Older users' acceptance of an assistive robot: Attitudinal changes following brief exposure

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Introduction Many older adults wish to age-in-place. Robot assistance at home may be beneficial for older adults who are experiencing limitations in performing home activities. In this study we investigate older Americans' robot acceptance before and after exposure to a domestic mobile manipulator, with an emphasis on understanding trialability (i.e., 'trying out' a robot for a short time period) and result demonstrability (i.e., observing the results of the robot's functionality). **Method** Older adult participants observed a mobile manipulator robot autonomously demonstrating three tasks: delivering medication, learning to turn off a light switch, and organizing home objects. We administered pre and post exposure questionnaires about participants' opinions and attitudes toward the robot, as well as a semi-structured interview about each demonstration. **Results** We found that demonstration of a mobile manipulator assistive robot did, in fact, influence older adults' acceptance. There was a significant increase, pre vs. post, in positive perceptions of robot usefulness and ease of use for 8 of the 12 Robot Opinions Questionnaire items. Furthermore, in the Assistance Preference Checklist, eighteen tasks significantly differed between pre and post exposure, with older adults showing a greater openness to robot assistance after exposure to the robot. **Conclusion** Demonstration of robot capability positively affected older adults' preferences for robot assistance for tasks in the home. Interview data suggest that the robot's capability and reliability influenced older adults' first impressions of the robot.

Keywords: human-robot interaction, aging-in-place, mobile manipulator, assistive robotics

Maintaining independence is a primary goal of older adults and a key component to successful aging-in-place[1-4]. Given age-related needs for assistance, the growing number of older adults creates financial and logistical concerns at the societal level. Technological innovation, such as robotics, has potential to ease the burdens arising from the aging population, especially for older adults encountering limitations in performing home activities[5,6]. The potential benefits of robot assistants can only be realized if they are adopted. To facilitate the diffusion of robotic innovation, we must involve older adults early in the development process. In this study, older adults' reactions and acceptance towards robot assistance in the home were measured in response to live demonstrations. By providing a tangible example to react to, the older adults had a concrete reference point to compare to their ideal of a robotic assistant.

This research builds on work investigating older adults' attitudes toward mobile manipulators[7]. However, unlike previous work in which participants imagined[8] or viewed a video[7] of robots demonstrating their capabilities, in this study we emphasized the constructs of trialability (i.e., 'trying out' a robot for a short time period) and observability (i.e., observing the results of the robot's functionality)[9].

Assistive home robots for older adults

Assistive technology, such as robots, has the potential to help older adults age-in-place. Assistive robotics are designed to aid individuals with tasks that they need or prefer help with. Assistance in this sense may encompass help with physical (e.g., manipulation of objects), cognitive (e.g., reminders), or socio-emotional tasks (e.g., social interaction).

Assistive robots can compensate for a user's lack of capability or skill in performing a task[7,10-12]. For example, many older adults reported difficulty with lifting heavy objects, and were open to robots performing this task. Assistive robots can also execute tasks that users find undesirable to perform themselves[10,13], such as housework or lawn maintenance. Furthermore, these robots can free up older adults' time and energy[10,11,13-15] allowing them to select and attend to tasks that they find enjoyable[16].

To date, assistive robotic development has largely focused on assistance with physical day-to-day tasks required to maintain a home[16,17]. Vacuum cleaners[18], mobility assistance[19], and physical monitoring[20], are a few examples of robots in research, development, and/or commercialization.

Compensation for cognitive decline has also been investigated, although to a lesser degree than physical assistance. Examples include robots such as Care-O-Bot[20] and iRobiQ[21], which offer reminders, health monitoring, and cognitive training/gaming.

Lastly, assistive robots have been identified as potential emotional or social supports. Social connectedness through telepresence systems[22] has the potential for keeping older adults in communication with family and friends. Social companion robots, such as PARO[23], may benefit older adults with dementia by reducing depression and loneliness in nursing home settings and are viewed positively by healthy elders as well[24].

Assistive robots should meet an older adult's needs and preferences to be perceived as useful[25]. Older adults' preferences and needs may differ from other segments of the population, and a range of studies and reviews identify tasks that older adults may want or need robot assistance with[7,8,11,26-28].

When asked to imagine a domestic robot, American older adults reported a preference for robots to perform tasks that required little physical human-robot interaction (e.g., home monitoring) compared to tasks that required more physical interaction, such as cooking[8]. Tasks that required social human-robot interaction, such as having a conversation with a robot, were rated as least useful. This finding was further supported in more recent work[7], where older adults identified, via a questionnaire, preference for robot assistance with chores, manipulating objects, and information management. Conversely, the same older adults preferred assistance from a human (as opposed to a robot) with leisure activities and personal care.

In a study conducted in Germany[27], older adults reported, via a questionnaire, robotic assistance for social and personal tasks (companionship, games, bathing) as less useful. In contrast, in a New Zealand study, older adults identified robot assistance with physically- and socially-oriented tasks (e.g., lifting heavy objects, housework, socialization) as useful[26]. Thus, the literature suggests that older adults are open to robot assistance for some household tasks, although preferences are selective based on the nature of the task. Moreover, attitudes vary across people and more research is needed to understand the variables influencing these opinions.

Acceptance of assistive robots

Robots are a relatively novel technology for the older population. An understanding of how assistive robots may be adopted is important to determine how this technology will spread, be used, and meet user needs. The availability of complementary technologies positively affects the adoption rate of new substituting technology[29]. However, this may not necessarily be the case for assistive robots that lack predecessor commercial products. Several previously mentioned studies investigating older adults' attitudes provided insight into the facilitators and barriers to robot acceptance. For example, if older users perceive a robot as useful, they are more likely to rate the robot as acceptable[7,9,26,30]. Furthermore, perceptions of ease of use, privacy, capability, and social engagement have been identified as potential reasons behind why older adults hold certain preferences or attitudes[31-34].

Theories and models that identify factors that influence acceptance have informed much of this research. Two traditional models of acceptance are the Technology Acceptance Model (TAM[35]), and the Unified Theory of Acceptance and Use of Technology (UTAUT[36]). TAM identifies perceptions of usefulness and ease of use as the primary factors that influence and predict technology adoption. UTAUT expanded on TAM by proposing four constructs as direct determinates of behavioral intentionality to adopt technology – performance expectancy, effort expectancy, social influence, and facilitating conditions. These theories provided the underlying framework for the Almere Model[30], which investigated the acceptance of assistive social agents by older adults in the Netherlands. Attitudes, perceived usefulness, ease of use, enjoyment, and social influence were identified as statistically influential in older users' intentions to use a robot.

Also related to theories of technology acceptance is Rogers' Diffusion of Innovation framework[9], which describes how, why, and at what rate innovations (i.e., new ideas, practices, or objects) are spread through cultures. The Diffusion of Innovation framework identifies five attributes of technology that users evaluate a system (Table 1). In general, all five attributes influence intentional acceptance[37] and technologies that rate higher on these five attributes (except complexity) are more readily accepted[9,37].

Trialability and observability are two constructs of focus in this article. Trialability[9] is the "degree to which an innovation may be experimented with on a limited basis". That is, trialability allows a user to 'test drive' or experience demonstrations of a new technology, without committing to purchasing it. Allowing a user to experiment with an innovation on a limited basis may reduce uncertainty, give the user more information to evaluate how they might use the technology, demonstrate how easy it is to use, estimate how often they may use it, and so forth. According to Rogers[9], innovations that are more trialable are adopted more often than innovations that are less trialable.

In general, older adults have limited experience in using robots[7,8], which may contribute to uncertainty or lack of knowledge about robots[9,38]. Direct experience of using a robot has been shown to have a positive effect on older adults' attitudes and reduce their negative emotions[13,39]. Furthermore, trialability, according to Rogers, plays a role in peer-to-peer conversations about technology, which in turn positively influences the diffusion of the innovation[9,14,18]. This trialability could reduce the risk of uncertainty related to trying a new product, because new users may be comforted by credible reassurances from peers that the robot should be adopted.

Observability[9] is "the degree to which the results of an innovation are visible to others"; innovations that are more observable are more readily adopted. Observability can be broken down into two sub-attributes: visibility and result demonstrability[40]. Visibility is the degree to which a technology is obvious to others, for example, a user viewing a peer using a technology. This exposure effect via other people could increase positive attitudes and openness to adopting a robot. Result demonstrability is the degree to which an individual can observe, measure, and communicate the results of using the technology[40]. If older adults are able to discern tangible results of a technology[10,13-14], then result demonstrability may have a positive effect on acceptance.

Trialability and observability were of particular interest in this study because these constructs have not been systematically investigated with regard to older adult use of domestic assistive robotics, particularly those robots that assist with physical tasks that older adults wish to have help with. Prior studies of acceptance of domestic assistive robots have investigated imagined robots[8,41], videos[7], or Wizard of Oz methodologies[30], with which trialability and observability could not be assessed.

Trialability and observability are likely important constructs to consider for domestic robots because the home is a very private and individualistic environment. Exposure to a robot, actually located and operating within a home, would allow older adults to better consider how such technology will fit into their home, meet their individual domestic needs, and become a part of their daily home life. Such assessments are crucial for understanding the diffusion of domestic robot innovation into older adults' lives.

*Table 1. Attributes of technology from diffusion of innovations[9]; *similar to perceived usefulness (TAM[35]); **similar to ease of use (TAM[35])*

Attribute	Definition
Relative advantage*	The degree to which an innovation is perceived as better than the idea it supersedes
Complexity**	The degree to which an innovation is perceived as difficult to understand and use
Compatibility	The degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters
Trialability	The degree to which an innovation may be experimented with on a limited basis
Observability	The degree to which the results of an innovation are visible to others

Goals of research

Acceptance is one challenge in the development and implementation of assistive robots for the older population. Given that most older adults do not have experience with robots, an understanding of the factors related to the diffusion of assistive robot innovation is important. Specifically, the purpose of this study was to understand if or how trialability and result demonstrability influence older adults' acceptance of an assistive robot. As such, our goals were as follows:

- To understand older adults' first impressions (attitudes) of the assistive robot after each demonstration, and identify reasons why they held such impressions;
- To determine if older adults' preferences and acceptance for robot assistance for home tasks would change between pre and post demonstration.

Guided by the TAM and the diffusion of innovation frameworks, we included the following key variables: perceived usefulness and perceived ease of use (shown to be similar to relative advantage and complexity, respectively); previous technology and robot exposure because such experience is related to compatibility; trialability and observability (specifically, result demonstrability). These latter constructs are of particular interest within the scope of assistive robotics. Therefore, trialability, in this study, was operationally defined as the experience of interacting with the robot first hand for a limited basis, whereas result demonstrability was operationally defined as the experience of observing the robot's functionality.

This research is unique in several ways. First, we emphasize in-person interaction to investigate the influence of trialability and observability attributes on acceptance. Second, little research has investigated the benefits and operation of robot assistance demonstrated in an actual home environment (for exception see Roomba studies[14,18]). We assessed in-person interactions with the mobile manipulator in the Georgia Tech Aware Home (http://www.awarehome.gatech.edu) wherein participants could observe the robot in an actual home setting, with an emphasis on robot operation in the living room and kitchen.

Method

Participants

Participants were 12 independently living older adults (6 males) aged 68-79 years (M = 72.6, SD = 3.9) recruited via the Human Factors and Aging Laboratory participant database, from the community of Atlanta, GA, USA. The participants were not told in advance that the study was about robotics; thus, the participants were not biased towards robot acceptance. The sample was racially diverse: half the participants reported themselves as White/Caucasian and the other half identified as Black/African American. Additionally, they were educationally diverse with half the participants reported holding a Bachelor's degree or higher. Participants reported taking five medications on average, and their self-reported health ranged from good to excellent.

At the start of the study, we administered a questionnaire to the participants to assess their level of familiarity with 13 types of robots (e.g., manufacturing, surgical). Participants were somewhat familiar with the robots listed (i.e., have only heard about or seen this robot). Older adults reported being most familiar with entertainment/toy robots (e.g., Aibo, Furby), and least familiar with remote presence robots (e.g., Texai, Anybot). However, participants reported little to no experience in using any robot.

Materials and apparatus

Robotic platform – Personal Robot 2 (PR2)

The PR2 is a human-sized commercially available mobile manipulator. Characteristic features of the PR2 include an omni-directional wheeled base, two 8 DOF arms/grippers, a telescoping spine (height can range from 130 cm to 160 cm), and a pan-tilt head carrying two stereo camera pairs and a LED texture projector.

Aware Home Research Facility

The Aware Home Research Facility at Georgia Tech is a unique home-like laboratory (www.awarehome.gatech.edu). This facility provided a venue to understand older adults' interactions with a robot in an authentic home environment.

Robot demonstrations

Medication hand-off demonstration

The PR2 was programmed to execute a medication hand-off task to the participants (for technical details[42,43]). By tagging medication bottles and having each participant wear a UHF RFID tag, the robot used RFID search to acquire a medication bottle and then discover, approach, and deliver it to the participant in a timely fashion.

We outfitted the PR2 with two long-range UHF RFID patch antennas affixed to its shoulders. By design, we assumed the intended recipient was in the Aware Home's living room, and the robot had already acquired the tagged medication bottle elsewhere in the home. The robot was tasked with delivering the tagged medication bottle to the intended recipient wearing a tagged necklace. Each medication delivery trial involved the following steps:

First, the PR2 moved from any starting location in the Aware Home to the center of the living room. From this vantage in the center of the living room, the PR2 panned its directive antennas back and forth to search for the ID tag being worn by the older adult. Making continuous readings of the UHF RFID tag worn by the recipient, the robot slowly moved forward (at 10 cm/sec), stopping within 10 cm of the intended recipient[42,43]. Next, the robot reached out its gripper (holding the medication bottle) to a fixed position. When the older adult grasped the medication bottle and the tactile sensor values exceeded a threshold, the robot opened its gripper and released the object. This completed the delivery process, and the robot returned to its initial starting location.

Autonomous learning demonstration

In this demonstration in the living room, we showed participants the robot failing to turn off the lights using a rocker switch but then learning from this failed trial to succeed in its second attempt. As part of another project[44], we developed custom algorithms for robots to autonomously learn to detect 3D locations. By using autonomous learning, the PR2, with its ability to push rockers switches and determine whether the lights turn on, can learn about the visual appearance of new rocker switches on its own through a process of trial and error.

First, the robot navigated to the rocker switch, and used its grippers to press the switch. To detect whether the lights have turned off or not after executing, the behavior measured whether the lighting intensity changed. The robot in this demonstration first failed to turn off the light, and then learned from this failed trial to succeed in its subsequent attempts. This demonstration of autonomous learning was a realistic portrayal of robot learning a new task, allowing older adults to observe first-hand a robot learning from its mistakes.

Table clean-up demonstration

The PR2 also demonstrated a pick and place procedure which simulated the task of "cleaning up" a dining table in the kitchen area of the Aware Home. We programmed the robot to perform overhead grasps on three common household objects laid out on a table and place them neatly in a basket also on the table. Our grasping routine was a heavily modified version from Ciocarlie and colleagues[45]. First, the robot was driven to a marked base pose and the objects and basket were placed on the table. The basket was affixed to the table using Velcro. (Note that the participant was taken to a different room as this task was being set up.) Once the set up was ready, the participant was seated at the kitchen table. The PR2 looked at the set of objects and used the Kinect RGB-D sensor on its head to capture a point cloud of the table scene. The gripper then moved directly down at a constant speed until contact was made with the table. The PR2 detected collision with the table, the gripper closed on the object and lifted the object directly up. In a similar fashion, the object was moved over the basket and placed in a programmed location. This process repeated for all three objects.

Questionnaires

Demographics

Participants provided demographics, general health, and technology experience information[46]. Robot familiarity was also assessed, with 13 different robot types such as military robots, manufacturing robots, and surgical robots[7].

Robot opinions

We measured participants' attitudinal acceptance of robots before and after their exposure to PR2. The questionnaire consisted of 12 items (e.g., "My interaction with a robot would be clear and understandable", "I would find a robot useful in my daily life", and "Using a robot would make my daily life easier.") and participants responded to each item on a 7-point Likert scale.

Assistance preference checklist

An Assistance Preference Checklist revised from a previous study[7] assessed preferences for assistance (human versus robot) for a variety of home-based tasks. We asked participants to imagine they needed assistance in everyday life and to indicate preferences for human versus robot assistance with 58 home-based tasks, assuming the robot could perform those tasks to the level of a human. Assistance preference was indicated on a 5-point scale. This checklist was administered both before and after participants interacted with the robot. The questionnaire's pre exposure (Cronbach's alpha, $\alpha = 0.98$) and post exposure ($\alpha = 0.98$) internal consistency reliability was high.

Demonstration questionnaire

This questionnaire assessed participants' experience with the robot during the demonstration tasks (e.g., How much would you trust a robot to deliver over the counter medications? How useful would it be for the robot to remind you to refill your medication? How useful would it be for a robot to reach up high/low?), as well as their general attitudes toward using PR2 in their home (e.g., How willing would you be to have a robot in your home?).

Control methods
This questionnaire was used to assess participants' willingness to use a variety of control methods for interacting with a robot[47].

Structured interview
We developed a 5-part interview script for an in-depth qualitative assessment of older adults' attitudes toward assistance from a robot. Part 1 involved systematically introducing the idea of a robot for assistance at home, and focused on appearance and control aspects of the robot. Parts 2-4 inquired about opinions related to each of the tasks demonstrated by the PR2. Part 5 was comprised of closing questions such as "If someone gave you this robot today, would you want it in your home?"

Procedure
After arriving at the Aware Home, participants signed an informed consent document and then completed questionnaires. Prior to exposure to the robot, participants were given a brief overview of the functioning of the robot in lay terms. They were also assured that the robot was safe and the researcher could stop the robot anytime via the run-stop button, if they felt uncomfortable. To minimize demand characteristics, participants were made aware that the researchers and interviewers were not the designers of the robot. Moreover, the programmers were not present during the experiment. Instead, the demonstrations were programmed so they could be executed autonomously and without programming expertise.

At different points during the study, participants witnessed from a close proximity the three different robot task demonstrations in the living room and kitchen area. Participants were informed that the robot independently performed these demonstrations (i.e., autonomously). We made clear that the robot was not limited to what the older adults witnessed. After each demonstration, participants were taken to a private room where they were interviewed and encouraged to think of their present and future needs. The entire study lasted about 2.5 hours. At the end, participants completed additional questionnaires, as well as were debriefed and compensated for their time (*Table 2*).

Table 2. Procedural flow of the study

Procedural flow	Methods used
PRE-questionnaires	Demographics questionnaire Robot opinions questionnaire-PRE Assistance preference checklist-PRE Robot familiarity & use questionnaire
Introduction	Informed consent and introduction
Demo 0	Robot shown to the participant
Interview: Part 1	Questions on appearance and control
Demo 1	Robot hands off medication bottle
Interview: Part 2	Questions on medication management
Demo 2	Robot turns off a light switch
Interview: Part 3	Questions on robot learning new tasks
Demo 3	Robot organizes items at a table
Interview: Part 4	Questions on cleaning and organizing
Interview: Part 5	Concluding questions
POST-questionnaires	Demo-specific questionnaire Methods of control questionnaire Robot opinions questionnaire-POST Assistance preference checklist-POST

Results
Interview analysis
The audio recordings were professionally transcribed verbatim. Transcripts were segmented into units of analysis; the focus of the segmentation was to categorize participants' first impression affect (e.g., positive or negative). The second focus was to identify categories that drove their positive/negative first reaction. A segment was defined as a statement or description, that answered an interview question. For example, a participant's entire response to "what was your first reaction to the robot performing ____ task" was considered a segment. This segmenting approach was used to maintain context and completeness of the participants' lengthy and thoughtful responses.

Next, a coding scheme was developed to categorize each segment. We developed the coding scheme by reviewing a random sample of two transcripts and extracting common themes based on themes already known to be related to acceptance (i.e., a top-down approach based on the literature). Also, an iterative category generation strategy was used. In this approach, the first segment was coded either on a category already included in the coding scheme, or assigned a new category label determined by the researcher that describes the general idea of that segment (i.e., a bottom-up approach). Therefore, each segment was grouped naturally by its label(s).

Four coders were calibrated by conducting two rounds of independent coding on the same two randomly selected transcripts. Each round was followed by discussion of discrepancies and revision to the coding definitions. The final round of reliability resulted in an average of 90% agreement among the four coders (defined as the proportion of agreeing judgment coding pairs between the four coders). The remaining transcripts were divided among the four coders to code independently.

The following results are organized based on the participants' responses to the three tasks the robot performed. For each task, the participants' initial impressions are reported, then data about the reasoning driving their first impressions are reported.

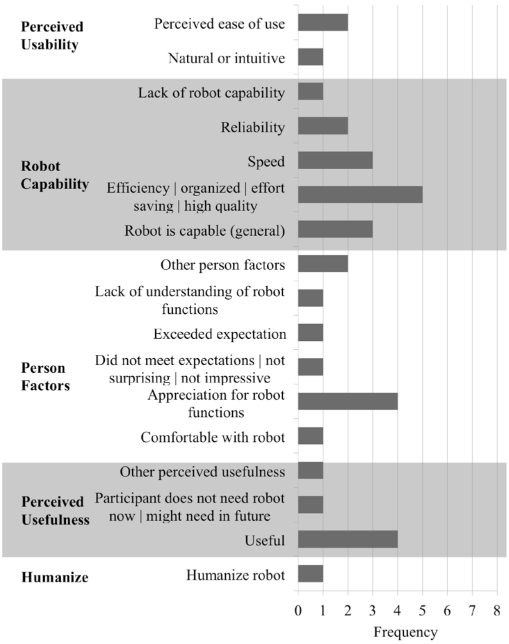

Figure 1. Reasons for first impression of medication delivery

Medication delivery task

When asked "what is your first impression of the medication delivery task?", a majority of the participants responded positively (9 of 12 participants). Two participants were negative, stating that the robot was slow. One participant conditionally liked the task, stating that, while it may not be useful for them currently, they could imagine it being useful in the future. We asked participants to elaborate on why they held certain first impressions. As depicted in *Figure 1*, they reported many factors influencing their first impressions. We coded their responses (as shown in the bar chart), and then further categorized each code into five larger themes (i.e., perceived usability, robot capability, person factors, perceived usability, and humanize).

The reasoning behind their impressions was largely the robots' capability. For example, they recognized that the robot would save them time and effort by retrieving medications. Person-related factors were mainly categorized as an appreciation or liking toward the robot.

When the older adults were asked whether they would prefer the robot to deliver a bottle versus individual pills, 8 of the 12 participants indicated a preference toward the bottle. This preference was driven by the older adults' perceptions of reliability. With 4 of those older adults stating that it would seem more reliable and less likely for error if the robot delivered the bottle. The remaining 4 participants who did not specify a preference for bottle delivery stated that they were not sure. They said it depended on the robots' capability as well as their own; one participant stated, "Today, the bottle would be fine. If the roles change and the robot is thinking more clearly than I about how many [pills] do I take, then yes…ideally [the robot would] give you what you need and only what you need."

Finally, participants were asked if compared to their current method, would robot medication delivery increase their likelihood of taking medications. The responses were split, with 5 older adults responding 'yes', 5 responding 'no', and 2 that said conditionally 'yes' if their capabilities declined with age.

Learning light switch task

Participants' reactions were mixed regarding their first impressions of the light switch task, with a range of positive (4 participants), negative (3 participants), and conditional responses (4 participants). One participant's first impression was unclearly stated and not able to be categorized.

Robot capability (16 times mentioned) and person factors (13 times mentioned) influenced the older adults' first impressions (*Figure 2*). Regarding robot capability, many participants (7/12) had an issue with the speed; they thought that three attempts to learn the light switch seems too tedious for what they perceived as a straightforward task. However, overall the

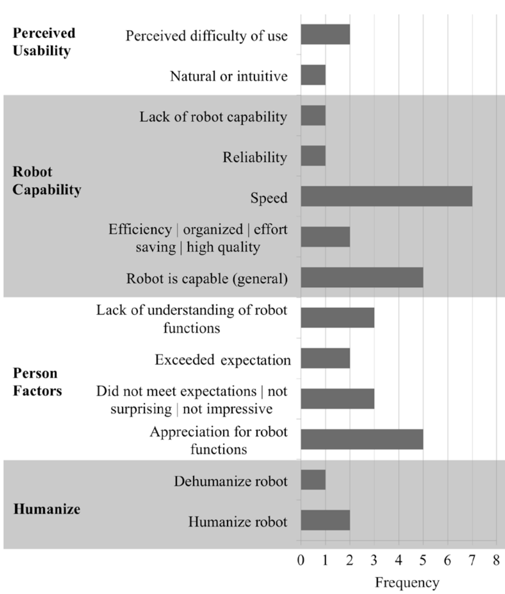

Figure 2. Reasons for first impression of turning off light switch

participants did like the idea of the robot being capable of learning.

Person factors related to the light switch task were mixed. Some participants said the robot failed to meet their expectations; "I thought it was overly tedious, labored, cumbersome." Others were more positive, "I think [it is] quite impressive, simply because you were not controlling [the robot]…it actually used logic to go up there, scan the wall, find the switch…" When asked if it is okay for the robot to make mistakes while learning a task, the majority of the older adults said this is okay (7). None of the participants had an outright objection to the robot making mistakes. Those older adults who had mixed feelings about it (4) said that it would be okay as long as the mistake did not cause damage to the home. The primary reason for older adults' opinions on making mistakes related to humanizing the robot. For example, participants indicated that it would be expected of the robot to make mistakes while learning, because that is what people do. "Well, even when you're learning something, you make mistakes. So why should I expect a machine to do something better than me?"

Organizing objects task

Older adults' first impressions of the organization task were very positive, with 10 participants liking the task. This is in line with previous findings[7,8,11,18,26-27,48-50] suggesting that robot organization and manipulation of household items/clutter is a task many older adults would find desirable. One participant said, "well, from watching him [the robot] I could see that I could get him to really get my stuff organized, like I can never keep plastic stuff organized… he could just keep everything organized for me." The participants' first impressions (*Figure 3*) were largely driven by appreciation for how well the robot performed the task, particularly the robot's speed. The participants also discussed how the task could save them time and energy. Due to age-related changes, picking up clutter can be cumbersome, particularly when stooping low or reaching high is required.

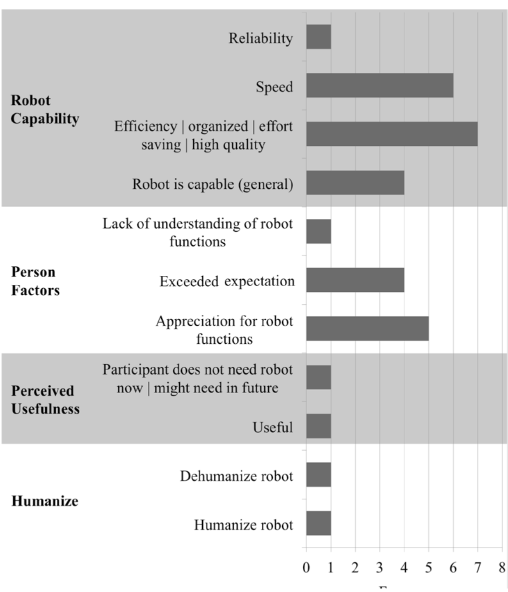

Figure 3. Reasons for first impression of organizing objects

Robot opinions questionnaire

The robot opinions questionnaire measured participants' perceptions of usefulness and ease of use of robots. Histograms representing the change between pre exposure and post exposure with the robot are depicted in *Figure 4* and *Figure 5*. The histograms show a general trend of participants' perceptions on usefulness and ease of use becoming more positive after exposure to the robot ('post' black bars vs. 'pre' grey bars).

The older adult participants were generally open to accepting robots as evidenced by the median scores of the Pre Robot Opinions Questionnaire (*Table 3*). Wilcoxon sign-rank statistical tests were used to compare the pre and post robot exposure medians. A significant increase in positive responses was found for 8 of the 12 interview items (3 perceived usefulness items and 5 perceived ease of use items). In general, the median responses changed from 5 (slightly likely) to 6 (quite likely).

Assistance preference checklist

The Assistance Preference Checklist was administered both pre and post study. Of the 58 tasks, 18 significantly changed from pre to post, with participants being more open to robot assistance. For these tasks (*Table 3*), participants' median responses increased from a 2 (slightly unlikely) to a 3 (neither unlikely or likely), or from a 3 (neither unlikely or likely) to a 4 (slightly likely), or the median remained the same but the range of responses decreased with a trend toward preference for robot assistance. Thus for these tasks, exposure to the robot increased the participants' openness to robot acceptance.

To identify post exposure tasks for which older adults either preferred human or robot assistance, we conducted one-sample Wilcoxon sign-rank tests to compare each post study questionnaire task median against 3.00, which represents no preference. The current post study data yielded similar trends compared to Smarr et al.[7]. In Figure 6, we presented the Assistance Preference

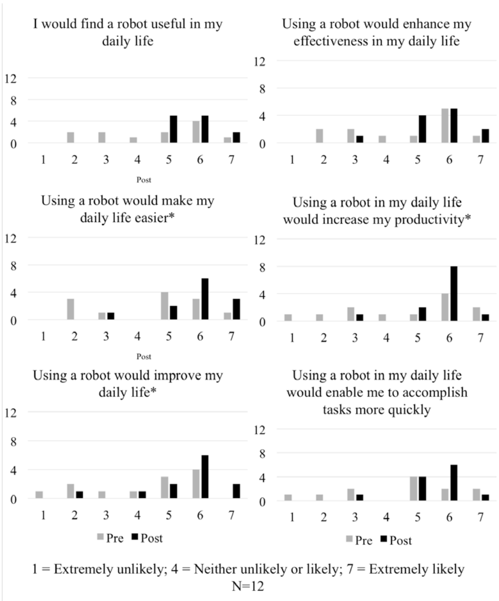

*Figure 4. Histograms of pre and post robot exposure on perceived usefulness questionnaire items; *indicates significant difference between pre and post robot exposure (p < .05)*

Checklist item means (and standard errors) organized by categories.

Conclusion

We found that exposure to robots matters. Demonstration of a mobile manipulator within the context of the Aware Home and the exposure to the robot performing the task yielded a richly detailed set of comments from the older adults. They were well able to imagine a robot in their own home and verbalize their opinions about the potential costs and benefits of a mobile manipulator robot for their needs.

First, older adults were overall very positive about the three tasks that they observed the robot perform. The most commonly mentioned reasons behind their first impressions were driven by robot capability. The capability of the robot's performance impacted how open the participants were to a robot providing assistance with medication delivery, learning to turn off light switches, and organizing objects.

Even topics categorized under person factors were related to robot function. Commonly mentioned person factors often included the participants' pre-existing expectations of what the robot could do, or their level of understanding regarding how the robot works or functions. In sum, first impressions, for this study, were function-oriented. These findings are in line with previous studies[7,8].

Additionally, participants' perceptions of reliability were important. However, older adults did express tolerance for mistakes. For example, some older adults felt it was acceptable for a robot to make mistakes while learning, because that is what humans do. Their tolerance for mistakes was maintained as long as the robot was not perceived as inefficient for the sake of learning. This poses an interesting trade-off for robot mistakes versus efficiency, suggesting a threshold of tolerance for mistakes.

Criticality of mistakes was also mentioned regarding welfare of the home, for example, the robot might knock over knickknacks or run into walls/objects. Interestingly person's safety was not mentioned; the older adults were less concerned with the possibility that the robot could bump into them, causing physical harm, than they were with the robot damaging their home. This could be due to the safety measures we had in place; we explained to the participants that they could tell us to 'stop' the robot at any time. However, the older adults' overconfidence in personal safety is worrisome. No robot is 100% reliable; thus, older adults should have realistic knowledge about how to properly and safely operate a home robot.

Our second research goal was to determine if older adult preferences and attitudes toward assistance changed from pre to post exposure. In previous works[7,8,26,27], pre and post attitudinal

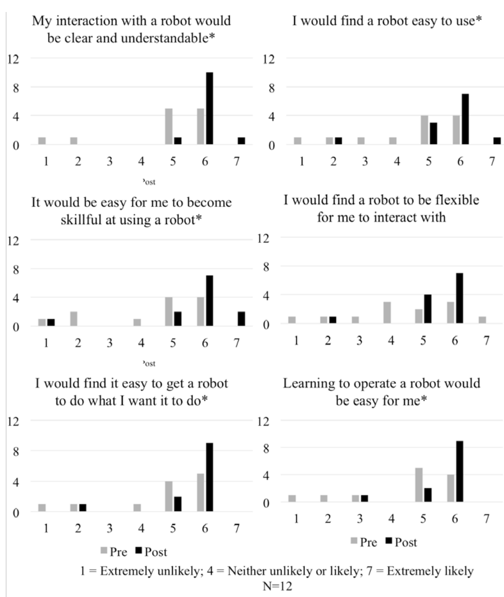

*Figure 5. Histograms of pre and post robot exposure on perceived ease of use questionnaire items; *indicates significant difference between pre and post robot exposure (p < .05)*

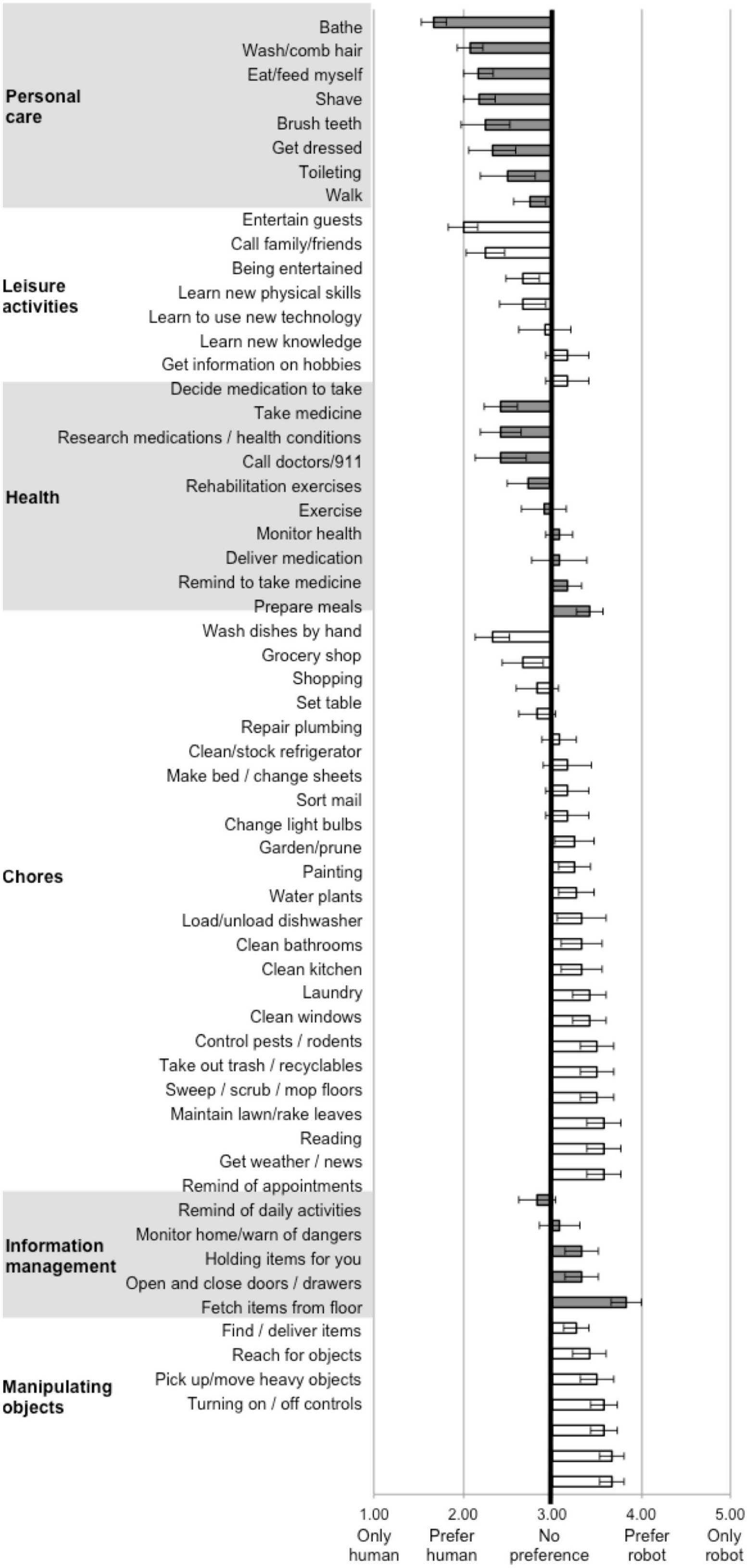

*Figure 6. Assistance Preference Means; Bold line = 3.0 no preference; Means < 3.0 (to the left of bold line) indicates preference toward human assistance; Means > 3.0 (to the right of the bold line) indicates preference toward robot assistance; * indicates tasks where older adults significantly (p<.05) preferred robot assistance compared to no preference (post study).*

Table 3. Pre and post robot-exposure results on a 7-point Likert-type scale: 1=extremely unlikely, 4=neither unlikely nor likely, 7=extremely likely; Mdn=Median value; *statistically significant ($p<0.05$); Z=Wilcoxon sign-rank test

Item	Pre Mdn	Pre Range	Post Mdn	Post Range	Z	n	p
Perceived usefulness							
I would find a robot useful in my daily life	5	2-7	6	5-7	-1.72	12	0.09
Using a robot would enhance my effectiveness in my daily life	5.5	2-7	6	3-7	-1.78	12	0.08
Using a robot in my daily life would increase my productivity	5.5	1-7	6	3-7	-2.02	12	0.04*
Using a robot would make my daily life easier	5	2-7	6	3-7	-2.59	12	0.01*
Using a robot would improve my daily life	5	1-6	6	2-7	-2.07	12	0.04*
Using a robot in my daily life would enable me to accomplish tasks more quickly	5	1-7	6	3-7	-1.62	12	0.11
Perceived ease of use							
My interaction with a robot would be clear and understandable	5	1-6	6	5-7	-2.41	12	0.02*
I would find a robot easy to use	5	1-6	6	2-7	-2.14	12	0.03*
I would find a robot to be flexible for me to interact with	4.5	1-7	6	2-6	-1.70	12	0.09
It would be easy for me to become skillful at using a robot	5	1-6	6	1-7	-2.14	12	0.03*
I would find it easy to get a robot to do what I want it to do	5	1-6	6	2-6	-2.33	12	0.03*
Learning to operate a robot would be easy for me	5	1-6	6	3-6	-2.15	12	0.02*
Assistance preference checklist							
Being reminded of daily activities	3	1-4	3	2-4	-2.12	12	0.030
Being reminded to take medicine	3	1-4	3	3-4	-2.33	12	0.020
Cleaning windows	3	1-4	4	2-4	-2.50	12	0.010
Controlling for pests/rodents	3	1-4	4	2-4	-2.33	12	0.020
Delivering medication	2	1-4	3	2-4	-1.99	12	0.046
Doing laundry	3	1-4	4	2-4	-2.46	12	0.010
Fetching objects from floor	3	1-4	4	2-4	-2.11	12	0.040
Gardening/pruning	3	1-4	3	2-4	-2.24	11	0.030
Getting information on hobbies/topics of interest	3	1-4	3	2-4	-2.24	12	0.030
Keeping refrigerator clean/stocked	3	1-4	3	2-4	-2.34	12	0.030
Learning new physical skills (e.g., dancing)	2	1-3	3	1-4	-2.00	12	0.046
Learning new skills (e.g., second language)	3	1-4	3	2-4	-2.65	12	0.008
Loading/unloading dishwasher	3	1-4	3.5	2-4	-2.45	12	0.010
Monitoring home/warning about dangers (e.g., fire)	3.5	1-4	4	3-5	-2.07	12	0.040
Painting (e.g., interior/exterior of home)	3	2-4	4	1-4	-2.00	11	0.046
Picking up/moving heavy objects	4	2-4	4	3-4	-2.00	12	0.046
Reading (e.g., bills, newspaper)	2	1-3	3	2-4	-2.65	12	0.008
Rehabilitation exercises	2.5	2-3	3	2-4	-2.24	11	0.030

measurement has not been a focus, thus this is an important contribution of the current study. To this end, we investigated older adults' perceptions of usefulness and ease of use via a robot opinions questionnaire (based on TAM[35]). There was a significant difference between pre and post for 8 of the 12 Robot Opinions items, suggesting that seeing the robot performing tasks in person, rather than on video, yielded an increase in positive perceptions of usefulness and ease of use. This may be due to the possibility of trialability and result demonstrability providing additional information to the older users that influenced their attitudes in a positive manner.

We investigated older adults' preferences for assistance with home tasks via the Assistance Preference Checklist. Task preferences identified in this study are consistent with the previous claims that older adults are open to robot assistance with chores, manipulating objects, and information management[7,11,26]. Older adults in this study preferred human assistance over robot assistance for tasks related to personal care and leisure activities, consistent with previous studies where older adults rated healthcare robots as least useful for social and personal tasks[7,26,27].

However, novel from previous studies, we administered the Assistance Preference Checklist both before and after exposure to the robot. Eighteen tasks significantly differed between pre and post exposure, with older adults showing a greater openness to robot assistance after exposure to the robot. This finding suggests that demonstration of robot capability positively affected older adults' preferences for robot assistance for tasks in the home.

Discussion

Advancing theory and application

This study provided richly detailed data to advance our understanding of robot acceptance. We discuss the primary contributions, in three sections: trialability, result demonstrability, and initial user attitudes (i.e., first impressions).

Trialability

In this study, participants took part in a 2.5 hour-long study in a home environment. The effect of trialability may explain our findings of pre vs. post exposure differences in perceived ease of use, where participants' perceptions of ease of use increased after exposure (*Figure 5*). Perceived ease of use was low during pre exposure, likely because of a mental hurdle in expectation that robots might be difficult or complex to use. The PR2 may have looked complex, but it performed autonomously. Participants expressed "surprise" in watching the robot perform tasks, and its functionality was beyond their initial expectation.

This finding is important for a few reasons. First, designers should consider ways in which older adults can use robots during a trial run (e.g., leasing) before committing to purchase, which may increase acceptance. Furthermore, it is important for designers to consider how to manage first impressions. How the robot is advertised, introduced, and physically designed (i.e., appearance[51,52]) will influence the users' expectations of its capability. This expectation should match the actual robot's capability. For example, after a short trial use of the robot, if the users' expectations of robot capability are not met, then the user will be very unlikely to actually adopt the robot. This might explain why some robots are designed to have a child-like appearance, which may increase the users' expectation that the robot may not perform perfectly, and will be required to learn.

Result demonstrability

Result demonstrability focuses on tangible results. We demonstrated three tasks: medication delivery, turning off light switches, and organizing objects. Participants focused not only on how it was done, but also what was done when the task was complete – in other words, they viewed the end product of each task. It is important to differentiate between how well a task is performed (perceived usefulness) and what is the result of a task.

In our study, participants were able to put themselves into a situation, within a simulated home environment, and see the results of a robot performing a task. Participants' attitudes did change as a function of result demonstrability, and became more positive after exposure. In fact, even when the older adults thought the robot performance was lacking (e.g., they thought the robot was too slow with learning how to turn off a light switch), the majority of participants still recognized and discussed the benefit of the result of the task itself – that assistance with light switches, medication delivery, and organizing objects is beneficial, even if the robot performed slowly. This is an important distinction because future studies should carefully distinguish between user's perceptions of task performance versus task results. These perceptions are related, yet separate, constructs, and important for predicting adoption of technology.

Initial attitudinal acceptance

In this study we investigated older adults' first impressions of a domestic robot, and reasons why they held those impressions. Understanding the reasons why older adults hold certain attitudes can help modify existing acceptance theories by honing on determinants of attitudinal acceptance – this is particularly important for radical technologies such as robotics. Our findings support the role of several variables in shaping older adults' attitudes, namely: humanizing the robot, perceived usefulness, person factors (e.g., expectations), and robot capability. Robot capability was the primary factor discussed during the interview for all tasks. This finding suggests that domestic robot acceptance could be reliant on task-technology fit[53]. Published robot acceptance models have not yet incorporated the role of task[30].

However, it is important to note that determinants of 'why' older adults hold certain attitudes are likely a lot more complex. Attitudes depend on both the robot and the task, as evidenced by our pie charts, which differed for each task. Our findings relate to only one class of robots, mobile manipulators, and other robots that may differ in appearance or function will likely be influenced by different attitudinal variables, or the same attitudinal variables but for different reasons.

Future directions

There are a number of methodological strengths to highlight in this study. We focused on trialability and result demonstrability. The robot demonstrations were an integral part of the current methodology, with the Aware Home providing a realistic home testing environment. These demonstrations were carefully chosen, based on previous data[7], as feasible home tasks that older adults might want or need help with as they age. We also demonstrated the robot making a mistake, instead of a 'best case scenario', so we could assess older adults' reactions to the very realistic possibility that a home robot will not always be perfectly reliable and will need to learn how to perform certain tasks.

We chose to use interview data and questionnaires as a primary means of understanding older adults' attitudes. We have used these methodologies in earlier work[7,8,10] and other HRI researchers have used them as well[11,26,27]. This mixed-method approach allowed us to address different aspects of our research questions. For example, the pre versus post exposure questionnaire was compelling in showing that exposure to the robot positively influenced the older adults' opinions and attitudes toward robots. However, when asked in the interview, the older adults suggested that their opinions had not changed much (this was a closing question). Thus, there was a mismatch between what they said, and what they indicated in the questionnaire. It could be because the interview questions were very general, whereas the questionnaire items tended to be more specific, which provided more context and cues for participants to decide what they felt about the robot or its assistance. This demonstrates why mixed-method approaches are beneficial, because asking the same question, but in different formats, can yield different details in users' responses.

Using a mixed-method approach is not without its caveats. Although our sample size is relatively small (n = 12), it is typical for qualitative research. The in-depth nature of the interview provided us with ample data to analyze and better understand the reasoning behind why participants held certain opinions. However, to systematically investigate the effect of trialability, longer-term studies are needed with larger sample sizes for statistical analysis. Secondly, we chose to investigate independently living older adults because most older adults live independently in their own homes as they age[3]. We recognize that due to our specific sample demographics, our results may only generalize to the healthy older adults who live in their own homes in the United States.

We did not investigate older adults living in assisted living facilities, or older adults with disabilities[54], cognitive impairment[55], varying levels of robot/technology experience, or cultural differences. Investigation of these variables would be valuable in the future. Furthermore, our findings may not generalize to other types of robots or to other home tasks.

There are a number of future research directions. First, other age groups may have different perceptions and attitudes toward robot assistance. Furthermore, other user characteristics, such as technology experience, may influence acceptance. Our users had little to no prior experience with robots, so remains open questions: 1) how their attitudes would compare to those with more experience and 2) which of them would be 'early' or 'late' adopters of robots – an important consideration in the rate of diffusion of innovation[9].

Our study lasted 2.5 hours, longer than most HRI studies[11,26,27]. However, our data may still be affected by a novelty effect. Time is a component in the Diffusion of Innovation framework[9]. Longer-term HRI studies are needed to understand the role of novelty, and how attitudes, acceptance, and adoption evolve over the course of weeks, months, or years.

Next, the PR2 was not specifically designed for social interaction. The robot is a mobile manipulator designed to perform physical tasks. The robot's appearance may have influenced user perceptions of it performing socially-oriented tasks. Robots designed to assist in a social manner may be perceived differently, and appearance may play a different role in determining which tasks older adults are most comfortable when having a robot perform. For example, older adults generally prefer a more human-like robot appearance, however their preferences tend to be highly individualized and dependent on the type of task the robot might perform[51,52].

Lastly, the construct ease of use was not often mentioned in the interview. This may be due to the fact that the robot performed autonomously. However, not all domestic robots will perform autonomously; in fact, it is likely that many future robots will require sliding, or adjustable autonomy[56]. Therefore, investigation of usability warrants further study.

In closing, our findings suggest that there is much potential for older adults to benefit from robotic assistance. Robots are an emerging technology, and understanding users' attitudes, and the factors that influence such attitudes, are imperative to design accepted robots. Research with the older population is important for driving design, and increasing the likelihood of adoption when home robots are more widely deployed and commercially available.

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