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Identifying Features that Enhance Older Adults' Acceptance of Robots: A Mixed Methods Study

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Aging · Socioemotional selectivity theory · Selective optimization with compensation model · Acceptability · Preference · Robotics · Technology

Abstract
Background: With global aging, robots are considered a promising solution for handling the shortage of aged care and companionships. However, these technologies would serve little purpose if their intended users do not accept them. While the socioemotional selectivity theory predicts that older adults would accept robots that offer emotionally meaningful relationships, selective optimization with compensation model predicts that older adults would accept robots that compensate for their functional losses. ***Objective:*** The present study aims to understand older adults' expectations for robots and to compare older adults' acceptance ratings for 2 existing robots: one of them is a more human-like and more service-oriented robot and the other one is a more animal-like and more companion-oriented robot. ***Methods:*** A mixed methods study was conducted with 33 healthy, community-dwelling Taiwanese older adults (age range: 59–82 years). Participants first completed a semi-structured interview regarding their ideal robot. After receiving information about the 2 existing robots, they then completed the Unified Theory of Acceptance and Use of Technology questionnaires to report their pre-implementation acceptance of the 2 robots. ***Results:*** Interviews were transcribed for conventional content analysis with satisfactory inter-rater reliability. From the interview data, a collection of older adults' ideal robot characteristics emerged with highlights of humanlike qualities. From the questionnaire data, respondents showed a higher level of acceptance toward the more service-oriented robot than the more companion-oriented robot in terms of attitude, perceived adaptiveness, and perceived usefulness. From the mixed methods analyses, the finding that older adults had a higher level of positive attitude towards the more service-oriented robot than the more companion-oriented robot was predicted by higher expectation or preference for robots with more service-related functions. ***Conclusion:*** This study identified older adults' preference toward more functional and humanlike robots. Our findings provide practical suggestions for future robot designs that target the older population.

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Introduction

With the aging of the population, demands for daily living assistance and companionship are expected to increase, while the labor supplies may be short to meet such demands. In addition, modern changes in societies may further complicate this issue [1]. For instance, in the past, older adults tended to age at home with the care of their children. Yet, with a decreased fertility rate and family structure changes (e.g., with both spouses working or single families), caring for older adults at home may be even more challenging for modern families. Some researchers [2, 3] have suggested that robots have the potential to provide the daily assistance and the social support that older adults may need.

For older adults, robots not only are more likable than other technologies, but also associated with several additional positive outcomes. For one, older adults seemed to interact more positively with a robot compared to a computer tablet [4]. Interactions with an animal-like robot, for example, appeared to improve older adults' mood [5, 6]. Moreover, learning how to use new technologies seemed to have cognitive benefits for older adults [7]. Hence, future applications of robots seems promising, especially for older adults.

Currently, there are a number of robots designed specifically for the older generations [8]. For example, ZoraBot from Belgium could lead older adults to do therapeutic exercises, Care-O-bot from Germany had the capacity to help with chores such as getting a glass of water or make an emergency call, and Cody from the United States could help older adults to take a bath. However, it appears that the prevalence of these robots is still relatively low [9]. In a study by Heerink [10], older adults were less willing to use robots than were their younger counterparts.

Renaud and van Biljon [11] suggested that older adults' pre-implementation acceptance toward the new technology (i.e., acceptance before using the technological product) is a precondition or antecedent of the actual technology adoption. Indeed, learning and adapting to a novel product can cost money and time. A person's willingness to begin such time and financial investments may largely depend on his or her attitude toward the product beforehand, even before product testing. Hence, in an effort to create the most suitable robots for older adults, numerous studies have examined the factors that contribute to older adults' pre-implementation acceptance toward robots. For instance, perceived benefits [12], user beliefs [13], perceived learning support, and expected learning difficulties [14] all showed to influence on older adults' acceptance toward robots even before they interact with one. Furthermore, various theoretical models were developed to better predict general acceptance for new technologies such as the Technology Acceptance Model [15] and the Unified Theory of Acceptance and Use of Technology (UTAUT) [16]. Peek et al. [17] systematically reviewed the factors that influence older adults' acceptance of technologies, and proposed a model for pre-implementation acceptance, which included factors like social influence, concerns, benefits, need, alternatives, and individual characteristics. In addition, the Subjective Technology Adaptivity Inventory [18] was developed to measure technology acceptance specifically for older adults. These models (e.g., Technology Acceptance Model) were shown to be useful in predicting potential implementation later [19]. While it is important to focus on the end users' attitudes or perception in relation to technology acceptance, an additional direction is to investigate what older adults need or prefer in a robot prior to any direct experience with the product (i.e., developers may modify the robotic products to increase technology acceptance), which some studies have attempted to address.

In the current literature, findings on the types of robotic features such as functions and appearance that older adults prefer are mixed. First, it is unclear whether older adults prefer more service-oriented or companion-oriented robots. For example, an interview study [20] with 10 older interviewees found that they preferred robots that could do household chores such as cleaning and washing. Yet, a recent study [6] demonstrated that healthy older adults had positive attitudes toward a more companion-oriented robot, Paro. Another study by Smarr et al. [21] using a checklist questionnaire also suggested that older adults preferred robotic assistance for instrumental or service-related tasks (e.g., laundry and housekeeping) over human assistance, and vice versa for companion-related tasks such as guest entertainment. Thus, it is possible that previous mixed findings resulted from differences in needs and concerns. For instance, a lonely older adult with a higher level of needs for companionship may prefer a more companion-oriented robot more than a more service-oriented robot. Interestingly, in a university sample study [22], usefulness and companionship were both identified as important factors that determined younger adults' acceptance towards a robot. This study tested whether the same would also be true for older adults.

Moreover, earlier studies found mixed results in terms of preferred robotic appearance. On the 1 hand, 1 study suggested that robots should display some humanlike features in order to facilitate social interactions [23, 24]. Another study [25] also illustrated that, in general, people preferred robots with humanlike qualities. On the other hand, Mori et al. [26] proposed a popular idea termed "the uncanny valley," which suggested that animal-like or robotic-like robots received more positive evaluation than did overly realistic human-looking robots. This idea was replicated in a cross-cultural study [27]. Hence, further research in this area is necessary.

Since the targeted group is older adults, it is important to take aging theories into consideration. Yet, it appears that different theories generate different predictions regarding older adults' robot preferences. One dominant aging theory is socioemotional selectivity theory [28]. This theory predicts that, with age, people tend to prioritize emotionally meaningful relationships over future-oriented ones. In other words, although a good technological product should satisfy both functional and relational needs, people might care more about the relational aspects of the product with age, as their relational needs become more salient. From this perspective, it is possible that older adults would prefer more companion-oriented robots over more service-oriented robots. It is also possible that older adults would prefer more humanlike robots over more animal-like or machine-like robots, as humanlike qualities are closely related to meaningfulness. Another influential aging theory is the theory of selective optimization with compensation [29]. This theory posits that, as people age, they tend to accept services that either optimize their current abilities or compensate for their functional losses. In this case, older adults would prefer a robot that provides service-related functions over a robot that provides companion-related functions. To test these competing hypotheses, the present study aimed to compare older adults' level of acceptance towards a more service-oriented robot against a more companion-oriented robot.

Taken together, the present study had 3 key aims. First, we aimed to understand the features and functions that older adults were mostly likely to seek out in robots prior to any interaction with robots. Such impressions from the older adults are considered to be important because older adults tend to have less means (i.e., physical capacities and financial resources) to access novel technologies [30]. Thus, understanding of pre-implementation expectations or acceptance would provide some insights as to what the future gerontechnological development should strive for. To do so, we conducted semi-structured interviews to gather ideas for older adults' ideal robot characteristics, which included functions and appearance.

Second, we aimed to examine older adults' pre-implementation acceptance towards 2 currently available robots (i.e., Paro and Zenbo). These particular robots were chosen because they were equally available on the market but differed in terms of their main functions and appearance. For Paro, a white seal robot, its primary function is to provide intimate companionships with comfortable physical contacts and realistic responses [31]. Although this robot was primarily used to provide companionship for cognitively impaired individuals, a recent study [6] found that it might potentially provide social and emotional support for independently living older adults who were cognitively intact. On the contrary, Zenbo, a more humanlike robot in comparison to Paro, was mainly designed to provide light instrumental support, such as making phone calls and finding online information. Hence, comparing older adults' acceptance ratings on these 2 robots would allow us to understand more about older adults' preference for more service-oriented versus companion-oriented robots. Since the focus of the study is not to compare the 2 robot brands but to compare the robot types, we will address Paro as Robot A and Zenbo as Robot B from this point onward.

Finally, to take advantage of the current design, we aimed to test the association between "ideal robot characteristics" and "existing robots' acceptance ratings" using a mixed methods analysis. As suggested by Tashakkori et al. [32], mixed methods design incorporates the advantages from both quantitative and qualitative sides: while quantitative research tend to focus more on establishing the associations between constructs, qualitative research tend to focus more on the processes and contexts of behaviors. By combining the 2 methods, mixed methods studies offer a more in-depth investigation of the phenomenon in question. A number of previous studies have also identified robot characteristics that older adults preferred [9]. Yet, it is still unclear whether these self-reported characteristics actually contribute to older adults' perception and motivation to use a real robot. In the current study, we addressed this issue by predicting older adults' acceptance of existing robots using the factors older adults identified as ideal for robots. This way, it allows us to further understand which factors are more useful in shaping older adults' perception of robots.

Method

Participants

A total of 33 community-dwelling Taiwanese older adults (26 women, 8 men, M_{age} = 66.3 years, age range: 59–82 years) participated in the current study. Participants were recruited by advertisements posted in local hospitals in Taiwan and referrals. Inclusion criteria include age (must be age 60 or above), literate level (able to read and understand Mandarin), and eye sight (able to respond to questionnaires). A participant who was a month from turning 60 years old was included in our data. All participants were screened for potential cognitive impairment prior to their participation using the Montreal Cognitive Assessment (the higher the score the better the cognitive ability), and only individuals who scored 26 or above (out of 30) were included [33]. As a group, these participants were relatively well-educated (all received more than 10 years of education). See Table 1 for more details.

Data Collection and Data Analyses

This study was approved by the ethics review board of the National Taiwan University (IRB code: 201706HS062). Participants were invited to the laboratory on the National Taiwan University campus and their written consent was obtained.

As a mixed methods study, we divided the study into 2 parts. In the first part, an interviewer conducted a 15-to-20-min semi-structured interview in Mandarin. A research assistant was present to take additional notes. We asked participants to take some time to "design" and draw their ideal robot that would make their life easier and more enjoyable without considering any potential technical or financial limitations. The drawings were meant to facilitate a more concrete and detailed image of the ideal robot. For individuals who found it difficult to draw, we asked them to write short descriptions of the robot on a paper. After a 3-to-5-min drawing/writing time, we asked follow-up questions based on their drawings or descriptions (e.g., What is this part? What is the function of this part of the robot?). Each interview was audio-recorded and transcribed verbatim.

We performed conventional content analysis in order to understand the qualities of an ideal robot that older adults looked for. Therefore, these functions were included regardless of whether participants indicated them in the interviews. Other items and categories (e.g., appearance, place, companion-related functions … etc.) emerged from the initial coding of the first 2 interviews. Together, these categories formed the preliminary coding scheme (42 codes). After the first 10 interviews were coded using the preliminary coding scheme with notes made for potential additional codes, a modified coding scheme (45 codes) was finalized to code the rest of the interviews (see online suppl. Appendix 1; see www.karger.com/doi/10.11549/000494881 for all online suppl. material). Transcriptions were coded by 2 coders individually and inter-rater reliability was satisfactory (kappa >0.67). Discrepancies were discussed and final codes were agreed by both coders. Transcribing and coding works were completed in Chinese in order to avoid any losses in translation. Quotes of participants included in the results section were translated for this paper by a research assistant who is fluent in both English and Chinese.

In the second part of the study, the picture and information of the 2 commercially available robots (i.e., Robot A and Robot B) were shown to participants separately in a counterbalanced order. We made an attempt to portray Robot A as a more companionship-oriented robot and Robot B as a more service-oriented robot through the functions that we mentioned (see online suppl. Appendix 2). For instance, we did not mention Robot B's social- or companionship-relevant functions, such as storytelling, to ensure the interpretations of Robot B are more service-oriented. Since our participants had no prior encounter with these robots, their impressions of the 2 robots were likely to be shaped by the picture and the information provided in this study. Immediately after being shown the picture and information of each robot, participants were asked to fill out the 41-item UTAUT questionnaire [34] for the particular robot. This inventory contained a total of 13 domains (e.g., anxiety, perceived ease of use, attitude. etc.) and each domain included 2–5 items on a 5-point Likert scale ranging from 1 (totally disagree) to 5 (totally agree). The questionnaire was modified by replacing the more general term "the robot" to the name of the particular robot we targeted (i.e., Robot A and Robot B). This particular questionnaire was chosen because it has been utilized to measure older adults' robot acceptance [35].

Table 1. Demographic characteristics of the participants

Characteristic	Total sample (n = 33)
Age, years	66.32±5.86
Years of education	15.57±3.99
MoCA score	27.85±1.33
Gender	
Male	8 (23.5)
Female	26 (76.5)
Personal income*	
<20,000	3 (9.4)
20,000–39,999	9 (28.1)
40,000–59,999	13 (40.6)
>60,000	7 (21.9)

Data are presented as n (%) or mean ± SD.

* Income measured in NTD and the exchange rate during the time of data collection was 1 USD to 29 NTD.

MoCA, Montreal cognitive assessment; NTD, New Taiwan Dollars.

Results

Interview

To further our understanding of what older adults looked for in a robot, we analyzed their descriptions of ideal robots. Their responses highlighted various aspects of a robot, including its functions, interaction styles, appearance, features, texture and personality, and worries and barriers as a user.

Functions

We quantified the interview results by counting the number of times when each function was mentioned by our participants (Fig. 1). The results yielded 4 companion-related functions and 15 service-related functions.

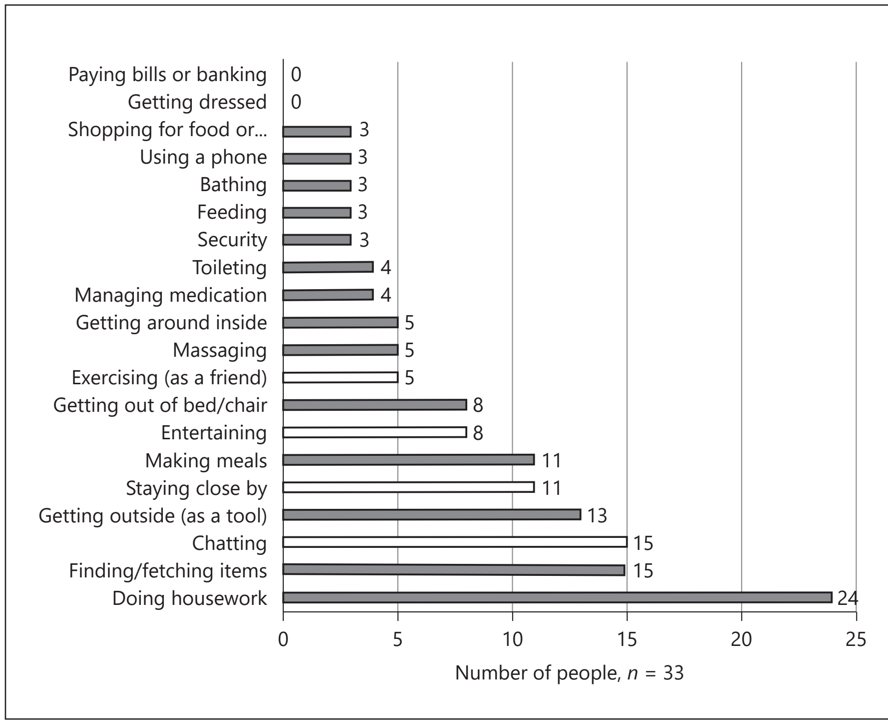

Fig. 1. Ideal functions mentioned by participants. A total of 20 functions was identified with 4 of them being categorized as companion-related functions (white bars) and the rest as service-related functions (gray bars).

When focusing on the most mentioned functions, the results suggested that older adults valued both service-related and companion-related functions in their ideal robots but with a slight preference for service-related functions. The most mentioned functions were service-related – doing housework, which was mentioned by 24 out of 33 participants. Next, 15 of the 33 participants indicated that they would like to have a robot that could find or fetch objects for them, especially if the object was placed at a high location. However, 15 out of 33 participants also indicated that they would like to have a robot that could chat with them, and 11 out of 33 participants reported that they would like the mere presence of the robot. Indeed, in our sample, none of the participants preferred a solely companion robot (all mentioned at least one service-related function), but 26 out of 33 participants did mention at least one socially related function.

Interaction Style

We also coded older adults' preferred interaction styles. We found that the majority of older adults (22 out of 33) wanted to engage in a moderate level of interaction with their ideal robot, which means that the robot would not constantly interact with its user but would be available when needed. Some participants (8 out of 33) were fine with robots following them automatically to provide constant interaction and surveillance. Two participants indicated that their ideal interaction time depended on the context (e.g., their health status). Only one of the participants resisted the idea of having a robot at home.

Appearance

A number of interviewees (19 out of 33) indicated that they preferred a human-like robot. Seven interviewees preferred humanoid-looking robot, 1 preferred an animal-like robot, 4 preferred a machine-like robot, and only 2 individuals preferred the robot to be either stuffed animal-like or machine-like.

> [Robots] must be humanlike. Yes, [it] has to be humanlike … we cannot just look at something cold and hard, right? … if it is more humanlike, it may be easier to accept [it] … just like as we (interviewer and interviewee), I showed my emotions and my internal feelings outward …, so [the interaction] is better! (Participant 6)

In terms of size, the majority of older adults (25 out of 33) wanted a robot that was close to human size, while 5 out of 33 participants indicated a medium or pet-like size. One of the participants was fine with both human size and medium size, and 2 interviewees did not answer. Interestingly, 9 of the older adults coincidently reported that the ideal height of a robot would be around 150 cm because it would allow older adults to make "eye contact" with the robot without having to look down, at the same time not too tall to seem intimidating. However, 6 of the older adults suggested that 160–170 cm was their ideal robot height so the robot would be big enough to do some of the tasks.

> The size [of the robot] shouldn't be too big … should be slightly shorter than [the respondent]. If it is too big, I would feel intimidated, but if it is too short, I would worry that it cannot perform any task such as moving objects higher (Participant 13).

Features

Although different participants focused on different features, there were some commonalities, such as the presence of a face, eyes, ears, mouth, legs, hands, and arms. For some features, the functions desired by older adults were quite obvious (e.g., they wanted the robot to have hands and arms in order to help out with chores and finding stuff at home). However, other features were more thought-provoking. For instance, many of them mentioned that they wanted the eyes to be able to perform tasks such as providing lighting (i.e., served as an automatic flashlight) or detecting danger in the surrounding. Nine of the older adults also preferred the robot to be voice-controlled. Similar to older adults' desire for a humanlike robot in terms of its appearance, they also mentioned various aspects of the robot to resemble humans. For example, they wanted their ideal robot to have humanlike eye movement (e.g., blinking), to chat and sing with older adults, and to display genuine emotions.

> … I am not sure if current technology advances allow [robots] to have different emotions, that I don't know, but at least [it should display] a smiley face … and the way it looks with its eyes should be gentle … gentle, yes! … I am not sure if current technology advances can achieve this … [the robot] should be able to blink … and can see the eyeballs moving … so it is more realistic (Participant 9).

Another participant also mentioned that the ideal robot should have various humanlike features, not for their specific functions, but to look like human.

> [Interviewer: So why did you design the eyes? Is there anything [the robot] should see?] No, [I designed the eyes] so at least I can communicate with a person, that is with eyes, nose, mouth, so I know it is the same as me (Participant 32).

Texture and Personality

Some interviewees indicated that they hoped their ideal robot to be soft and warm, which again resembled real human beings. More interestingly, many of them highlighted that robots should have a warm, gentle, and patient personality. One of the interviewees explained that such personality was what distinguished robots from human, which would be the selling point of robots dedicated to caring for older adults.

> … [Robots for older adults] should be humanlike! [It] should be able to empathize with the individual it takes care of. And when it is taking care [of older adults], its touch should feel like a living being with energy and warmth. [Robots should] be patient and move like humans, not too violent … (Participant 19).

Worries and Barriers

In addition, 25 out of 33 older adults indicated that they have some concerns regarding robots in general. First, 14 older adults feared that they could not handle malfunctioning and rusting of the robot, which might cause more problems (e.g., the need to bring the robot back to the store to be fixed). Second, 10 participants worried that they could not afford the price of an advanced robot and the electrical consumption. Finally, 6 older adults were uncomfortable about the potential privacy issues with a robot that could constantly collect an enormous amount of personal information at one's home.

> If I have to take care of [the robot] then it would be a problem (laughing). … You must have privacy! For example, … everyone is more relaxed at home [in terms of dress and conversations] … so [the robot] should not tell what it should not tell (Participant 6).

Questionnaire

Next, we examined older adults' levels of acceptance toward different types of currently available robots (i.e., Robot A and Robot B). We first checked the internal reliability of the UTAUT questionnaire for Robot A and Robot B separately. We then extracted the components with satisfying reliability (i.e., Cronbach's alpha >0.70; Table 2) and performed a repeated measure ANOVA in order to compare the acceptance ratings of Robot A and B. The extracted components were attitude, intention to use, perceived adaptiveness, perceived sociability, perceived usefulness, and trust.

Before the main analyses, we tested the potential demographic and clinical differences in robot acceptance within the current sample. In terms of gender differences, females ($M = 3.88$, $SD = 0.66$) tended to perceive significantly greater social value of Robot A than did males ($M = 3.16$, $SD = 0.84$). Females ($M = 4.29$, $SD = 1.07$) also showed a significantly higher level of intention to use Robot B than did males ($M = 2.79$, $SD = 1.78$). We found no gender difference in other acceptance constructs. We also did not find significant association between acceptance ratings and demographic and clinical variables (i.e., education, personal income and cognitive ability).

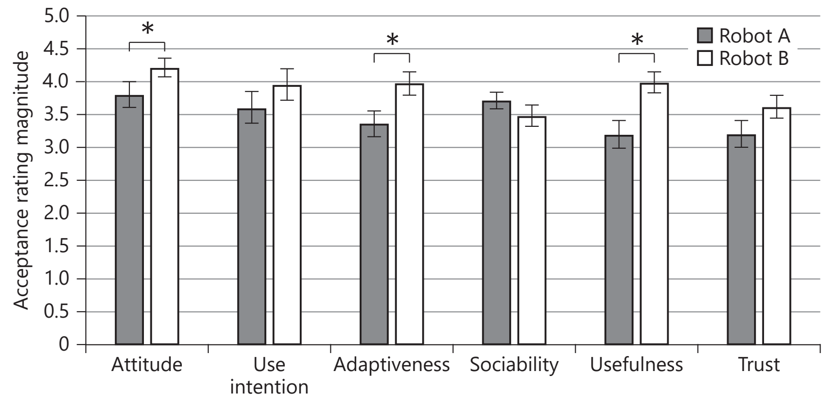

Fig. 2. Repeated measure results that compared the UTAUT measures of Robot A (gray bars) and Robot B (white bars).

To compare the UTAUT acceptance constructs between Robot A and Robot B, we performed a repeated measures ANOVA. The difference between Robot A's acceptance ratings and Robot B's ratings was significant (Wilks' Lambda = 0.489, $F(6,28) = 4.87$, $p < 0.01$). We also checked the univariate tests, and found significant differences between Robot A and B in terms of older adults' attitude ($p < 0.05$), perceived adaptiveness ($p < 0.01$), and perceived usefulness ($p < 0.01$). Specifically, Robot B's ratings were significantly higher than Robot A's in all these components (Fig. 2), suggesting that older adults considered Robot B to be more positive, and with greater adaptiveness and greater usefulness than Robot A.

Table 2. UTAUT reliability results

Construct	α (Robot A)	α (Robot B)
Anxiety	0.680	0.761
Attitude	**0.928**	**0.873**
Facilitating conditions	0.664	0.703
Intention to use	**0.963**	**0.966**
Perceived adaptiveness	**0.850**	**0.850**
Perceived enjoyment	0.749	0.692
Perceived ease of use	0.647	0.636
Perceived sociability	**0.744**	**0.757**
Perceived usefulness	**0.908**	**0.884**
Social influence	0.717	0.573
Social presence	0.767	0.622
Trust	**0.886**	**0.780**

Bolded constructs had satisfactory reliability for both robots and were selected for further analyses.

UTAUT, unified theory of acceptance and use of technology.

Mixed Methods Findings

As mentioned, previous studies had mixed findings on older adults' preference for robot appearance and functions. From the questionnaire portion of this study, we found that Robot B, which has a more humanlike appearance and more service-related functions, has higher overall acceptance ratings than Robot A. However, it is unclear which of the 2 factors (i.e., appearance and function) contributed to such difference. To answer this question, we investigated how older adults' ideal robot expectations (measured in interview study) influenced their acceptance toward existing robots (measured in questionnaire study) by performing multiple linear regression analyses. From the interview study, we had 3 quantifiable variables (i.e., desired humanness of robot, number of service-related functions mentioned, and number of companion-related function mentioned). We utilized these variables to predict older adults' ratings of Robot B after subtracting their ratings of Robot A in terms of attitude, perceived usefulness, and perceived adaptiveness in separate analyses. This analysis only included participants who rated Robot B over Robot A on each acceptance component ($n = 26$). For attitude, the regression model showed a significant good fit, $F(3, 23) = 3.98$, $p = 0.021$, $R^2 = 0.34$. The attitude rating difference between Robot A and B was significantly predicted by older adults' expected service-related functions ($\beta = 0.62$, $p < 0.01$). This finding suggested that older adults who preferred robots with more services were more likely to show a more positive attitude towards Robot B over Robot A. However, older adults' expectations of ideal robots did not significantly predict their preference of existing robots in terms of perceived usefulness or perceived adaptiveness.

Discussion

In the present study, we first identified the features that older adults looked for in an ideal robot. We then compared older adults' acceptance ratings of 2 robots with different targeted functions, service-oriented and companion-oriented functions respectively. Lastly, we utilized the mixed methods data to test the association(s) between "ideal robot characteristics" and "existing robots' acceptance ratings." In summary, our findings demonstrated that older adults seemed to prefer robots with humanlike appearance and attributes in describing their ideal robot. When evaluating currently available robots, older adults also preferred Robot B (robot with a more humanlike appearance and service-oriented functions) over Robot A (robot with a more animal-like appearance and companion-oriented functions). Finally, we found evidence that older adults' tendency to view Robot B more positively than Robot A might be explained by their preferences for robots with more service-related functions, but not by their preferences for robots having more humanlike qualities.

For the question of whether older adults preferred more service- or companion-oriented robots, our findings seemed to suggest a relatively higher preference for more service-oriented robots. From the interview study, the most mentioned function was "doing housework" and "finding or fetching items," which were both service-related. In addition, all of the participants indicated at least 1 service-related function, but not necessarily a companion-related function, during their interview. Moreover, from the questionnaire study, older adults demonstrated greater acceptance toward Robot B over Robot A. From the mixed methods analyses, older adults showed more positive attitude for Robot B than Robot A, which was predicted by older adults' ideal expectation for robots with more service-related functions. Thus, our findings seemed to support the theory of selective optimization with compensation, which posited that older adults would prefer robots that could help them to maintain their everyday competence.

Nevertheless, the socioemotional selectivity theory was useful in predicting older adults' preference for robot's appearance and degree of humanness. Indeed, from the interview study, older adults indicated many humanlike qualities and reported higher acceptance ratings for Robot B (more humanlike) than Robot A (more animal-like). At first glance, our findings about older adults preferring more humanlike robots may seem to be contradictory with the idea of uncanny valley proposed by Mori et al. [26]. The uncanny valley suggests that people generally like inanimate objects to look like real human (e.g., a cartoon-looking robot is preferred over a machine-looking robot). Yet, if something mimics human appearance in a fake-looking way to a certain extent (e.g., a *bunraku* puppet, a mannequin, a zombie … etc.), a decline in affinity would occur [26]. Hence, the fact that older adults in our study preferred robots with humanlike appearance was quite surprising. However, we would like to emphasize that the present study asked participants to *imagine* their *ideal* robots. As depicted in Mori et al. [26], real human appearance has the highest affinity ratings. Thus, it appears quite natural that older adults, without considering technical limitations, would prefer real-human-looking robots. In addition, compared to other humanoids, Robot B in this study was relatively more cartoon-like and less humanlike (see online suppl. Appendix 2 for Robot B's appearance). Thus, its degree of humanness might be insufficient to provoke a decline in affinity. With current robotic advances, we may not entirely avoid the uncanny valley when designing the appearance of a robot. Nevertheless, developers may consider focusing more on other aspects that older adults also mentioned in the study, such as humanlike personality and texture of the robot.

Taking both the socioemotional selectivity theory and the theory of selective optimization with compensation into account, it appeared that both aging perspectives were useful in predicting older adults' needs and motivations in the context of accepting novel technologies but for different domains. In terms of functions, older adults seemed to value service-related functions. However, we also found that chatting, a companion-related function, was also relatively popular among older adults. As for socioemotional selectivity theory, it was relatively less supported based on our findings on older adults' ideal robotic functions. Yet, this theory was useful in explaining why older adults might like humanlike qualities in robots. Perhaps, future robot designs should consider customizing robots' displayed emotions and characteristics according to its functions (e.g., warmer texture and personality for a companion or care-related robot versus a robot for cooking or house-cleaning).

The present study is unique in terms of its applied and theoretical extension from previous studies. In terms of applicability, previous studies [20, 21, 35] tended to examine older adults' interaction and ratings on robots that were either too expensive for older adults to have at home or yet to be commercialized. We made an improvement on this problem by assessing older adults' preference and acceptance using robots that were readily available on the market instead of prototypes in the laboratories. Furthermore, prior research, despite focusing on older adults, rarely applied developmental perspectives or aging theories to the study of acceptance of robots. With aging theoretical background (i.e., the socioemotional selectivity theory and the theory of selective optimization with compensation), we not only built a better foundation for our hypotheses but also tested which aging theory might be more applicable in the context of technology adoption.

Admittedly, there are some limitations in our study. First, we cannot ensure that Robot A and B are comparable robots. For instance, there are more functions in Robot B, which might have contributed to higher preference ratings. However, we attempted to minimize this difference by providing standardized description of each robot. Second, this study's findings may not be generalizable to other robots, as different robots have different functions and appearance. Third, as mentioned in the method section, the current sample is quite small, relatively healthy and active, highly educated and recruited from urban areas, so it is possible that our findings may not be generalizable to other populations (e.g., clinical samples or older adults in rural areas). Moreover, it is possible that there is a gender difference in robot acceptance, which cannot be captured by the current sample due to the limited number of male participants. Finally, personality traits may influence the acceptance ratings of participants. For example, individuals with higher agreeableness and extraversion tended to report more positive evaluation of an interaction with robot [36, 37]. However, we did not measure or control the personality factor in the analyses. Future studies should aim to compare robots with more dichotomized purposes, include a larger and more representative sample, take personality traits into account, and compare the acceptance of robots with that of other home-based technologies, such as a fall detector or telehealth monitoring device.

Nevertheless, the present study contributes to the literature by applying aging theories to understand older adults' acceptance and preference of novel technologies. Unlike previous studies that examined the acceptance of non-commercialized robots, we compared 2 commercialized robots that are readily available on the market. In addition, the utilization of a mixed methods design furthered our understanding beyond simple preferences and probed into the potential factors that contributed to such preferences. For future studies, researchers may further explore the specific types of humanlike attributes or traits that older adults look for in a robot and examine how developers may effectively achieve these attributes. It does not necessarily mean that robots need to look exactly like a real human, but resemblance in terms of features, personality, and texture should be considered.

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