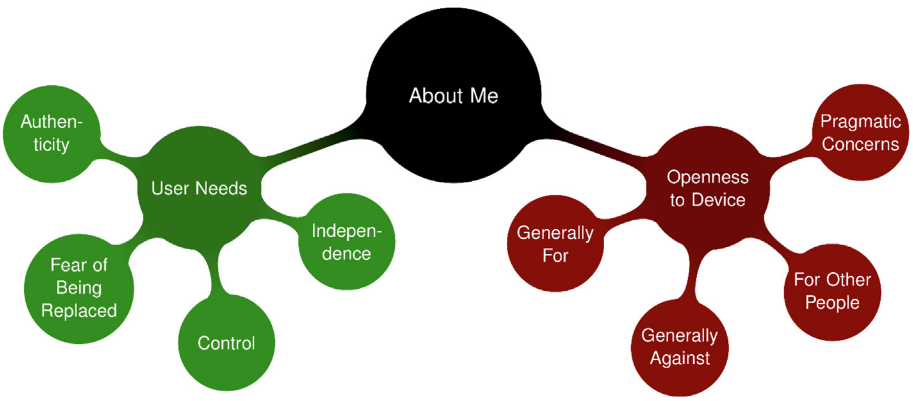


**Fig. 4.** Theme II, "About Me", and its two categories (User Needs and General Acceptance), made up of eight groups. This theme includes quotes regarding the participants themselves, their role, and their personal preferences with respect to robotic devices.

> The advantage is that I have to be the one to make an effort. It can keep my brain active. It can help me keep my abilities for longer. (P10, Male, 90)

> No, I'd rather it be stationary. I would still want to be … when I felt that I would no longer be in control of what I was doing I would retire to an old people's home (P21, Female, 78)

Two participants stated that they felt a moving robot allowed for more possibilities. An additional two discussed how the robot should move, wanting it to act like a dog or move in a non-threatening way.

> I find them eerie. Somehow I find the moving one less eerie than the stationary ones. Maybe because I've seen these things in movies for decades whereas I haven't seen stationary ones (P22, Female, 86)

In sum, our findings suggest that in many cases mobility was perceived as an unfavorable design aspect.

#### 4.1.3. Speech

17 quotes discussed the device's ability to talk. 6 were in favor, and 11 against. Comments against a talking device indicated strong negative attitudes. Reasons included feeling that it was "intrusive", "frustrating", and "difficult to understand the robotic voice".

> Maybe if it didn't talk it might be a bit more acceptable. When it's talking it's intrusive (P2, Male, 90)

Comments in favor did not explain further as to why; simply saying it would be a "nice" feature.

In sum, our findings suggest that more participants were against speech than for it.

### 4.2. Appearance

This category emerged from groups that dealt with the appearance of the robotic device. This category is comprised of two quotation groups: Size, and Creature-like vs. Object-like.

#### 4.2.1. Size

All 15 quotes regarding size indicated a preference toward smaller devices. 10 comments were about PR2 being "too big", claiming it would "get in the way", and that they "can't see anything this big in the house." Two comments stated that ElliQ was too big for their preference, and would "take up too much space on the counter."

In sum, our findings suggest that participants showed a clear preference toward smaller devices.

#### 4.2.2. Creature-like vs. object-like

Of the 40 quotes, 22 preferred the device to resemble an object (abstract) and 18 preferred it to resemble a creature (human-like or animal-like). Those who preferred the device to look like an object said it was because it was "elegant", "beautiful", and "non-intrusive".

> For its function, I think ElliQ looks rather elegant. (P4, Male, 72)

Three participants specifically stated that they preferred an object-like design because it meant the device is not pretending to be a human or animal.

> It's trying to persuade you it's something that it's not. I mean a robot's a robot, it's not a human being or an animal. It's not alive. It's not a sentient being. (P2, Male, 90)

A recurring response for preferring a creature-like appearance was because it made the device "cute", "comfortable", or reminded them of something they already recognized.

> He looks friendly, he's cute and comfortable. (P26, Female, 79)

In sum, our findings indicate that participants had no clear preference for either creature-like or object-like appearance. However, when the social interaction was the robot's main function, several participants expressed a strong rejection towards creature-like appearance.

### 4.3. Function

This category emerged from groups that dealt with the activities and functions the robot was intended to perform. It is comprised of three quotation groups: Social, Assistive, and General Functionality.

#### 4.3.1. Social

Quotes regarding the device being social were divided into quotes ‘for’ (22 quotes) and ‘against’ (6 quotes). 14 participants discussed wanting social abilities because they liked having something to communicate with, allowing for a connection with the device. Participants reacted to the non-verbal communication capabilities of some of the robots, stating:

> It's like having another person in the flat that would communicate with me rather than me communicate with it all the time. I like that. (P19, Male, 83)

Responses against the device having social abilities noted that they felt strongly that a robot should not be used for company.

> I think I'd have to be senile to want to do anything like that … if I've got to that stage I'd know I didn't have my wits about me anymore … I wouldn't want to feel that this is what I had to be in contact with for company. (P21, Female, 78)

In sum, our findings suggest that most participants were open for social interaction with a robot. However, When the social interaction was the robot's main function, participants expressed a strong rejection.

#### 4.3.2. Assistive

Quotes regarding the device being assistive were overwhelmingly ‘for’ (47 quotes) in comparison to ‘against’ (2 quotes). The most common response (18 quotes) for wanting an assistive device was for it to do errands the older adult didn't enjoy doing themselves. 13 of these comments were specifically about having a robot that cleans.

> I wouldn't want it to take over something I enjoy doing. It can do the cleaning. (P3, Female, 70)

The second most common reason for wanting an assistive device was to have help in what has become difficult (12 quotes). Of those, 7 quotes wanted specific help in remembering.

> Under the circumstances that I'm alone at home and I need to remember to do something specific, [this] could be the solution. (P29, Male, 85)

Seven participants mentioned wanting an assistive device so that it could facilitate certain activities, not due to hardship but for increased comfort.

> Ooh I'd like one of those … ‘Make me a cup of coffee!’ (P21, Female, 78)

P26 was against the device being assistive, saying that they could “manage on their own”. P9 responded that they would “rather have a person than a robot”.

In sum, our findings suggest that most participants appreciate assistive functions for robots.

#### 4.3.3. General Functionality

25 comments emphasized a preference for a robot that does something “meaningful”, has a “purpose”, and “adds to the quality of life”. A majority (17 quotes) of these responses mentioned purpose, as in “having a meaningful goal”, without detailing a specific function, and rejecting the robot when it did not fulfill any function.

> This is completely undesirable … I don't understand why this would be useful, it doesn't do anything. (P14, Female, 67).

Another recurring response (7 quotes) discussed how the robot's function should bring purpose into the individual's life.

In sum, our findings suggest that participants believed the robot should have a clear function that can enhance their quality of life.

## 5. Theme II: about me

The second high-level theme emerged from participants’ responses regarding themselves, their role, and their personal preferences with respect to interaction with a robotic device. The two main categories in this theme are, the User Needs of older adults and their general Openness to a Device (see: Fig. 4).

### 5.1. User needs

This category includes the four user needs raised by older adults, as well as values that are important for them, and they felt should not be compromised during the interaction with the robotic device. As common in HCI qualitative need identification studies, the identified needs are subjective. However, our data analysis process highlights needs only if they were repeated several times across many participants. The four needs that emerged from the data were: need for authenticity, fear of being replaced, need for independence, and need for control.

#### 5.1.1. Need for authenticity

The largest group of comments (34) in this category discussed participants' opposition toward a robot “pretending” to be what it’s not. The main concepts from the comments included opposition to how the robot looks and how it interacts. 16 comments were made regarding not wanting the robot to pretend to be alive when it's not, with regards to how it looks or the materials it's made of.

> An animal is something that's alive. It's got a heart … it's got a feeling. Just because it has fur? This is dead! It's nothing, an inanimate object. It's like I can sit here and I can pet this stupid table or this chair because it's soft? No. (P8, Male, 87)

14 comments discussed rejecting a robot that pretends to be what it’s not in terms of authenticity in the interaction with the human.

> I need a personal touch. Because the only thing that a robot could do to me or to respond to me would be a response that's been built in, it's not spontaneous. (P4, Male, 72)

In sum, our findings suggest that participants require authenticity and most of them reject devices that pretend to be something they are not. They perceive the artificial design as insulting.

#### 5.1.2. Fear of being replaced

The second largest group, including 28 quotes, discussed the participant's opposition towards a robotic device replacing them in tasks or activities they feel are meaningful to them. Participants shared a strong desire to feel they are still capable, saying they insist on doing the activity themselves.

> Why would I need this? I have hands, everything is fine, I still have my strength, why wouldn't I just do it myself? (P11, Female, 80)

Recurring responses regarding this included a fear of becoming “irrelevant” and a concern for the lack of activity that could occur due to the free time enabled by the robot.

> If I have something like that I'll do nothing but sit all day and ‘do this do that’ and that's the end of me! I don't think I would want anything like that. As long as I can do things myself, that's what I want to do. (P7, Female, 86)

In sum, our findings suggest that many of the participants are concerned by "being replaced" and strongly defend their need to do things themselves, especially tasks they value as important.

#### 5.1.3. Need for independence

19 quotes discussed the older adults' desire to keep their independence, not wanting to become dependent on the usage of a robotic device. This is similar to results found in previous work, in which older adults were concerned that using a device could result in loss of autonomy, even though the device could provide necessary assistance (Lee & Riek, 2018; Mynatt, Melenhorst, Fisk, & Rogers, 2004). The threat to autonomy reduced older adults' acceptance of the device (Mynatt et al., 2004).

> I think people could get dependent on it in a bad way. Unless they absolutely need it. But I think it's easy to get lazy and get too dependent on it … it won't be good for their brain. (P22, Female, 86)

In sum, our findings suggest that several participants worry about losing their independence and find the use of a robot as a threat to their autonomy.

#### 5.1.4. Need for control

19 quotes discussed participant's desire to remain in control of their lives and of the device.

I just feel that as long as I can keep control of what I want to do then I don't need something like that to tell me … I just think that for somebody who is active and knows pretty much what they're doing, it's intrusive … If I got to the stage where I needed something like that [robot], I'd just give up. (P21, Female, 78).

Participants also discussed control in terms of wanting to be in control of the device (12 quotes). This finding is in line with findings from previous work indicating that older adults wished to have full control of the device. (Lee & Riek, 2018).

> Machines should be under our control … you choose to use it. You switch on the robot and say 'do the ironing'. (P2, Male, 90)

6 responses discussed not wanting the robot to tell them what to do or reminding them to do things.

> I really don't like how it was telling you what to do, I could just use a pen and paper. (P8, Male, 87)

In sum, our findings suggest that some participants mentioned staying in control as an important factor that should be addressed in the robot's design.

### 5.2. Openness to device

The last category includes quotes regarding older adult's overall willingness to use the device. The four groups in this category are: "Generally For", "Generally Against", "Not for me, but for others", and "Pragmatic Concerns".

#### 5.2.1. Generally for

52 general positive comments were made regarding the devices. The positive comments ranged from slightly positive:

> Theoretically yeah, I don't mind, any help I can get. (P30, Female, 75)

To very positive:

> All these are good things. I can't see any disadvantage for any of these. They all have different functions, they're there for different things to do … it would be a great advantage. (P19, Male, 75)

#### 5.2.2. Generally against

77 negative responses were made regarding the devices. The negative comments ranged from slightly negative:

> This kind of technology doesn't "speak" to me. (P15, Female, 75)

To comments that were very negative:

> I think it's dehumanizing. If you walk into a house and you can't put your finger on the light you have to say lights on please, it's infantile. (P22, Female, 86)

#### 5.2.3. Not for me, but for others

9 responses were made regarding how the participants felt the device could be suitable for someone else. 7 participants mentioned that the device could be for someone who is lonely, but not for them at this point in time.

> I'm for it, in certain circumstances obviously, but not now. If, for example, I will be alone or something like that, and I would need somebody. (P16, Male, 86, living with spouse)

#### 5.2.4. Pragmatic concerns

25 responses discussed the operation and ease of use of the various devices. The most common concern dealt with the role of the individual in the use of the device (11 quotes).

> Well somebody would have to program him and I couldn't do that. (P22, Female, 86)

Another main concern that arose (9 quotes) discussed general complexity.

> I think it's pretty complicated no? All these machines look pretty complicated. (P1, Female, 84)

In sum, findings regarding participants' openness to device indicated that older adults do not overtly reject or accept robots. Participants' responses indicated that the negative and positive reactions were evoked by specific design aspects represented by the different robots. Thus, older adults may reject or accept the idea of using a robot depending on its specific design and function. This finding supports the motivation of this work, which indicates that the evaluation of older adults' attitudes towards robots should be done with a variety of home robots manifesting a variety of design aspects, and not with a general notion of a "robot".

## 6. Discussion and design recommendations

The analysis of cognitively-intact older adults' reactions to the videos of robotic devices revealed common themes that can guide designers, researchers, and practitioners working with robots for this specific population. Our analysis identified robot features and design aspects ("About the Robot") on the one hand, and user needs ("About Me") on the other. In this section, we integrate these themes and discuss how older adults are open to home robotic devices only if they are designed to address the four user needs: the need for authenticity, the fear of being replaced, the need for independence, and the need for control. We argue that a better understanding of these needs can guide robot designers when addressing a robot's features, and we provide design recommendations related to the categories found in our data: function, speech, appearance, size, proactivity, and mobility.

### 6.1. Function

The robot's function, even if useful, can raise a fear of being replaced and threaten older adults' need for authenticity. Our findings suggest that older adults consider the device's function as a critical design aspect. There was a consensus in their responses, indicating that the robot should have a meaningful function that is relevant to their daily routine. However, older adults' preferences can turn into rejection if the function raises their fear of being replaced. Under these constraints, participants were open to both assistive and social functions, but had different reservations for each type.

For assistive functions, older adults were willing to accept robot assistance (in line with previous work; Smarr et al., 2014), but only if they were not interested in performing these tasks themselves. Participants rejected assistance in activities they found personally meaningful, and in many cases found it as a threat to their self-efficacy, raising the concern that the robot will “replace” them. As expounded in Ezer et al. (2009), there is a difference between younger and older adults in regards to the tasks they want an assistive robot to perform. A younger adult may desire a robot that performs a routine household assistive task, while older adults may view this specific action as essential for their self-efficacy, and as a result reject the robot. Choosing which function to assist in is not trivial, as the function that a robot can fulfill without threatening the user needs is subjective. For example, household functions (e.g. cleaning) and cognitive functions (e.g. reminding) can be preferred by one older adult and rejected by another, based on their individual abilities and desires.

For social functions, older adults were willing to accept social interaction with the robot only if the device was perceived as being authentic. Participants rejected a device that was pretending to be their friend, so much so that in some cases the idea of befriending an artificial robotic device was seen as an insult to their intelligence. Participants were especially against companionship when it was the robot's only function. They perceived it as an artificial attempt to pretend to be something it is not. Therefore, companionship is not an acceptable function for healthy older adults as it violated the robot's authenticity.

A possible approach to address the above challenge is to design single-function robots. These robots would fulfill a practical function that is useful for older adults. This function cannot be companionship, as it will threaten the older adult's need for authenticity. The single-function approach can account for the individual differences among older adults and can empower them to make their own decisions when choosing a robot. Older adults can decide whether they wish to perform a certain function themselves or prefer to purchase a robot that performs it for them. In contrast, a multi-function device presents a risk, as it increases the possibility that one of the robot's functions will conflict with a task the older adult considers important for their self-efficacy. It may seem that a multi-function approach can provide the same solution, as users can decide if they want to activate or deactivate a certain function. However, based on participants' responses in the interviews, it seems that this specific population is quick to reject devices that threaten their self-efficacy, even in the case that the function is optional and can be deactivated. One way to explain this finding is by “stereotype threat” (Chasteen, Kang, & Remedios, 2012), in which an individual becomes sensitive to possible threats on their self-efficacy due to relevant stereotypes. Therefore, our recommendation is to design a range of single-function devices rather than one multi-function device, allowing older adults to make a deliberate choice and purchase a robotic device that does not conflict with tasks that they want to perform themselves.

Regarding the social aspect, participants did appreciate social cues, suggesting they are important for older adults. However, they strongly conveyed their rejection when social interaction was the main function of the device. Therefore, we recommend that social cues should be integrated into the robot's non-verbal communication as a secondary function, providing a subtle sense of social interaction while not threatening the need for authenticity. The non-verbal social features should be presented as the device's interface, the way the robot communicates with the older adult, and not as its function. This way the robot may provide companionship indirectly, through implicit interaction.

### *6.2. Speech and appearance*

Participants tended to reject devices that pretend to be something they are not: a friend, a pet, or any other living entity. We found that speech was often rejected by participants due to two reasons: perception difficulties (i.e. difficult to understand), and violation of the need for authenticity. While some participants appreciated verbal communication, their reactions suggested that it should be considered with caution, as it increases the chances that the robot will be perceived as “pretending” to be something it's not. This could be due to the designer's specific choice of words (e.g. “goodbye, I'll be here when you return”) or the formation of an artificial ‘Persona'.

Regarding appearance, participants did not show a clear preference for either object-like or creature-like (human or animal) appearance. However, findings were more conclusive about a robot's appearance being rejected when it suggested that the main function of the device is to be a friend or pet. This finding extends the Almere model (Heerink et al., 2010), as appearance was evaluated in the context of several design aspects, revealing a wider view on user's preferences towards appearance.

Taken together, both the device's appearance and verbal communication were rejected when participants perceived it as an attempt to create an artificial companion. Therefore, we recommend that verbal communication should be used carefully and preferably not for social communication, but only as an interface that supports the robot's main function. Word choice should be such that they do not imply the robot is something that it is not. Similarly, the robot's appearance should also avoid associations to living companions, and if possible, should be designed to directly relate to the robot's function.

### *6.3. Size*

The size of a robot is a critical factor for older adults and it should not stand out in their home environment. Participant's opinions regarding the robot's size were conclusive, with a strong preference towards smaller devices that would not take up space in their home and would integrate seamlessly into their current lifestyle. Smaller size, in addition to a design style that is relevant for this population, is especially important as older adults often move to smaller houses at an older age, and each new object has to fit naturally and comfortably in their lifestyle. This finding extends prior research which suggested that older adults want robots to be discreet (Prakash et al., 2014; Wu et al., 2012).

### *6.4. Proactivity and mobility*

A robot's proactivity and mobility may threaten older adults' need for control and independence. Reactions regarding proactivity were not conclusive. Some participants strongly rejected it, stating it would threaten their independence. They felt it competes with their wish to stay proactive themselves for as long as possible. This finding also highlights the difference between older adults' and younger adults' needs. Participants were concerned about becoming dependent on the robotic device, stating that if the robot performs tasks instead of them, over time they would no longer be able to perform the tasks themselves and would eventually become too dependent on the robot. Participants also discussed the need for having authority in any given situation, explicitly stating that the more proactive the robot, the less they feel in control. Similar reactions were stated about mobility. Not all participants rejected proactive and mobile robots, stating that they would like having reminders and suggestions for activities and that mobility is acceptable if it is essential for the robot's function.

Therefore, our recommendation is to address the proactivity and mobility challenge by addressing the user's need for independence and control. This can be done by utilizing interaction techniques that give the user a proper choice and allow the user to influence the robot's function, leading to a feeling of human-robot collaboration rather than using an independently proactive robot. Even if a robot can perform a task independently, without the user activating it, designers should include some level of human-robot collaboration paradigms that will give older adults a role in the task performance (supporting the need for independence) and control over its execution (supporting the need for control).

For example, when the robot is ready to execute an automatic operation, like suggesting an activity, designers can add a "subtle invitation to interact" that invites the user to make a specific choice of if she wants a suggestion now or not, therefore supporting her need for control. Designers can potentially take it further and design actions that can be done together, through turn-taking or joint action, such interaction techniques may even contribute to a feeling of teamwork, so as to address the fear of becoming dependent on the robot. This should be further studied before specific conclusions are made, however, it is in line with Lee and Riek's (2018) finding that older adults prefer to preserve their autonomy and independence even if it means compromising the robot's assistive capabilities.

In sum our findings suggest that healthy older adults' acceptance is influenced by the specific design aspects and their relation to older adults' user needs. More research is needed to better understand the influence of a variety of design aspects, as well as the interaction between them, on the attitudes of older adults. Our research serves as a first step in expanding this perspective.

## 7. Limitations

Our study has several limitations. As a qualitative study based on face-to-face interviews, our interviewers could unknowingly influence an interviewee's responses (Opdenakker, 2006). We made our best effort to mitigate this well-known effect, by training the interviewers according to detailed interview protocol and increasing their awareness to this effect (Opdenakker, 2006). In addition, our choice of video study rather than live interaction study to introduce the different types of robotic devices may have influenced aspects of the results. Video studies are a known method in human-robot interaction research. Disadvantages of this method include a less realistic experience (Schilbach et al., 2013), and the lack of direct, live interaction between the older adult and the robotic devices (Bretan & Weinberg, 2014). Advantages include increased consistency (Ho et al., 2008; Wu et al., 2012), and mainly the ability to introduce a wide range of robotic devices, including some that are not yet available commercially. Mixing between introducing some robots through video and others through live interaction would lead to an inconsistent experience and thus would not be a valid research methodology. Hence, we limited the study to video introduction allowing to consistently present a wide range of devices to older adults. When such a large variety of robots become available and useable, a direct interaction study should be performed. An additional known limitation of qualitative studies is that data collection relies on the honesty and sincerity of participants and may be affected by the "good subject effect" (Nichols & Maner, 2008). However, in this study, there were no "correct" responses that could please the researcher, and participants were informed that the interviewer had no relation to the robots presented. In addition, the data analysis reveals that participants provided a variety of both positive and negative responses, leading us to believe that the results found go beyond demand characteristics. With regards to the pool of participants, we note that the selected participants represent only a specific target group of older adults, and the perceptions of participants are limited to the context of this study. Future studies should further ensure replication and saturation.

## 8. Conclusion

Our study indicates that cognitively-intact older adults are willing to accept robotic devices into their home, but have very specific preferences and concerns that must be addressed. Our qualitative analysis revealed four user needs that are at risk of being threatened by design aspects of home robots: the need for independence, the need for control, the fear of being replaced, and the need for authenticity. We presented a set of design recommendations, informing designers how they can address high-risk design aspects (function, speech, appearance, size, proactivity, and mobility) and improve acceptance by considering older adults' needs:

1. Function: Design single-function social robotic devices, with a leading function that is meaningful for healthy older adults. Social features should not be the leading function, but rather be integrated as a secondary function, for example through non-verbal communication.
2. Speech and Appearance: Design speech and appearance to be authentic and support the robot's main function. Speech and appearance should not communicate a false perception of companionship, as if the robot is a friend.
3. Size: Robots should be designed to be small, with style and appearance that naturally fit older adults' home environment.
4. Proactivity and Mobility: Proactivity and mobility should not be designed as autonomous features, but should be utilized to increase older adults' need for control and need for independence. Allow users to choose which actions should be performed, and assign a role for the older adult in the task, aiming for human-robot collaboration.

To conclude, we believe that there is a strong connection between older adults' user needs and their reactions to specific robotic design aspects. These user needs should be considered when designing robots for healthy older adults. We hope our findings and design recommendations may assist designers, researchers, and practitioners in addressing the challenges of designing robots for the growing subpopulation of healthy and active older adults.

## Declaration of interest

All authors report no financial, personal or other relationships with commercial interests.

## Indications of previous presentation

No previous presentation, nor date(s) or location of meeting.

## Funding

The study was supported by a grant from The Israel Ministry of Science and Technology (Grant #54178).

## Acknowledgments

This research was supported by a grant from the [removed for anonymity]. The authors wish to thank all of our study participants for their insightful comments, ideas, and inspiration.

## References

Adams, K. B., Sanders, S., & Auth, E. A. (2004). Loneliness and depression in independent living retirement communities: risk and resilience factors. *Aging & Mental Health, 8*(6), 475–485.

Anki, Inc. (n.d.). Cozmo. Retrieved from: https://www.anki.com/en-us/cozmo Accessed 16 March 2018.

Barber, S. J., Mather, M., & Gatz, M. (2015). How stereotype threat affects healthy older adults' performance on clinical assessments of cognitive decline: The key role of regulatory fit. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 70*(6), 891–900.

Barr, M. (2018). Student attitudes to games-based skills development: Learning from video games in higher education. *Computers in Human Behavior, 80*, 283–294.

Beyer, H., & Holtzblatt, K. (1997). *Contextual design: Defining customer-centered systems.*

Elsevier.
Breazeal, C. (2003). Toward sociable robots. *Robotics and Autonomous Systems, 42*(3–4), 167–175.
Bretan, M., & Weinberg, G. (2014). Chronicles of a robotic musical companion. *NIME* (pp. 315–318). .
Broadbent, E., Stafford, R., & MacDonald, B. (2009). Acceptance of healthcare robots for the older population: Review and future directions. *International journal of social robotics, 1*, 319–330 .
Broekens, J., Heerink, M., & Rosendal, H. (2009). Assistive social robots in elderly care: A review. *Gerontechnology, 8*(2), 94–103.
Caleb-Solly, P., Dogramadzi, S., Ellender, D., Fear, T., & Heuvel, H. V. D. (2014, March). A mixed-method approach to evoke creative and holistic thinking about robots in a home environment. *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction* (pp. 374–381). ACM.
Central Bureau of Statistics (2017). *Population by age, gender and religion.* Retrieved from http://www.cbs.gov.il/reader/cw_usr_view_SHTML?ID=803/, Accessed date: 12 December 2018.
Cesta, A., Cortellessa, G., Giuliani, M. V., Pecora, F., Scopelliti, M., & Tiberio, L. (2007). Psychological implications of domestic assistive technology for the elderly. *PsychNology Journal, 5*(3).
Chasteen, A. L., Kang, S. K., & Remedios, J. D. (2012). *Aging and stereotype threat: Development, process, and interventions*.
Dario, P., Guglielmelli, E., Laschi, C., & Teti, G. (1999). MOVAID: A personal robot in everyday life of disabled and elderly people. *Technology and Disability, 10*(2), 77–93.
Dautenhahn, K. (2004). Robots we like to live with! A developmental perspective on a personalized, life-long robot companion. *Procs 13th IEEE Int workshop on robot and human interactive communication* (RO-MAN).
Dautenhahn, K., Woods, S., Kaouri, C., Walters, M. L., Koay, K. L., & Werry, I. (2005, August). What is a robot companion-friend, assistant or butler? *Intelligent robots and systems, 2005.(IROS 2005). 2005 IEEE/RSJ international conference on* (pp. 1192–1197). IEEE.
Ezer, N., Fisk, A. D., & Rogers, W. A. (2009, July). Attitudinal and intentional acceptance of domestic robots by younger and older adults. *International conference on universal access in human-computer interaction* (pp. 39–48). Berlin, Heidelberg: Springer.
Fang, Y. M., & Chang, C. C. (2016). Users' psychological perception and perceived readability of wearable devices for elderly people. *Behaviour & Information Technology, 35*(3), 225–232.
Frennert, S., Eftring, H., & Östlund, B. (2013, October). What older people expect of robots: A mixed methods approach. *International conference on social robotics* (pp. 19–29). Cham: Springer.
Frennert, S., & Östlund, B. (2014). Seven matters of concern of social robots and older people. *International Journal of Social Robotics, 6*(2), 299–310.
Frennert, S., Östlund, B., & Eftring, H. (2012, October). Would granny let an assistive robot into her home? *International conference on social robotics* (pp. 128–137). Berlin, Heidelberg: Springer.
Gibbs, G. R. (2007). *Thematic coding and categorizing. Analyzing qualitative data.* London: Sage.
Giuliani, M. V., Scopelliti, M., & Fornara, F. (2005, August). Elderly people at home: Technological help in everyday activities. *Robot and human interactive communication, 2005. ROMAN 2005. IEEE international workshop on* (pp. 365–370). IEEE.
Gomez, R., Szapiro, D., Galindo, K., & Nakamura, K. (2018, February). Haru: Hardware design of an experimental tabletop robot assistant. *Proceedings of the 2018 ACM/IEEE international conference on human-robot interaction* (pp. 233–240). ACM.
Google Inc. (n.d.). Google home specifications. Retrieved from: https://support.google.com/googlehome/answer/7072284?hl=en/Accessed 16 March 2018.
Graf, B., Hans, M., & Schraft, R. D. (2004). Care-O-bot II—development of a next generation robotic home assistant. *Autonomous Robots, 16*(2), 193–205.
Hartson, R., & Pyla, P. (2012). *The UX book: process and guidelines for ensuring a quality user experience.* Waltham: Elsevier.
Havighurst, R. J. (1963). Successful aging. *Processes of agingSocial and psychological perspectives, 1*, 299–320.
Heerink, M., Kröse, B., Evers, V., & Wielinga, B. (2010). Assessing acceptance of assistive social agent technology by older adults: The almere model. *International journal of social robotics, 2*(4), 361–375.
Hirsch, T., Forlizzi, J., Hyder, E., Goetz, J., Kurtz, C., & Stroback, J. (2000, November). The ELDer project: Social, emotional, and environmental factors in the design of eldercare technologies. *Proceedings on the 2000 conference on universal usability* (pp. 72–79). ACM.
Hoffman, G. (2016). March). Openwoz: A runtime-configurable wizard-of-oz framework for human-robot interaction. *2016 AAAI spring symposium series*.
Hoffman, G., & Ju, W. (2014). Designing robots with movement in mind. *Journal of Human-Robot Interaction, 3*(1), 91–122.
Hoffman, G., Zuckerman, O., Hirschberger, G., Luria, M., & Shani Sherman, T. (2015, March). Design and evaluation of a peripheral robotic conversation companion. *Proceedings of the tenth annual ACM/IEEE international conference on human-robot interaction* (pp. 3–10). ACM.
Ho, C. C., MacDorman, K. F., & Pramono, Z. D. (2008 March). Human emotion and the uncanny valley: A GLM, MDS, and isomap analysis of robot video ratings. *Human-robot interaction (HRI), 2008 3rd ACM/IEEE international conference on* (pp. 169–176). IEEE.
Huang, E. M., & Truong, K. N. (2008 April). Breaking the disposable technology paradigm: Opportunities for sustainable interaction design for mobile phones. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 323–332). ACM.
Hudson, J., Orviska, M., & Hunady, J. (2017). People's attitudes to robots in caring for the elderly. *International Journal of Social Robotics, 9*(2), 199–210.
Hutson, S., Lim, S. L., Bentley, P. J., Bianchi-Berthouze, N., & Bowling, A. (2011, October). Investigating the suitability of social robots for the wellbeing of the elderly. *International conference on affective computing and intelligent interaction* (pp. 578–587). Berlin, Heidelberg: Springer.
Intuition robotics, Ltd. (n.d.). ElliQ. Retrieved from: https://elliq.com.
Jeste, D. V., Savla, G. N., Thompson, W. K., Vahia, I. V., Glorioso, D. K., Martin, A. V. S., ... Depp, C. A. (2013). Association between older age and more successful aging: Critical role of resilience and depression. *American Journal of Psychiatry, 170*(2), 188–196.
Kidd, C. D., Taggart, W., & Turkle, S. (2006, May). A sociable robot to encourage social interaction among the elderly. *Robotics and automation, 2006. ICRA 2006. Proceedings 2006 IEEE international conference on* (pp. 3972–3976). IEEE.
Kujala, S., Kauppinen, M., & Rekola, S. (2001). Bridging the gap between user needs and user requirements. *Advances in Human-Computer Interaction, I*, 45–50.
Lee, M. K., Forlizzi, J., Rybski, P. E., Crabbe, F., Chung, W., Finkle, J.,., & Kiesler, S. (2009, March). The snackbot: Documenting the design of a robot for long-term human-robot interaction. *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction* (pp. 7–14). ACM.
Lee, H. R., & Riek, L. D. (2018). Reframing assistive robots to promote successful aging. *ACM Transactions on Human-Robot Interaction (THRI), 7*(1), 11.
Lee, H. R., Šabanović, S., Chang, W. L., Nagata, S., Piatt, J., Bennett, C., et al. (2017, March). Steps toward participatory design of social robots: Mutual learning with older adults with depression. *Proceedings of the 2017 ACM/IEEE international conference on human-robot interaction* (pp. 244–253). ACM.
Lee, H. R., Tan, H., & Šabanović, S. (2016, August). That robot is not for me: Addressing stereotypes of aging in assistive robot design. *Robot and human interactive communication (RO-MAN), 2016 25th IEEE international symposium on* (pp. 312–317). IEEE.
Lehmann, H., Saez-Pons, J., Syrdal, D. S., & Dautenhahn, K. (2015). In good company? Perception of movement synchrony of a non-anthropomorphic robot. *PLoS One, 10*(5), e0127747.
Lowsky, D. J., Olshansky, S. J., Bhattacharya, J., & Goldman, D. P. (2013). Heterogeneity in healthy aging. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 69*(6), 640–649.
Luria, M., Hoffman, G., Megidish, B., Zuckerman, O., & Park, S. (2016, August). Designing Vyo, a robotic Smart Home assistant: Bridging the gap between device and social agent. *Robot and human interactive communication (RO-MAN), 2016 25th IEEE international symposium on* (pp. 1019–1025). IEEE.
Martelaro, N. (2016, March). Wizard-of-oz interfaces as a step towards autonomous hri. *2016 AAAI spring symposium series*.
Martelaro, N., & Ju, W. (2017, February). WoZ Way: Enabling real-time remote interaction prototyping & observation in on-road vehicles. *Proceedings of the 2017 ACM conference on computer supported cooperative work and social computing* (pp. 169–182). ACM.
Martelaro, N., & Ju, W. (2019). The needfinding machine. *Social internet of things* (pp. 51–84). Cham: Springer.
Mashav-JCD (2015). *Health characteristics of adults aged 65+ and patterns of use of selected health services.* Retrieved from http://mashav.jdc.org.il/?pg=MashabSearch&CategoryID=231/, Accessed date: 12 December 2018.
Mast, M., Burmester, M., Berner, E., Facal, D., Pigini, L., & Blasi, L. (2010). Semi-autonomous teleoperated learning in-home service robots for elderly care: A qualitative study on needs and perceptions of elderly people, family caregivers, and professional caregivers. *20th international conference on robotics and mechatronics* Varna, Bulgaria, October 1-6.
Mast, M., Burmester, M., Krüger, K., Fatikow, S., Arbeiter, G., Graf, B.,., & Qiu, R. (2012). User-centered design of a dynamic-autonomy remote interaction concept for manipulation-capable robots to assist elderly people in the home. *Journal of Human-Robot Interaction, 1*(1), 96–118.
McCreadie, C., & Tinker, A. (2005). The acceptability of assistive technology to older people. *Ageing and Society, 25*(1), 91–110.
Misselhorn, C., Pompe, U., & Stapleton, M. (2013). Ethical considerations regarding the use of social robots in the fourth age. *The Journal of Gerontopsychology and Geriatric Psychiatry, 26*(2), 121–133.
Mitzner, T. L., Boron, J. B., Fausset, C. B., Adams, A. E., Charness, N., Czaja, S. J., ... Sharit, J. (2010). Older adults talk technology: Technology usage and attitudes. *Computers in Human Behavior, 26*(6), 1710–1721.
Moon, A., Danielson, P., & Van der Loos, H. M. (2012). Survey-based discussions on morally contentious applications of interactive robotics. *International Journal of Social Robotics, 4*(1), 77–96.
Mutlu, B., & Forlizzi, J. (2008, March). Robots in organizations: The role of workflow, social, and environmental factors in human-robot interaction. *Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction* (pp. 287–294). ACM.
Mynatt, E. D., Melenhorst, A. S., Fisk, A. D., & Rogers, W. A. (2004). Aware technologies for aging in place: Understanding user needs and attitudes. *IEEE Pervasive Computing, 3*(2), 36–41.
Nichols, A. L., & Maner, J. K. (2008). The good-subject effect: Investigating participant demand characteristics. *The Journal of General Psychology, 135*(2), 151–166.
Obaid, M., Barendregt, W., Alves-Oliveira, P., Paiva, A., & Fjeld, M. (2015, October). Designing robotic teaching assistants: Interaction design students' and children's views. *International conference on social robotics* (pp. 502–511). Cham: Springer.
Opdenakker, R. (2006, September). Advantages and disadvantages of four interview techniques in qualitative research. *Forum qualitative sozialforschung/forum: Qualitative social research: Vol. 7* 4.
Pantofaru, C., & Takayama, L. (2011). Need finding: A tool for directing robotics research and development. *RSS 2011 Workshop on perspectives and contributions to robotics from the human sciences*.
Patnaik, D., & Becker, R. (1999). Needfinding: The why and how of uncovering people's needs. *Design Management Journal, 10*(2), 37–43.
Prakash, A., Kemp, C. C., & Rogers, W. A. (2014, March). Older adults' reactions to a

robot's appearance in the context of home use. *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction* (pp. 268–269). ACM.
Ribeiro, T., & Paiva, A. (2012, March). The illusion of robotic life: Principles and practices of animation for robots. *Proceedings of the seventh annual ACM/IEEE international conference on Human-Robot Interaction* (pp. 383–390). ACM.
Riek, L. D. (2017). Healthcare robotics. *Communications of the ACM, 60*(11), 68–78.
Robinson, H., MacDonald, B., & Broadbent, E. (2014). The role of healthcare robots for older people at home: A review. *International Journal of Social Robotics, 6*(4), 575–591.
Rowe, J. W., & Kahn, R. L. (1987). Human aging: Usual and successful. *Science, 237*(4811), 143–149.
Rutkowska, J., Lamas, D., Visser, F. S., Wodyk, Z., & Bańka, O. (2017). Shaping loyalty: Experiences from design research practice. *Interactions, 24*(3), 60–65.
Scanaill, C. N., Carew, S., Barralon, P., Noury, N., Lyons, D., & Lyons, G. M. (2006). A review of approaches to mobility telemonitoring of the elderly in their living environment. *Annals of Biomedical Engineering, 34*(4), 547–563.
Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., et al. (2013). Toward a second-person neuroscience 1. *Behavioral and Brain Sciences, 36*(4), 393–414.
Sequeira, P., Alves-Oliveira, P., Ribeiro, T., Di Tullio, E., Petisca, S., Melo, F. S., ... Paiva, A. (2016, March). Discovering social interaction strategies for robots from restricted-perception Wizard-of-Oz studies. *The eleventh ACM/IEEE international conference on human robot interaction* (pp. 197–204). IEEE Press.
Shamsuddin, S., Ismail, L. I., Yussof, H., Zahari, N. I., Bahari, S., Hashim, H., et al. (2011, November). Humanoid robot NAO: Review of control and motion exploration. *Control system, computing and engineering (ICCSCE), 2011 IEEE international conference on* (pp. 511–516). IEEE.
Smarr, C. A., Mitzner, T. L., Beer, J. M., Prakash, A., Chen, T. L., Kemp, C. C., et al. (2014). Domestic robots for older adults: Attitudes, preferences, and potential. *International journal of social robotics, 6*(2), 229–247.
Sofaer, S. (1999). Qualitative methods: What are they and why use them? *Health Services Research, 34*(5 Pt 2), 1101.
Super, N. (2002). *Who will be there to care? The growing gap between caregiver supply and demand*.
Syrdal, D. S., Dautenhahn, K., Koay, K. L., Walters, M. L., & Ho, W. C. (2013, October). Sharing spaces, sharing lives–the impact of robot mobility on user perception of a home companion robot. *International conference on social robotics* (pp. 321–330). Cham: Springer.
Takayama, L., Dooley, D., & Ju, W. (2011, March). Expressing thought: Improving robot readability with animation principles. *International conference on human-robot interaction (HRI), 2011 6th ACM/IEEE* (pp. 69–76). IEEE.
Tapus, A., Tapus, C., & Mataric, M. J. (2007, April). Hands-off therapist robot behavior adaptation to user personality for post-stroke rehabilitation therapy. *Robotics and automation, 2007 IEEE international conference on* (pp. 1547–1553). IEEE.
Wang, P., Sibi, S., Mok, B., & Ju, W. (2017, March). Marionette: Enabling on-road wizard-of-oz autonomous driving studies. *Proceedings of the 2017 ACM/IEEE international conference on human-robot interaction* (pp. 234–243). ACM.
Willow Garage, Inc. (n.d.). The PR2 robot. Retrieved from: http://www.willowgarage.com/pages/pr2/overview/Accessed 16 March 2018.
Woods, S. N., Walters, M. L., Koay, K. L., & Dautenhahn, K. (2006, September). Methodological issues in HRI: A comparison of live and video-based methods in robot to human approach direction trials. *ROMAN 2006-the 15th IEEE international symposium on robot and human interactive communication* (pp. 51–58). IEEE.
World Health Organization (2016). *World health statistics 2016: Monitoring health for the SDGs sustainable development goals.* Retrieved from: http://www.who.int/gho/publications/world_health_statistics/2016/en/, Accessed date: 4 February 2018.
Wu, Y. H., Fassert, C., & Rigaud, A. S. (2012). Designing robots for the elderly: Appearance issue and beyond. *Archives of Gerontology and Geriatrics, 54*, 121–126.
Young, J. E., Hawkins, R., Sharlin, E., & Igarashi, T. (2009). Toward acceptable domestic robots: Applying insights from social psychology. *International Journal of Social Robotics, 1*(1), 95.
Zaga, C., de Vries, R. A., Li, J., Truong, K. P., & Evers, V. (2017, May). A simple nod of the head: The effect of minimal robot movements on children's perception of a low-anthropomorphic robot. *Proceedings of the 2017 CHI conference on human factors in computing systems* (pp. 336–341). ACM.