Reframing Assistive Robots to Promote Successful Aging

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We are living in an exciting time, as people are living longer, active lives. This is reshaping how we think about aging. Rather than viewing aging as a problem to be fixed (i.e., a deficit model of aging), many aging researchers are viewing aging as a developmental stage of life to be celebrated and supported, i.e., "successful aging." In this paper, we embrace this approach and consider it in the context of assistive robot design, in an aim to steer the conversation away from deficit models that have limited robot design possibilities. To explore an alternative design approach to the study of aging in HRI, we invited five aging researchers (three geriatricians, one gerontologist, and one epidemiologist), and nine older adults to participate in our research. In the study, participants illustrated their interpretations of aging and suggested potential assistive robots. We found that while all participants perceived the importance of potential disabilities due to aging, they considered potential disabilities as only one aspect of the experience of aging. They highlighted other key themes to consider in designing robots to support successful aging such as older adults' autonomy and resilience. We discuss these findings for the HRI community and call for "robots for successful aging."

CCS Concepts: • **Computer systems organization → Robotics**;

Additional Key Words and Phrases: Successful aging, healthcare robotics, assistive robots, participatory design

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1 INTRODUCTION

Due to an increase in life expectancy and a decrease in the fertility rate, population aging has become an important social issue [6, 76]. As the baby boomer generation (born after World War II) reached age 65 in 2012, people over 65 began to outnumber their younger cohorts. The UN reported that those aged 60 and over will make up 25 percent of the population in North America and Europe by 2030 [76]. Because of considerable changes in population age structure, the UN suggested that governments design policies to support possible issues older adults will face (e.g., housing, employment, health care, social protection).

Policy makers and other government officials have looked to robots as one means to address issues the aging population faces, and many researchers in the robotics community have explored the use of assistive robots for older adults [10, 22, 58, 62, 75]. However, despite decades of assistive robotics research yielding a range of research prototypes and commercial products, older adults rarely adopt assistive robots in their lives [26, 29, 66].

HRI researchers have identified several reasons behind the low adoption rate of assistive robots. First, current assistive robots are too difficult for older adults to use, and are not well-suited to the

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environments they are deployed in [62, 66]. Second, poorly-designed hardware hinders older adults' adoption of robots since people do not want to look strange or stand out by using strange-looking technologies [62]. Third, many older adults have negative reactions towards assistive robots due to the fact that the framing of technology tends to present stigmatized or stereotyped images of aging. For example, assistive robotics research on the whole tends to negatively describe aging as a problem and to foreground older adults' potential disabilities. Older adults tend to react negatively to this framing [46, 53, 79].

To increase the acceptance of assistive robots, researchers have employed user-centered research approaches that invite older adults into the assistive robot design and evaluation process [9, 15, 23, 78]. As older adults become more involved in the research process, they have had more opportunities to express their perspectives on aging. The integration of their voices has the potential to increase the acceptance of assistive robots.

However, a majority of these studies to date continue to follow a deficit model of aging, and tend to focus on older adults' potential disabilities [66]. A *deficit model of aging* characterizes the normative course of aging as a series of losses [7]. This framing tends to restrict the design possibilities for robots. For example, two of the most dominant types of existing assistive robots have either semi-humanoid or zoomorphic appearances, and are intended to fill service or companionship roles [14]. However, there are a plethora of other possible morphologies and roles for robots in the lives of older adults which remain underexplored [62]. While the previous articles have critiqued how assistive robot designs reflect aging as a problem to fix, they have not yet suggested alternate design possibilities for design [46, 53, 79].

In this paper, we explore an alternative design approach to the study of aging in HRI. Rather than following a deficit model, we explore how a *social model of aging* (from sociology) and a *successful model of aging* (from gerontology) could be reflected in assistive robots for aging [5, 33]. As a critique to the clinical model of disability, sociologists suggested employing a social model of disability, which argues that disability is caused by a society rather than by individuals' biological impairments. This approach has been largely used to address public health policies for people with disabilities. Also, we employ a multifactorial model of successful aging, which contains interrelated components such as physical functions, social engagement, and self-confidence [33] Both approaches define aging as holistic experiences with multidimensional factors.

To uncover alternative views on aging in the context of HRI, we invited key stakeholders to engage in assistive robot design research with us. These included five aging researchers (three geriatricians, a clinical psychologist, and an epidemiologist), as well as nine older adults. We began by asking stakeholders to describe their understanding of aging from their own perspective. After participants defined the meaning of aging from their own perspectives, they envisioned possible robot designs for aging interpreted (see Section 3). Throughout the interviews, we found that all participants perceived potential disabilities as important issues related to the experience of aging; however, at the same time, they were only one aspect of aging and should not be a sole defining factor. The participants suggested alternative roles and functions for robots, such as robots that provide sympathy and active listening, robots that are personalizable, and robots that support an older adult's existing ability (see Section 4).

When the participants framed their aging experience and envisioned robots for aging, they followed social and successful models of aging rather than a deficit model of aging. The participants described older adults as people who have their abilities and robots as supporters which strengthen older adults' existing abilities. The participants did not represent older adults as people who are loosing their abilities due to aging and need help to fix what they have lost. Social and successful models of aging were reflected as a new design theme from the participants' framings. Considering this new view on aging, assistive robots might not be the right framing for studies investigating

aging in HRI since "assisitive" robots imply that the robots' goal is providing assistance and represent older adults as people who need to fix aging-relate problems (see Section 5). As a conclusion, we call for robotics researchers to consider "robots for successful aging" as an alternative frame to study aging in HRI.

2 BACKGROUND

2.1 Assistive robots in HRI

In this section, we explain 1) how assistive robots for older adults emerged in HRI, 2) how assistive robots aim to tackle the potential declines of older adults, and 3) how "aging in place" became the prevailing paradigm of assistive robots.

Socially Assistive Robots (SARs) stimulated the growth of assistive robotics research for older adults in HRI [20, 75]. In contrast to physically assistive robots (e.g., smart wheelchairs [68, 71]), SARs were designed for social interaction with humans. Older adults became a popular user population for SARs since the exponentially increasing older adult population was expected to cause insufficient numbers of formal and informal caregivers [20, 75]. In this framing, older adults were often considered a societal burden, and they were personified as people with potential declines. Considering this continued representation, existing assistive robots are often designed to fix or compensate for decline, across physical, cognitive, and/or psychosocial dimensions [66]. We describe these compensatory framings below.

Physical compensation: A number of assistive robots aim to alleviate physical declines, which refer to older adults' ability to manage their bodies (e.g., mobility) and to perform their daily tasks (e.g., bathing, cooking, eating). Other systems aim to act in a preventative fashion, such as to help avoid falls, which causes thousands of fatal and debilitating injuries per year [62]. As technical solutions for physical decline compensation, HRI researchers developed assistive robots such as Hobbit [21] and Care-o-bot [35] that perform various daily tasks (e.g., fetch and carry, fall monitoring). These robots are also known as service robots since their semi-humanoid bodies (e.g., robotic arms) perform various tasks in older adults' homes [14, 35].

Cognitive compensation: HRI researchers have explored how assistive robots might compensate for cognitive impairments, including mild memory loss [27, 28] to more severe forms of dementia [49]. Assistive robots have been used to provide support for medication management, making appointments, and supporting cognitive wellness through daily interactions [28, 61, 67, 74]. Companion-type robots such as Paro (a zoomoprhic robotic seal) have been used to perform non-pharmaceutical interventions for people with dementia (e.g., calming patients down without medication) [49]. It is worth noting that there is a paucity of strong clinical evidence to demonstrate if these interventions are effective [61, 62].

Psychosocial compensation: Loneliness and social isolation are two problems faced by older adults, and can exacerbate the negative experiences of physical, behavioral, and cognitive changes with age [70]. Two types of robots are frequently discussed in the literature to provide psychosocial compensation: companion robots (e.g., Paro and iCat [30]) and telepresence robots (e.g., Ed and MRP [10, 11]). Assistive robot studies investigating support for psychosocial changes have particularly focused on a robot's social presence or agency.

2.2 User centered approaches for assistive robot design

As previously discussed, HRI researchers have developed a number of assistive robots based on their understanding of older adults. However, older adults have not adopted these robots as researchers expected [13, 22, 26]. The narrow market of assistive robots may be contributing to older adults' low acceptance of the robots, or it may be due to the level of technical complexity and poor usability of robots. While researchers have discussed the adoptability issue, there is a lack of detailed analysis as to the reasons.

To understand the aging experience of older adults, researchers often employed human-centered research approaches. In the studies, older adults gain more opportunities to explain their ideas about assistive robot designs and play a more active role in assistive robotics research. For example, Beer et al. [9] conducted a needs assessment with older adults that aimed to understand how older adults wanted robots in their homes to assist them (e.g., cleaning, fetching and organizing). They introduced a PR2 robot to participants, and described its functions. After that, older adults discussed what tasks the PR2 could perform in their homes.

Caleb-Solly et al. [15] performed robot design workshops with older adults, and asked them about possible designs and tasks which could be built into domestic service robots. Inspired by cultural probes [24], the researchers conducted an open-ended study to incorporate older adults' perspectives more actively.

Lee et al. [42] employed a participatory design approach that allowed older adults to be co-designers in the assistive robot development process. The older adult participants not only expressed their ideas about robots, but they also influenced the researchers to alter their research process. For example, the researchers originally planned to add more technical components (such as sensors) in their workshops. However, the researchers changed their plans when participants expressed concerns about the potential difficulties of working with technical robot components.

2.3 Critical perspectives toward aging: moving beyond declines

Recent literature suggests that HRI researchers' tendency to negatively frame aging contributes to older adults' limited acceptance of assistive robots [46, 53, 79]. The studies conducted in-depth interviews with older adults about existing assistive robots, and commonly asked whether "you" (the participants themselves) would use the robots. Although older adults reported that the robots would be useful for someone else, they rejected the robots for themselves. The researchers argued that older adults felt stigmatized because assistive robot designs depicted older adults as people with disabilities.

The authors suggested that HRI researchers critically examine their assumptions about older adults and whether they considered older adults as people with disabilities. As the studies discussed, from the older adults' perspectives, their impairments can be considered just one aspect of their lives [46]. Along with implying HRI researchers embrace a social model of aging, this framing also suggests improving their cultural competency in thinking about disability (e.g., a person is more than their disability) [19].

Researchers' negative perspectives toward older adults and aging have been investigated outside HRI in fields such as sociology, gerontology, and HCI. The studies commonly point out the existing emphasis on a deficit model of aging, which interprets aging as a process of losses [7] and problematizes aging bodies [34, 36, 39, 77]. Similar to the deficit model of aging, the clinical model of disability also problematizes disabled bodies and considers the bodies as problems to be fixed [33]. As a critique to the clinical model of disability, sociologists suggested employing a social model of disability, which argue that disability is caused by a society rather than by individuals' biological impairments [59]. For example, people with wheelchairs feel disabled when moving around a city

not because of their biological conditions but because public infrastructure was designed without considering wheelchairs.

In HCI, researchers scrutinized previous notions of aging within assistive technology studies and found that HCI researchers also followed a deficit model of aging. They critiqued how assistive technology designs reflect negative perspectives on older adults [39, 77]. Vines et al. [77] analyzed how aging has been stigmatized and problematized in assistive technology studies through meta-analysis of previous HCI literature. Lazer et al. [39] critiqued existing notions of aging, particularly dementia, as a problem in assistive technology research and suggested adopting critical perspectives toward dementia.

In this paper, we explore alternative ways to frame aging in assistive robotics. In particular, we aim to avoid a deficit model of aging and a clinical model of disability. These models explain aging as a process of losses. We define aging as a natural, developmental stage of life. As part of this process, people will experience age-related changes. In some cases, chronic or severe health conditions could result in impairment (problems in body functions or structure [55]) or disability (consequences of impairment in terms of functional activities [55]) within the process. However, age-related changes do not always indicate disability or impairment. This paper sheds light on aspects of aging less discussed in the literature such as how older adults can be resilient to changes related to aging or how they can maintain their autonomy. We uncover these concepts by employing a human-centered research approach which helps us learn about aging from our participants' perspectives. Also, we investigate alternative robot designs for aging developed based on our participants' interpretation of aging.

3 PARTICIPANTS AND METHODS

3.1 Participants

We included two types of participants in our research: older adults and aging researchers (e.g., geriatricians). Older adults are key stakeholders since they are the primary users of assistive robots, and are themselves experiencing aging. We invited aging researchers to understand the multifaceted aspects of aging. In particular, we were curious how aging researchers avoid stigma and negative interpretations of aging when they deliver care to older adults or include them in research.

We carefully interpreted the two perspectives of older adults and aging researchers. Through our analysis process, we tried to avoid valuing aging researchers' perspectives more than older adults' perspectives, as aging researchers are often considered to be more qualified knowledge makers. For example, when conducting our data analysis, we investigated how the two perspectives are related to each other instead of examining whose perspective is more accurate for explaining aging. It is important to scrutinize the relationship between the perspectives, in order to avoid ignoring the perspectives of those who tend to be marginalized in research (such as people with disabilities) [8, 18, 61, 62, 65, 73].

To represent our participants as distinct individuals in our data analysis, we assigned each participant a pseudonym rather than assigning an impersonal code name (e.g., p1 or p2). We chose these pseudonyms by searching for popular names from the year that participants were born, e.g., based on US Social Security records [69]. Pseudonyms helped us represent our participants as actual individuals with their own voices and perspectives based on their experiences.

3.1.1 Older adults.

We recruited nine older adults through snowball sampling, local events, and word of mouth. Six older adults were from a Midwest town in the US and three from Southern California. Their ages ranged from 62 to 85 years old (mean age = 69 years old). Five participants were female and four were male, all were Caucasian.

All participants were retired. Two participants live in independent living facilities [51] and seven live in their own homes. Four participants live alone and five participants live with either partners or spouses. Four participants stated they were experiencing gradual changes in their cognitive abilities (e.g., memory loss), but all participants were cognitively capable to consent to the study. One participant had a physical impairment, and had difficulties moving half of their body.

We adhered to IRB best practices when collecting health-related information. Participants could offer this information or not as they wished. Older adult participants shared such information of their own free will throughout the design process.

3.1.2 Aging researchers.

We recruited three geriatricians with MDs, one clinical psychologist with a PhD, and one epidemiologist with a PhD. All five researchers are affiliated with an aging research unit at a US-based medical school. Three geriatricians are primary care physicians, and one is a geriatric psychologist. The aging researchers have either practiced or studied for 15 to 30 years, and all have served as faculty. Their ages ranged from 46 to 76 years old (mean age = 58 years old). Three participants were female and two were male.

In their own research, several of the aging researchers investigate holistic approaches for aging, as an alternative to the deficit model of aging. For example, several investigate the role of community in aging, and also explore positive aspects of aging like gaining wisdom.

3.2 Methods

Since we are exploring alternative approaches to reframe aging in HRI, we aim to understand how participants frame aging from their own perspectives. To uncover how participants frame aging, we employed collaborative design methodologies [40, 43]. These provide comprehensive methodological tools including: means for understanding participants' situations, techniques to examine existing technologies, and methods for envisioning alternative technologies. In particular, the methodologies allow participants to have power to address their ideas rather than passively answer questionnaires developed by researchers. We employed three collaborative methods: collaborative map making [47] for understanding participants' interpretation of aging, artifact analysis [43, 44] for reviewing existing robots, and envisioning robot design possibilities [41, 45].

Most participants (12/14) determined the interview locations, since we wanted research settings where they felt comfortable expressing their perspectives and to have active roles in research. We met aging researchers in their offices, and older adults in cafes, community centers, and their own homes.

To adapt to participant scheduling constraints, we adjusted our research processes accordingly, though maintained a consistent structure. Due to the busy schedules of the aging researchers, we could only spend 30 to 45 minutes with each of them. With the older adults, we spent 45 minutes to 2 hours. We considered this as an opportunity to understand older adults more thoroughly, considering aging researchers have had more experience academically reflecting upon aging.

3.2.1 Collaborative map making: understanding aging.

We chose collaborative map making [47] as a first step to understand how participants interpret and frame the experience of aging. Rather than developing specific questionnaires, we only provided three keywords that we were interested in to minimize our influence on participants. For the older adults, the keywords were "aging," "home," and "me" and for the aging researchers, "aging," "older adults," and "independent lives". Both "aging" and "me (or older adults)" were chosen for both groups as they are core concepts in the use of assistive robots for aging. We chose "home" for older adults and "independent lives" for aging researchers based on the concept of "aging in place" common in both the existing assistive robotics and aging research literature [21, 23, 30, 51, 80].

(a) Jibo promotional video (b) Robot picture cards

Fig. 1. Materials used in the artifact analysis.

For older adults, we provided "home" as a keyword because "aging in place" implies enabling older adults' to live in their homes as long as possible [9]. For aging researchers, we provided "independent lives" since we wanted to examine whether the research participants have the same assumptions about "aging in place" as HRI researchers.

Procedure: First, we provided three keywords to participants. We asked participants to write any words that they thought were related to the three keywords on Post-it notes (see Figure 2). After writing 6 to 15 keywords, we first asked participants to categorize the words without providing any specific rules to group them, and then we asked them to make a title for each group. After finishing categorization, participants were asked to pick one to three of the most important words in their maps. After participants finish making their maps, we asked participants to explain their maps and to illustrate how they developed their maps and how they interpreted the three keywords.

3.2.2 *Artifact analysis: reviewing existing robots.*

Artifact analysis allows participants to examine existing robots based on their own evaluation criteria so that researchers can understand participants' perspectives on robots [43, 44]. We particularly utilized artifact analysis to explore how existing robots would fit into participants' maps of aging. Since aging researchers reported that older adults should determine the appropriate appearance and functions of assistive robots, they spent less time reviewing robots.

Research materials: We prepared both videos and pictures of existing robots (see Figure 1) Since existing studies found that older adults dislike the existing assistive robots due to stereotyped representations of themselves, we included both assistive robots (e.g., Care-o-bot [60], Ri-Man [54]) and non-assistive robots (e.g., Jibo [1], AUR [31], Relay [2], WowWee MiP [4]) (see Figure 3). To avoid limiting participants' imaginations, we also provided various types of cyberphysical technologies, such as smart fridges and emergency pendants.

Procedure: After viewing pictures and videos of existing robots, participants were asked to freely express their thoughts about the robots. For example, we asked whether participants think the robot is appropriate for older adults, or whether they think the robots can support the issues discussed during collaborative map making sessions. They also were asked to choose their favorite and least favorite robot.

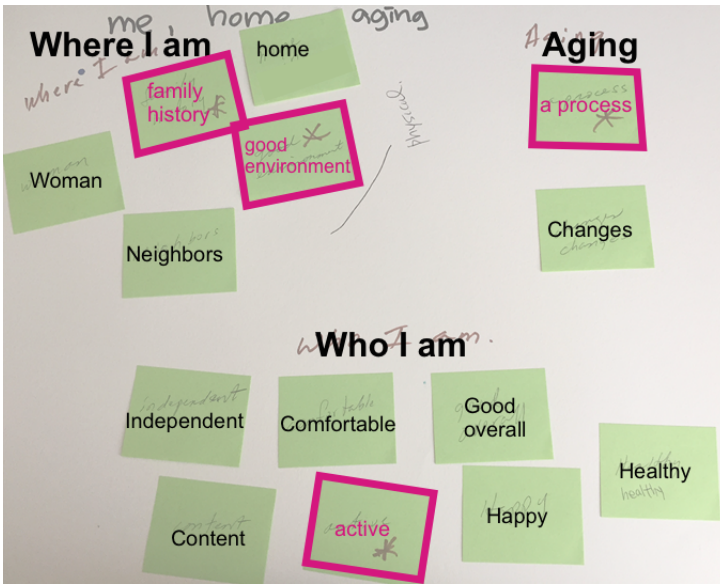

Fig. 2. Patricia's map of aging (F, Retired, 63)

Fig. 3. Tammy's artifact analysis session. (F, Geriatrician with over 20 years experience)

3.2.3 Envisioning robots for aging.

After reviewing robotic possibilities, participants went back to the map to think about possible robots that would fit their experience with aging and/or aging research. Participants explained their ideal robots for aging, and sketched robots together with us as described in work by Lee et al. [41, 45]. While sketching robots, we asked how the robots would interact with them. For example, "how does your robot report it finished the task?" or "what is the most important task that you want your robot to do?"

3.3 Analysis

We transcribed all the interviews and performed "theme-by-theme coding" following Grounded Theory [16]. Rather than examining data based on predefined hypothesis, Grounded Theory helps researchers to uncover emerging themes out of interview data. Through this bottom-up approach, we carefully analyzed participants' perspectives rather than interpret them through a deficit model of aging.

Along with the interview analysis, we also examined participants' maps of aging. Following Lee et al. [47], we analyze how each participant's map of aging can be connected to each other (e.g., how the most important words are related to each other).

4 RESULTS

4.1 Age-related changes do exist, but changes are only one aspect of aging

From the aging map making process, we learned how older adult participants understand and frame their experience with aging, as well as how research participants interpret aging. One of the most salient themes concerned the changes that older adults face through aging. However, the most important words which all participants from the two groups selected were not about the changes, but instead included ideas such as older adults' autonomy, resilience, and financial situations.

4.1.1 Aging is about maintaining older adults' existing abilities.

Aging researchers' perspectives: The most commonly used words on the aging researchers' maps of aging were about "mobility," "cognition," and "social connectedness."

All five aging researcher participants selected mobility as a keyword which explained aging, older adults, and living independently. Aging researcher participants sometimes referred to mobility as a "physical" ability or being about "maintaining function." The participants commonly related mobility to older adults' capability to perform Activities of Daily Living (ADLs); e.g., walking, toileting, dressing, feeding [37]. One research participant categorized mobility into "mobility in the home" and "mobility outside home."

Four out of five aging researcher participants also chose "cognition" as a common word to describe the keywords that we presented. The participants described cognition with words like "cognitive," "mental," "cognition," or "cognitive intactness." The researchers often connected cognition to ability to perform Instrumental Activities of Daily Living (IADLs); e.g., managing medications and finances, managing transportation, shopping, meal preparation.

"Social connectedness" was one of the most commonly used words, and mentioned by all aging researchers. They used words such as "connections," "social supports," or "social interactions." Some researcher participants added words such as "intergenerational," "socialization," and "being able to communicate" under "social connectedness." When explaining connectedness, the connection was not just with people but also with animals.

Mobility, cognition, and social connectedness have also been similarly discussed in HRI, and a number of studies investigated robots' capabilities as a way to compensate for losses related to the three [66, 72]. Smarr et al. [72] developed possible tasks of assistive robots based on ADLs and IADLs and investigated older adults' preferences among the tasks. Begum et al. [11] evaluated tele-operated robots to support ADLs of older adults with dementia. However, in the majority of prior studies in HRI, the relationships between these three concepts have rarely been explored. In contrast, 3/4 aging researchers discussed how the three are interconnected. This concurs with the biopscyhosocial model, a philosophy in healthcare which considers health broadly, from the molecular to the social [12, 25]. Geratricians in particular are likely to be trained to consider this perspective [50]. Furthermore, they discussed these themes in terms of the crucial abilities/capabilities of older

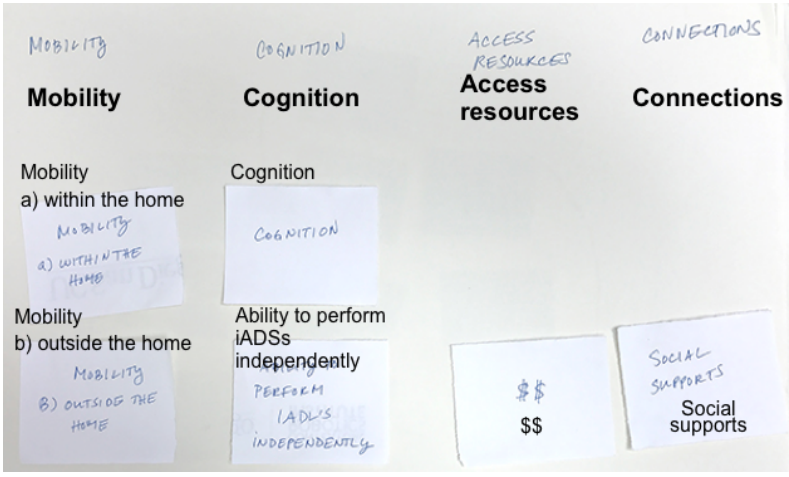

Fig. 4. Angela's map of aging (F, Geriatrician with over 20 years experience)

adults, which serves as a contrast to typical deficit-focused technological research. As Angela, an aging researcher, said:

> Even if you have none of the first three (mobility, cognition, and access [to] resources; see Figure 4), if you have social support then you may be in a sense able to live independently in the community. (F, Geriatrician with over 20 years experience)

Older adults' perspectives: Unlike aging research participants' maps, older adults' maps were diverse and used various terms to explain their situations. However, we found that all older adult participants often explained changes that they were experiencing through aging as one of the most common themes. Similar to HRI researchers' and aging researcher participants' understanding of aging, older adults pointed out their physical and cognitive changes in their aging experience.

All older adults employed words describing their physical, cognitive, and social relationship changes. Older adult participants used various terms to explain the physical changes, including "physical condition," "Exercise-use it or lose it," and "challenges." Although only two of the nine participants had considerable physical impairments, all participants described their physical changes in their bodies. Along with physical changes, some participants also mentioned their cognitive changes with the words "mild memory loss" and "mental health."

Although the older adults explained physical, cognitive, and social relationship changes in similar ways to HRI researchers and aging researchers, the older adults discussed them in a different way. They did not explain the three themes in terms of a dichotomy of ability and disability. Rather, they were explained in terms of their health condition. For example, in the map of William (M, Retired, 75), he employed the words "physical condition" and "mental health" to explain his physical and cognitive changes (see Figure 5). As any other people regardless of age, the older adults wanted to maintain their health through exercise.

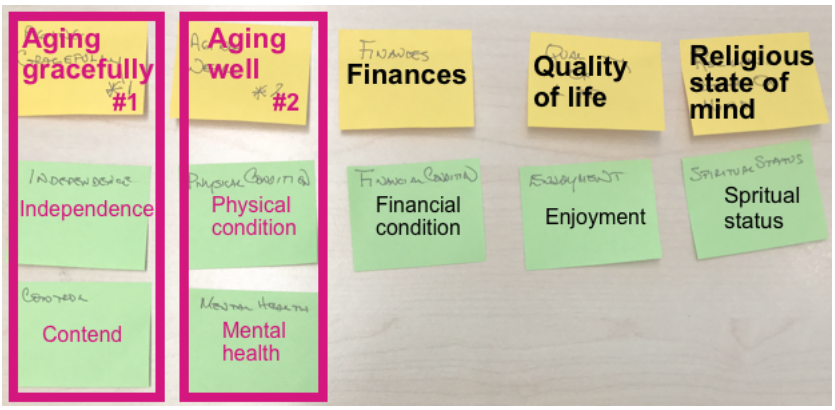

Fig. 5. William's map of aging (M, Retired, 75)

4.1.2 Different aspects of aging other than potential changes.
Importance of resilience when facing changes: Although potential physical, cognitive, and psychosocial losses were discussed as meaningful words for aging, both aging researchers and older adult participants addressed the importance of resilience.

Two of the five aging researchers commonly addressed how older adults' capability to be resilient through the changes of aging is crucial. They said that people have misconceptions about disabilities, and might believe that people with severe changes would not be as happy as they were before. However, some argued that this is not always true, as Scott (M, clinical psychologist with over 15 years experience) said:

> A lot of times people associate disability directly with quality of life. For example, if you are suddenly in a wheelchair, one would assume your quality of life goes down. A lot of people with wheelchairs do fine because they are *resilient*, they compensate, they can continue on doing the things they want to do.

As described in the map in Figure 6, Scott considered adaptability to be more important than capacity or disability. He explained that the map shows how disability could be filtered through adaptability in older adults and how older adults can maintain their quality of life even with disabilities.

Similarly, Arvind, a geriatric psychiatrist, argued that disability does not always refer to ruining a perfectly healthy life. He (M, a geriatric psychiatrist) said:

> [The person] might be a perfectly healthy person. Perfectly physically and cognitively healthy, but the person might be depressed. That is not good. On the other hand, a person with a disability... like someone with a wheelchair may be a very happy person.

The aging researcher participants' arguments resonated with older adult participants' attitudes towards their physical and cognitive impairments. As described previously, all older adult participants mentioned that they were experiencing physical and cognitive changes. However, those changes do not entirely determine who they are as people, although they describe that the changes are not very pleasant experiences. For example, one of our participants with considerable physical impairments said that realistically accepting who she is helps her continue to be happy, which is important to her.

Older adults' autonomy supporting their independence: Similar to the importance of resilience over potential disabilities in aging, Tammy, a research participant, argued for the importance of

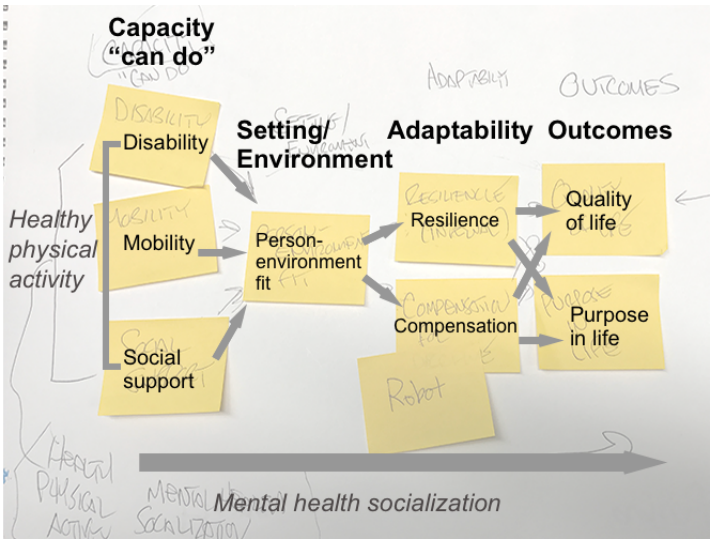

Fig. 6. Scott's map of aging (M, clinical psychologist over 15 years experience)

"autonomy" and "choice" to maintain older adults' independence. In her map of aging, Tammy (F, Geriatrician with over 20 years experience) marked "independence" as the most important word and that it encompasses two words, "autonomy" and "choice" (See Figure 7). She explained independence in her map as follows:

> "Being independent" means they are able to have a choice where they live and how they live. And do the things they want to do, which over time, that can really change. And so... that's what this is about.

When she described the meaning of independence, she mentioned how her 85-year-old father had a choice to determine wherever he wanted to live. She explained that independence is not just about staying at home as long as possible, but it is more about older adults autonomously making their decisions.

The geriatrician participant's definition of independence was also reflected in one of our older adult participants' experiences moving out from her own home to an independent living facility. In her map, the participant explained how fortunate she is, since she can still enjoy her life at the age of 85. When asked her about her transitioning from the previous home to her current one, she said that she moved because of her knee surgery. We asked whether she would stay in her previous place if she could manage herself with her ideal domestic robot. She answered:

> No, I like it here better than living alone. Don't think a robot would help... There's more going on here. Lots of good people to socialize with. Good, healthy food. Lots of exercise classes and intellectual stimulation. Cleaning lady once a week. Movies 4-5 times a week. Maintenance taken care of. Medical care available, limited but 24/7. Much more lively, safe, and healthy than living alone (Barbara, F, Retired, 85).

Although Barbara said that the transition was not very easy, her answer to our question shows how the current understanding of independence in HRI is limited.

Currently, following the focus of "aging in place," a majority of assistive robots are service robots that aim to help older adults stay in their homes. In a number of studies, being independent indicates staying in the home, which can certainly be a factor in older adults realizing independence. However,

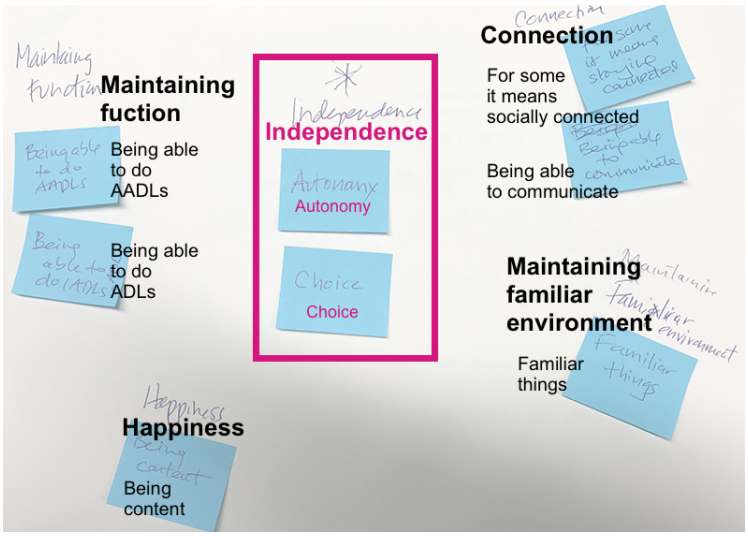

Fig. 7. Tammy's map of aging. (F, Geriatrician with over 20 years experience)

staying in the home as long as possible might not be the only way to maintain an independent life. What is more important than staying in the home is whether older adults can make choices and have the power to decide what they want to do.

Importance of one's financial situation: Three of the five aging researcher participants addressed the importance of financial conditions in aging. One of the aging researcher participants compared robots to medicine, and other resources for older adults, to argue the importance of considering the financial situations of older adults. She said:

> It's totally important because no matter where you go, everything is driven by money. So... that's why we can offer great access and things to help older people, but if they can't pay for it, it won't make any difference. We already have problems with drugs. Or physical therapy or home health physical therapy... occupational therapy, getting them meals, getting them eyeglasses, getting them dental care. All of that so... doing fancy robotics might not make any impact because there are limited resources (Angela, F, Geriatrician with over 20 years experience).

Most of the older adult participants talked about their financial situation as one of the most important components for aging. Since all older adults were retired, they did not have regular income in most cases. As the participants experienced physical and cognitive changes, they needed medicine and other resources accordingly. The map of aging (see Figure 8) developed by one of the older adults shows how funds are critical in her life. Her shortage of "funds" (a word from Jean's map, see Figure 8) fuels her most serious "fears" (a word from Jean's map, see Figure 8) rather than her having an incurable disease, which might take her voice away sometime soon.

The financial situations of older adults have rarely been reflected in the design of assistive robots. This may be due to various reasons (e.g., robot materials are expensive, robotics researchers are not concerned about bringing products to market, etc). However, this is problematic, as the cost of robotics technology greatly affects the likelihood that it will be adopted and used [62], and many older adults face difficulty meeting their basic needs. When designing assistive robots, it is important to not only consider the physical, cognitive, and social conditions of older adults, but also

Fig. 8. Jean's map of aging (F, Manager, 65)

to consider their financial situation. Other studies also addressed the importance of socio-economic situations when designing technologies [17, 57].

4.2 Reaction to existing robots for aging

4.2.1 Aging is heterogeneous.

When we showed existing robots and their potential functions to aging researcher participants, they were reluctant to express their ideas. All aging researcher participants (except one) said that we need to talk to older adults for this. Researchers said aging is a very heterogeneous experience and very robot would work for certain people. When asked whether the aging researcher participants can at least tell what the general age for older adults to use the technologies might be, Angela, a geriatrician, said:

> I've got [patients] 97 years old who would not need anything. And I've got patients 58 years old who would need wheelchairs. You can call that advanced physiological age; [it's] not necessarily about chronological age.

The research participants strongly emphasized that robot design should seriously avoid stigmatizing older adults. Three of the five researcher participants said that we should ask older adults about non-stigmatizing robot designs. The researcher participants explained that they cannot tell what is less stigmatizing because they are not older adults and have different perspectives. The researchers suggested several ways to avoid stigmatization related to the existing assistive devices. For example, three participants suggested designing "cool" looking devices. Tammy, a research participant, gave an analogous example of walking sticks to canes, and said:

> Some people refuse to use canes but they use walking sticks. And they (the walking sticks) may not be as effective as the canes in a way... but it's better than not having anything so they use walking sticks (Tammy, F, Geriatrician with more than 20 years of experience).

When explaining the meaning of "cool" designs, one participant mentioned smartphones as an example of a technology that everyone wants to have. She said:

> This (iPhone) is classic example. Everyone wears it. Everyone can't be away from it. You know. It's in part cause it does so much cool stuff. And this is relatively the right size although I broke the screen and I have a screen cover I can change. It is pretty well there wherever I go. This is of course the perfect example of some technologies that we use in our daily lives.(Tammy, F, Geriatrician with more than 20 years of experience)

The participants also suggested "customizable design" and "marketing" as additional solutions. This reflects findings from other researchers on the importance of non-stigmatizing design of technology as a key factor in its adoption [62, 65].

4.2.2 I don't like assistive robots but I might need a little help as everyone does.

The previous studies argued that stereotyped representations of older adults reflected in assistive robot design can cause older adults to have negative reactions. Considering the findings, we showed participants both assistive robots and non-assistive robots. Non-assistive robots included entertainment robots (e.g., the WowWee MiP) and robots for everyone (e.g., Jibo or Roomba). Since entertainment robots have not been built with assumptions that their users would experience declines, we expect that older adults might like those.

However, the older adult participants considered the entertainment robots as toys and perceived that they were not intended for them either. Rather, 7/9 older adult participants tended to choose robots that were meant to be used by anyone like AUR (an automated lamp) [31], Roomba, a smart fridge (a fridge providing a list of food in it), and Relay (an autonomous delivery robot) [2].

4.2.3 I don't like robots watching me all the time but I want to monitor myself.

About half of the participants expressed their concerns about robots that monitor older adults all the time. Kathleen, an older adult participant, compared the robots' monitoring function to surveillance cameras in public spaces and explained how people in her generation are sensitive to those. She said:

> That some of the things that younger Americans take for granted nowadays, like having the cameras that are suspended in wires in street intersections. I find it extremely disturbing. You will never have found this in the 1960s or 1970s of America. Absolutely not. People have been having fears about it. There is an entire generation now that takes them for granted. (Kathleen, F, Self-employed, 72)

However, at the same time, older adults wanted to monitor themselves and preferred to have wearable sensors over which they would have all control. Similarly, Robert, an older adult participant, said it is essential for him to make sure that he has full control over the autonomy of robots. He said:

> In the scientific book "1984," there is a dark side of robots, those robots are watching you. The big brother, government bad guys are controlling what you think, if you don't do things they want to do, they take you away. It's very scary and I'm worried things can go wrong. I don't like everything being controlled by computers. I like to set them myself, manually controlled. (Robert, M, Retired, 62)

4.3 Envisioning robots for aging

After discussing how aging researchers and older adult participants frame aging and how they interpret existing robots, they envisioned possible robots for aging.

4.3.1 Robots with sympathy.

Arvind, an aging researcher, suggested a robot with sympathy. The robot plays the role of a listener as a passive actor rather than taking an active role within their interactions with older adults. The

robot expresses its sympathy toward older adults rather than providing information, and thus, it doesn't need to be smart or informative. Also, the robot tries to connect the older adults to other people rather than trying to become their companion. The researcher participant provides the potential persona of the robot's user as follows:

> I am thinking about somebody who is, say, ... 85 years old. He is living by himself. He has some arthritis and some difficulty walking and some diabetes. I think he is reasonably independent. He does not need assistive living. And... but he is limited. He can't walk a mile on his own without help. He has a mild cognition issue but is not demented or not cognitively impaired. Feels lonely. There is no purpose to his life. And... depressed. And... so... living from day to day and trying to find something that would excite him and how to find something on a consistent basis (Arvind, M, geriatric psychiatrist with about 35 years of experience).

The participant explained that this person needs consistent and positive stimuli, and persistence and consistency are the key for the interactions. He also explained that human actors might not be as persistent and consistent since they also have emotions. He said:

> Listening is important. And sometimes [you ask], who cares about him a lot? Nobody cares about them. Nobody will listen. Who wants to listen to an 85-year-old person talking about all his arthritis and consistent pain?

Arvind also envisioned the interaction between the older adult and the robot as follows:

> The robot doesn't need to be a genius robot. Better not to be. But it is positive. It is like what you would like a human supporter to be like. Somebody who can understand is sympathetic. And yet. Who is more ... not overwhelmingly positive."Oh yes. Things would be fine... you will just fine... No that is not helpful. Oh... you did not have a nice sleep...You know what, it happens. Tomorrow will be a better day. You will do fine. But just tell me about what I can do to help you." Something like that. Where there is support and the person just wants to talk and the robot just listens.

The suggested role of a robot with limited intelligence resonates with older adult participants' concerns about Jibo as an active communicator with considerable intelligence. After watching a promotion video for Jibo [1], Kathleen said:

> The message of this video to me is "Jibo loves you" No. Jibo doesn't love you. It is a piece of technology; it does not love. And... so... I mean. It's cute. I think it has some application. But... hm... I don't know. For me, in particular, it will be very dangerous. Because if I have one in my house, being a person who is alone, I could start talking to it. And "Oh. Jibo is my friend." No. Jibo is not my friend. It's so easy to fall into that mindset. So for philosophical reasons, I disapprove of Jibo. I don't want Jibo in my home. (Laugh). I like my robots to be robots.

4.3.2 Modular robots for personalization.

Scott, an aging researcher participant, suggested modular robots that understand the heterogeneity and comprehensiveness of aging. The participant wanted to reflect a more holistic understanding of aging into robot design. For example, the robots aim to enhance older adults' resilience rather than to provide compensation for potential disabilities as a way to fix the disabilities. He explained his robot as:

> The issue here that it would take "a whole person approach" to assessing the person. Um... they have purpose for their lives ... given their level of capacity. So, I think the robots would think like geriatricians... they would have a pretty holistic, broad view of older adults and then, map recommendations based on what they are doing. So, I think

> it would do a host of different things: it might have different modules, for example, different actions or maybe it's a collection of different robots that provide assistance (Scott, M, clinical psychologist with over 15 years experience)

Another aging researcher participant, Tammy, wanted a modular robot that would allow participants to personalize their robots based on their own needs. She wanted older adults to have choices to determine the robot's appearance, personality, and functions, which she assumes will be different depending on the person. She explained her robot as:

> So it can be personalized into anything. I want a dog, but someone might want some alien-looking robot. It can be cute. It can be a Pokemon-like. Whatever it is, it can be your companion, but not a typically talking companion, but other sounds it can make. (Tammy, F, Geriatrician with over 20 years experience)

Since she acknowledged that not every part can be personalized, she thinks a modular robot would work for the personalization. She also thinks this personalization can support older adults' independence in that they have choices in shaping robot design.

4.3.3 Robots supporting an existing ability.

Cynthia, an aging research participant, suggested creating robots that support older adults' existing abilities and relationships. The participant envisioned a robot that can manage and maintain cats; in particular, robotic cat litter changers. Rather than developing pet-like robots, the pet management robots support older adults' existing abilities to maintain existing relationships with their own pets. She said:

> One of the big challenges that my mother has had is changing the kitty litter. She depends on the cat for the social interaction at home; the cats are really good to her. She is out there with people but when she is home, she really enjoys spending her time with the cat. And after she fractured her hip she couldn't change the litter. So she tried to hire a home health aide but they wouldn't change the kitty litter because they were there to help her. She really needed the help with the kitty litter. I think it will be great to have a robot that can change the kitty litter and take care of the cat. (Cynthia, F, Epidemiologist with over 30 years experience)

Supporting older adults' existing abilities can represent the idea that the aging researchers perceive older adults not as people to be fixed, but people with abilities. Since older adults are considered to be people with abilities, aging researchers' main goals include helping them maintain their existing abilities. On the other hand, in the previous HRI studies, compensation for potential disabilities has been an important issues due to the studies' focus on potential disabilities.

4.3.4 Robot connected with other sensors.

Older adult participants wanted robots that were connected to other types of sensors and that would manage, analyze, and report the sensor data. Jean (F, Manager, 65) had incurable neurological diseases and she wanted to monitor herself, especially for notifying her about "observed changes in everyday behavior." She also wanted a robot to be able to speak for her if she lost her voice, and she envisioned that the robot would be like Romeo [3]. Although she thought a Romeo-like robot would work well for her, she wanted to monitor herself through a smartwatch that could sense her wherever she goes. She did not want her robot to follow her around and observe her all the time.

> I am going to wear the sensors like watch, pendant or whatever wearable devices that I have. I don't like my robot to follow me around. If my heart stops for two seconds, then it says "Oh. She is not supposed to do that. What am I going to do?" So. It would be nice if the robot through this pendent or whatever could talk to me."

She made a joke that she expected her robot to stay in a closet all the time (even while the robot recognizes her experiencing an abnormal heart rhythm) unless she commands the robot to come out.

As for the monitoring functions, all older adult participants preferred wearable sensor devices over the robots, since they felt that the robots might be watching them. Not only the older adults, but also Scott, an aging researcher participant (M, clinical psychologist with 15 years of experience) thought that a technology that could stay with older adults all the time would work well. While talking about a robot that could always be with older adults, Scott and the first author sketched a small mobile robot sitting on an older adult's shoulder. He called this a parrot-like robot and thought it was strange. He said that older adults are actually not very different from us and having a parrot robot on their shoulders did not seem very normal. Rather than having a portable robot, he thought a robot could stay at home but it could be connected to the older adults through a wearable watch.

4.3.5 Other robots.

Participants also envisioned other types of robots. Cynthia (F, Epidemiologist with over 20 years experience) wanted robotic appliances that could indirectly monitor older adults' situations. For example, she suggested a gas stove that could detect humans around it and automatically turn off if needed, as well as a refrigerator that would report to a caregiver if an older adult did not open the door for long periods. Also, William (M, Retired, 75) said that he did not think older adults could individually afford these robots considering their financial situations. He suggested that robot designers could think about robots for a community or an organization, so that the robots could be shared by a group of older adults.

5 DISCUSSION

We found both older adults and aging researchers explained that aging is related to biological changes (e.g., physical and cognitive declines); however, at the same time, those changes narrowly describe aging. All participants also suggested alternative robots for aging. In this section, we discuss how the perspectives of our participants could reflect back to HRI research practices, so that the current conceptualization of aging in HRI can be reframed.

5.1 Adopting a social model of aging can provide an alternative approach to reframe assistive robots.

Throughout our interviews we found two different attitudes towards older adults' disabilities. All participants, both older adults and aging researchers, reported potential issues related to aging (e.g., physical and cognitive declines) throughout the interview process. For example, the older adults' maps contained words describing their memory loss and physical difficulties as well as their frustrations due to the changes; aging researchers also talked about potential disabilities from aging (e.g., unable to perform ADLs). However, at the same time, both groups of participants expressed how aging is a more complex experience, and that age-related changes and potential disability caused by those changes are just one aspect of aging experience.

Considering the complexity of aging, assistive robot design needs an alternative framework to study aging. Most of the previous assistive robot designs, following the deficit model of aging, generated designs that remind older adults about their losses. A social model of aging provides an interesting framework in that it defines older adults not as people with dysfunctions, but as people socially oppressed due to productivity-oriented social capitalism [5]. The early version of social model did not consider older adult's biological conditions since it pointed out social systems (e.g., welfare systems, healthcare policies) as the main problems causing disabilities [5].

Our results suggest that HRI researchers should consider incorporating a social model of disability that addresses the importance of both biological age-related changes and the social dimensions of disability [5]. Based on the model, we suggest older adults' autonomy as a way to reflect on both the biological and social dimensions of aging in HRI research.

5.2 Human Autonomy as a Main Theme

As a way to reflect the social model of aging, we suggest exploring older adults' autonomy as a main theme for assistive robot design. Older adults' autonomy enables HRI researchers to explore both biological and social dimensions of aging, since older adults can experience their autonomy both through their biological abilities as well as through social systems. In previous assistive robot studies, researchers discussed the importance of independent living similarly to autonomy. However, most of the studies defined independent lives in relation to older adults' ability to stay in their home [9, 21, 30].

We define autonomy as how much older adults feel in control over their lives, how many decisions they can make about their care, and to what degree [32]. To support older adults' autonomy, older adults should have enough control over robots. For example, older adults should have a right to turn robots completely off when they want. Also, both older adults and aging researcher participants said that robots should respect older adults' decisions even when the decisions might not necessarily improve older adults' health (e.g., not taking drugs). For example, Barbara (F, Retired, 85) said that robots should support euthanasia if older adults decide it for themselves. This raises fascinating ethical issues which are worthy of further exploration [63, 64].

5.3 Importance of HRI researchers' reflexivity to challenge ageism

Along with racism and sexism, ageism is one of the most prevalent forms of prejudice and discrimination that marginalized populations experience [52, 56]. In a broader sense, the deficit model of aging reflected in current assistive robot designs could be not just a design problem within HRI that hinders older adults' adoption of robots. As older adults have been represented as people with potential disabilities in assistive robot designs, assistive robots could propagate the message that aging is a problem for older adults (and to the public) and potentially reinforce ageism in society. HRI researchers might think that their technology-oriented robotics research is essentially neutral. However, in some cases, unexamined assumptions and biases of technology researchers could contribute to affirm prejudice or discrimination in society [38, 47, 64].

Considering the potential influence of robotics research on socio-political issues, we, HRI researchers, are both exploring innovative technologies and propagating certain messages to society. This is why it is important for HRI researchers to pay attention not only to investigating technically advanced robots but also incorporating socially conscious perspectives (or messages) in their work. This paper considers the potential social impact of robotics research as an exciting opportunity to promote positive social change. For example, incorporating older adults' perspectives into assistive robot designs could lead to the development of robots far better suited toward aging. Moreover, the research process itself could work as a way to advocate for older adults' points of views and to subvert beliefs of ageism.

Anthropologists have found that inappropriately representing research subjects could reinforce existing (or generate new) prejudice and discrimination against those subjects [48]. To avoid this issues, anthropologists have long addressed the importance of "reflexivity," which suggests researchers examine potential biases and assumptions they may have towards their research subjects.

Technology design researchers also have employed reflexivity as a way to avoid reflecting their biases towards research subjects. For example, Suchman [73] describes a project involving

prototyping new technologies in a law firm. The attorneys planned to have technology that could perform the coding tasks performed by litigation support workers. The attorneys (mostly men) interpreted the work of support workers (mostly women) as mindless, and wanted to save money through a this new technology system. However, with a reflexive research procedure, the designers found that the support workers' labor was stereotyped and ignored. Consequently, the design researchers were able to show the values of the support workers and instead designed technologies for the support work. Our work suggests reflexivity provides HRI researchers new opportunities to avoid potential biases so that they could develop robots promoting positive social changes.

6 CONCLUSION

In previous assistive robot studies, researchers mostly followed a deficit model of aging, which considers aging as a process of losses. The deficit model of aging is the dominant framework of aging in HRI, and might have limited the design of assistive robots, casting them into two categories: semi-humanoid service robots in the home, and pet-like companion robots. Also, older adults negatively reacted to previous assistive robots since they did not like their representations as people with disabilities in assistive robot designs. In this study, we found that while aging is closely related to potential disabilities, disability is just one aspect of the experience of aging. Following a social model of aging, we suggest the importance of older adults' autonomy as a promising design concept for assistive robots. Also, rather than calling the robots "assistive robots", which assumes older adults need "assistance" due to their possible disabilities, we instead consider how the robots can support human autonomy, i.e., "robots to support successful aging."

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