Evaluating Older Adults' Interaction with a Mobile Assistive Robot

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***Abstract*— This paper presents findings from two deployments of an autonomous mobile robot in older adult low income Supportive Apartment Living (SAL) facilities. Design guidelines for the robot hardware and software were based on query of clinicians, caregivers and older adults through focus groups, member checks and surveys, to identify what each group believed to be the most important daily activities for older adults to accomplish physically, mentally and socially. After data analysis, hydration and walking encouragement were found to be critical daily activities, becoming the focus of our deployments. The aim of the deployments was to understand the efficacy of human-robot interaction and identify ways to enhance the robot design and programming. Through observation of older adults with the robot and post-interaction surveys filled out by the older adults, conclusions were drawn for further advancement of the robot to be tested in future deployments. Results overall indicated high perceived usefulness and growing acceptance of the robot by older adults with increased interactions.**

I. INTRODUCTION

Older adults are forming a much larger percentage of the population leading to a strain in the healthcare sector. It is expected that the population aged 65 and over in the United States (US) alone will double in the next 30 years [1], with similar statistics observed around the world [2]. Despite abundance of the facilities to accommodate the growing older adult population, there is a shortage of caregivers to staff these facilities [3]. With the scarcity of care options available, low-cost robots may be a solution for simple tasks that would normally be handled by a caregiver. Tasks essential to maintain older adults independence, such as toileting, eating, or bathing are called Activities of Daily Living, or ADLs. Furthermore, tasks referred to as Instrumental Activities of Daily Living, or IADL, are tasks such as using a telephone, cooking, doing laundry or using transportation [4]. Service robots can help older adults be more independent with ADLs and IADLs.

Previous research in older adult-robot interaction research has often focused on specific applications. For example, entertainment [5], social motivation [6], companionship [7], [8], hygiene [9] and reminders [10]. In one study [11], robots for elder care were categorized as rehabilitation robots (such as smart wheelchairs and artificial limbs) and social assistive robots (SAR) [25]. SARs are subdivided into service type and companion type (such as commercially known robots, Paro and AIBO)[23], [24]. Other studies [12] used both focus groups and questionnaires to investigate possible tasks for a health care robot in a nursing home. Some of the most commonly identified tasks include detecting a fall, calling for help, lifting heavy objects and hydration reminders. More recently, the Healthbot [13], [14] demonstrated the capability of entertaining older adults, as well as vital sign measurement, medication management and fall detection.

This paper focuses on both behavioral and technical aspects of human-robot interaction. More specifically, focus groups and surveys from not only an elder standpoint, but also from the standpoint of healthcare professionals. Through multiple deployments, design guidelines are developed. This paper focuses on the conclusions drawn from two initial deployments in a low income Supportive Apartment Living (SAL) facility where water and walking reminder activities were deemed to be important. Overall contributions include:

- Understanding robot interactions with elders in a low income SAL.
- Development of design guidelines for robot hardware for tasks determined to be important from stakeholder focus groups and surveys.

II. PRE-DEPLOYMENT DATA ACQUISITION: A MULTI-METHOD APPROACH

To help determine what tasks a robot in the older adult environment should do, clinicians, caregivers and older adults at a Program of All-Inclusive Care for the Elderly (PACE) were queried using focus groups and surveys. Older adults at this facility are 55 years or older, in need of medical care or supportive services, and state-certified as nursing home eligible. We conducted three separate focus groups with 5 older adults living in a Supportive Apartment Living (SAL) facility, 8 clinicians from the PACE center and 5 caregivers working at the SAL. Participants in the focus groups then completed surveys to verify the focus groups' findings. Lastly, we surveyed an additional 42 older adults of mixed ability and mobility, 14 PACE clinicians and 15 PACE caregivers to gather information from a larger group of people who did not participate in the focus groups, and see what was important for them. Confidentiality of all participants was maintained. The study was approved by the

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Institutional Review Board of the University of Pennsylvania and all subjects gave written consent. The process and phases involved in the qualitative study, with the respective number of participants and tasks can be seen in Figure 1.

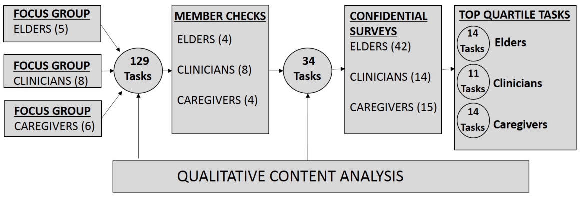

Fig. 1: Summary of the qualitative study process before deployments. Numbers in parenthesis indicate the total number of participants in each phase of the study.

A. *Focus Groups, Member Checks and Confidential Surveys*

From the focus groups [23] we identified 129 tasks that could be sorted into four themes: 1) Accomplishing Everyday Tasks, 2) Health and Safety Measures, 3) Personal Connections and Meaningful Activities, and 4) Cognitive Interventions.

Member checks, commonly known as participant verification and respondent validation [31] were used for further validation of data resulting from the findings on focus groups. The older adults, clinicians, and care givers were asked to rate the importance X_i of each task i selecting High (H), receiving a weight 3, Medium (M) a weight 2, Low (L) a weight 1, or Not Applicable (NA) receiving a weight 0. Members were also asked whether or not a respective task caused frustration, in which YES was coded as a 1 and NO as a 0, with average value F_i. In case a task was highly ranked by all clinicians, caregivers and older adults, its average importance was 3. Likewise, an average frustration level for a determined task would be 1 if highly ranked by all groups. Lastly, a confidential survey was conducted to gather information from a larger segment of the population at PACE. Survey participants were asked to rate 34 of the initial 129 tasks that were identified as most important in the same way as described for the member checks. The top quartile tasks were obtained by sorting the importance X_i and frustration F_i of the 34 tasks, leading to the final 14 tasks from elders and caregivers' perspectives and 11 tasks from clinicians viewpoint. From these highly ranked tasks, taking into consideration the most feasible, beneficial and efficient tasks that can be performed by a mobile-only robot at an affordable price, we selected water delivery and a walking encouragement as tasks to evaluate our system. Also, as a common practice at SAL facilities, following every interaction, the robot would request the older adults input regarding his or her current pain level. Appendices B-D present a summarized list of these ranked tasks for each of the three stakeholders.

III. System Description

Acceptance by both staff and bystanders is a critical first step to introducing mobile robots into service industries such as in healthcare and hospitality institutions. Design goals were set to develop an embodiment that garnered trust and empathy for the robot as well as addressed ergonomics, usability, and safety requirements. This study utilized the Savioke Relay mobile robot (Figure 2). The Relay robot has been designed for indoor delivery applications, where newer versions are currently used for room service delivery in hotels. Savioke identified three attributes that would help guide the design and interaction of the robot:

- Assume that every user is a first-time user
- Generate bystander empathy to make Relay more successful
- Honest design and managing user expectations

Peoples expectations have been set artificially high in robotics yet in reality, the field of robotics is still very much in its infancy. Being sensitive to this, Relay was designed to feel more pet than human, represented in the form of the robot with simple lines and an attentive posture. The user interface also addresses honesty by always disclosing the robots actions. This is achieved with simple messages displayed on his screen and iconic eyes to generate empathy without overstating its intelligence.

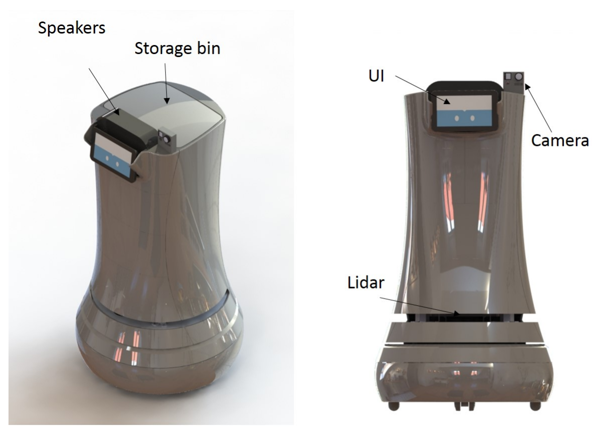

Fig. 2: The Savioke Relay robot, modified to the deployments at the SAL facilities.

A. *Hardware*

Multiple studies were performed by Savioke to understand the relationship between screen interactions and sentiments of intimidation by the robot. Participants were shown a variety of screen examples and asked to choose the ideal size laid flat on a table. The result of this design research concluded that subjects felt more comfortable when the top of the screen was below the horizon of their sight line. The position and design for Relays screen and payload were informed by ADA requirements [29] and informally tested against a variety of adult subjects. It was determined that a 0.8m height enabled a majority of people to interact with the robot in both seated and standing positions, with the goal of avoiding bending over or reaching out to access the payload and interact with the robots display.

The robot weighs 21kg, has a 177mm touchscreen monitor and uses arrays of Lidar and sonar sensors to navigate autonomously. It also has 21 liters of storage space, which includes a bin that is accessible by a robot controlled door on the top of the robot. A pocket camera was installed on the robot to record subject interactions and a speaker was added to enhance the sound, so older adults with decreased hearing could hear instructions.

B. Software

The Relay software includes a Savioke graphic programming language for creating new behaviors called CustomPrograms. The robot has a suite of actions, called primitives, to program user interactions [15]. These blocks can be organized in different hierarchies of menus to make the robot perform various tasks. Table I shows a few of the primitives that define the robots movement, user interaction and set of actions.

TABLE I: Example of Robot Primitives

Robot Movement	**User Interaction**	**Bin and Battery**
goTo()	displayMessage()	openBin()
move()	askMultipleChoice()	closeBin()
distanceTravelled()	askScale()	isLidOpen()
turn()	askNumber()	batteryPercentage

To help the interaction with older adults who may have poor eyesight and difficulty in reading the instructions, the robot spoke aloud any messages shown with the *displayMessage* function with text-to-speech.

C. Navigation

For the first deployment, we mapped the main floor where all participants lived by using the robots Lidar system and SLAM [28]. The map included public hallways and an elevator lounge, but did not include any older adult rooms, which the robot was not allowed to enter. Poses were defined in front of each room, so that the only requirement for navigation would be to input the room number. After completing a task, the robot returned to a homebase, defined as the elevator lounge. For the second deployment, which occurred at the PACE center, the robot navigation was remotely controlled by the observer and a camera mounted on the robot was used.

IV. Experimental Setup and Tasks

The first robot deployment took place at the SAL facility in Pennsylvania with older adults who were participants in the PACE program described earlier. Compared to other participants at the PACE center, the older adults in the SAL are provided with 24-hour home health care aides to assist them. The second robot deployment took place at the PACE center which includes approximately 460 older adults, most with an 8th-12th grade level of education and qualify for Medicaid, impoverished with limited previous access to technology. For both deployments, the older adults were consented and instructed on the robot sequence of actions before each interaction. All interactions were recorded and the reactions of the participants were evaluated by the observer based on the following criteria:

- Initial interaction and greeting by their name
- Facial expression of older adults (smile, frown, neutral)
- Participation in the task and specific task details
- Ability to understand and follow instructions
- Interaction with the robot user interface
- Request by the older adult for robot to return
- Observer intervention during interaction

The robot design requirements besides the obvious functional ones were:

- Simple user interface targeted for older adults with little or no experience with computers
- Ability to operate robot remotely and adjust task details to ensure interaction without human intervention or quick intervention if required
- Safe operation while interacting with the older adults.
- Appropriate language level and choice of a robot with an appearance to promote ease and comfort.

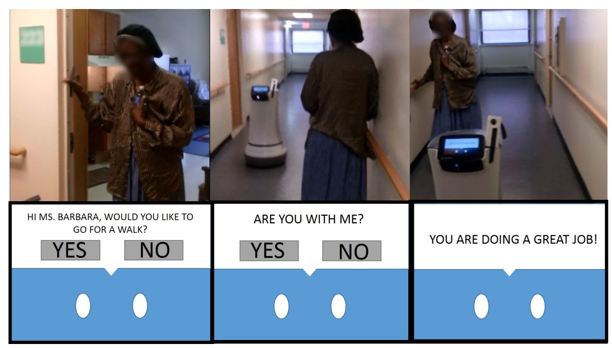

Fig. 3: Older adult waking on the hallway with the robot. Dialogues and screen options are shown below.

A. Water Delivery

Keeping older adults hydrated is becoming a challenging task, due to the loss of thirst receptors and short term memory loss as results of aging [17]. For this interaction, the robot was programmed to go autonomously to the older adults' room, make a knocking sound and wait for the older adult to open the door. Once the door was opened, the robot greeted the older adult and reminded them about the importance of being hydrated. It then offered water and asked when to make another water delivery (morning or evening). After the interaction and pain assessment, the robot returned to the base and reported to the observer whether the older adult accepted the water, the requested time for the next water delivery, and the current pain level.

B. Walking Encouragement

Physical activity is an important component of healthy aging [30]. In this walking task, the robot was teleoperated by the experimenter through a wireless joystick, with a camera mounted to aid navigation and to record the interaction (Figure 3). The robot traveled for 20 meters along the

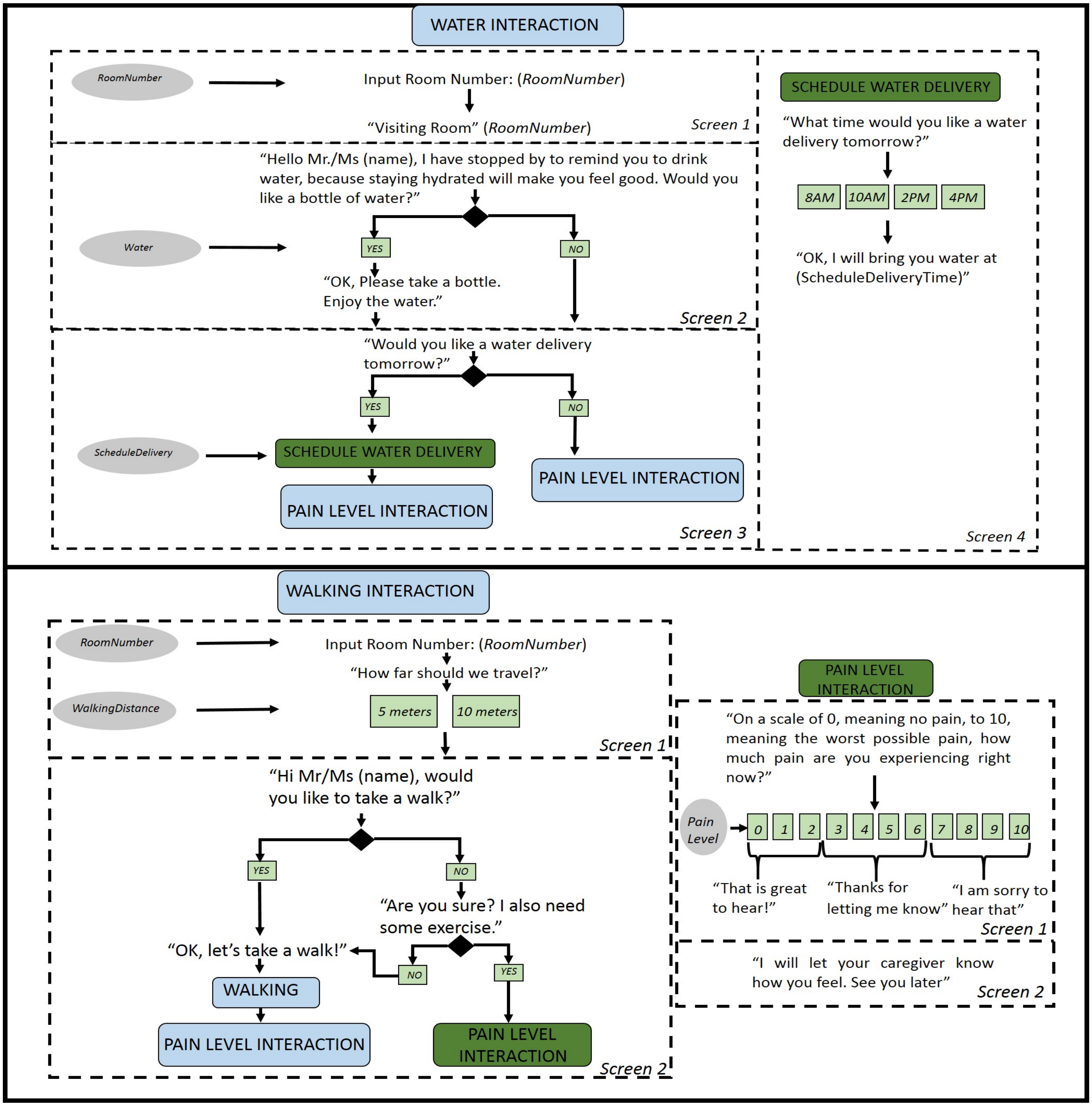

Fig. 4: Dialogues for water delivery, walking encouragement and pain level measurement. Light green buttons represent the touch options on the screen.

hallway, always maintaining a distance from the older adult and allowing them to dictate the walking pace.

C. Pain Assessment

Pain in older adults is generally under-assessed and under-treated [18]. Thus we regularly ask for levels of pain. To evaluate pain levels, a discrete visual analog measurement scale (DVAS) [19] was used as user interface. Depending on the input value from the older adult, the robot would respond differently (see Figure 4). Following the pain assessment interaction, the robot returned to the base, reported the results to the observer through the screen and in the event of reported pain, the observers would notify the caregivers. A detailed description of all tasks, dialogue and screen options are shown in Figure 4.

V. DEPLOYMENT RESULTS

The two robot deployments involved two different scenarios and levels of automation: the first deployment tested autonomous interaction with older adults by water delivery, while during the second deployment, the robot was teleoperated for walking tasks, encouraging the older adults to exercise. A total of 16 older adults interacted with the robot for both tasks: 4 older adults participated in the water task multiple times over the span of a week, and 12 older adults did the walking interaction over a two day period. The demographics of all participants is listed in Appendix A. Care was taken to avoid the observer (or "Hawthorne") effect during interactions, which refers to the change of behavior of the subjects in the awareness of the presence of the observers [22]. After every interaction, a post-interaction survey was conducted with the participant in order to better understand their reaction and record any change in response over subsequent interactions, according to the parameters on Table II, in accordance with the *Almere Model* [16].

TABLE II: Post-interaction parameters for surveying participants [16]

Anxiety during interaction	Attitude towards technology
Intention of use	Perceived adaptiveness
Perceived ease of use	Perceived sociability
Perceived usefulness	Social influence
Social presence and trust	Perceived enjoyment

A. First Deployment

The robot interacted with four subjects at the SAL location over the span of a week. Between the four participants, the robot performed 12 autonomous water deliveries twice per day (morning and evening). Participants were often uncertain about how to interact with the robot on their first encounter. In these instances, observers intervened to encourage participants. Observer interaction also occurred due to robot errors, such as people walking too close to the robot, which affected the autonomous navigation, dialog errors and the robot not being loud enough for the older adults with hearing problems. Results of the water interactions from the observer viewpoint can be seen on Figure 5.

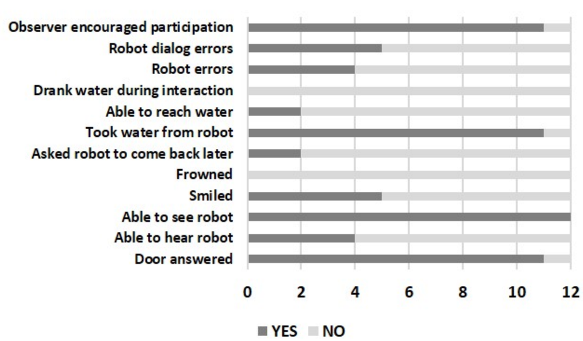

Fig. 5: Water Interactions from Observer viewpoint.

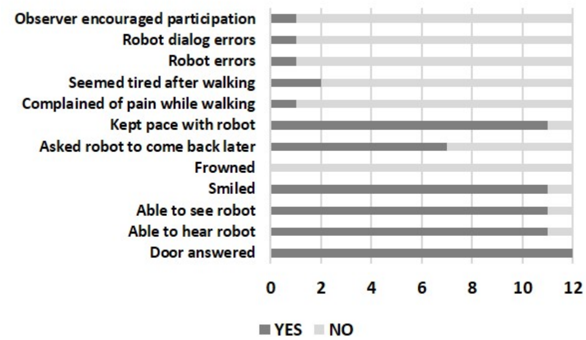

Fig. 6: Walking interactions from Observer viewpoint.

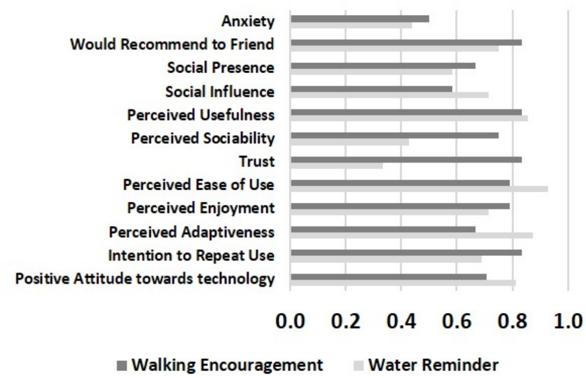

Fig. 7: Results of post-interaction surveys for both water delivery and walking encouragement tasks.

B. Second Deployment

The robot interacted with 12 elders, through teleoperation, walking with each elder for a distance of about 20 meters.

The robot operator, discretely distant from the elder and the robot, was cautious so that the robot would drive in pace with the walking elder, and would immediately stop if the elder also stopped (to catch their breath, for instance).

VI. Discussion

As a result of the deployments, some key observations, anecdotal conclusions and design guidelines regarding the robot hardware and the interaction itself can be discussed. Post-interaction survey responses (Figure 7) were weighted as: Very little = 0, Somewhat = 0.5 and Very much = 1. The maximum possible value, divided by the number of occurrences will be unity.

A. Observations

1) Observer Viewpoint: A comparison between the water and walking tasks from the observer viewpoint (Figures 5 and 6) shows great decrease in observer encouragement for the older adult participation. One factor is that, since the water task was autonomous, the observer needed to explain to the elder how to interact with the robot for the first time. Despite instructions however, most elders would get confused and forget to interact with the robot (tapping the touchscreen). In these cases, the observer would go over the entire interaction with the elder to make sure he or she comprehended how the interaction would occur. On the other hand, since the walking task simply involved walking and no touchscreen interaction, a more natural interaction was observed.

There were fewer dialogue errors for the walking task noted, and is attributed to dialogues played remotely (through a computer paired with the bluetooth speaker), allowing control over timing and repetition. Likewise, general robot errors were also lower in the walking task, since the robot was not relying on sensors (solely on teleoperation) and could get closer to the elder. Hearing the robot was also easier for the walking task, as the speaker was placed in front of the robot (rather than inside the storage bin during the water task).

2) Post-Interaction Surveys with Elders: From the post interaction surveys (Figure 7), taken by the observer immediately after each interaction, low values of anxiety were observed which is different than observed in some studies [26]. Anxiety in this context is usually associated with the fear of the elder in breaking the robot or doing something wrong during the interaction, or also finding the robot scary or intimidating [27]. However, the nature of the tasks (requiring only touchscreen and water bottle retrieval from the bin) and robust appearance of the robot may have contributed for low anxiety.

Various parameters like perceived usefulness, perceived ease of use, perceived enjoyment and intention to repeat use were rated highly by the participants. This shows that the robot and the interactions with the robot were well received by the older adults. This high rating is also partly explained because the subject population had a considerably high rating for positive attitude towards technology. Regarding social presence, high rating values may be due to the fact that tasks were done at the PACE center with other people present. It was observed that the human-human interaction was enhanced by the presence of the robot, which may have changed the perception of the social presence of the robot itself. Particularly, sociability increased for the walking task, as it was observed elders would commonly greet their peers and smile on the hallway while walking with a robot - not a normal everyday occurrence.

Trust on the robot was much higher for the walking task, compared to water delivery task, which could be explained by the smaller number of errors that occurred when teleoperating the robot to encourage walking, compared to the errors during autonomous water delivery. There were also limited observer interactions in the walking task compared to the water delivery task.

B. Anecdotal Conclusions

- Having older adults as a target community has difficulties not found in other demographics. The older adults who agreed to participate in the study often forgot, changed their minds or became too ill to participate. Also, the lower income target demographic had issues such as bed bug infestations, closing down testing. This mainly affected the first deployment, limiting the number of older adults available for the study.
- Including specific details about the older adult i.e. birthday date, or weather and news in interactions often made the older adults more positive about technology and increased the perceived sociability towards technology.
- In general, older adults were truthful about their pain level, consistent with what they would inform to caregivers.
- For the walking task, the participants were asked which name they would like to be called by the robot (which would then be programmed to say during the interaction). This seemed to have a positive effect.
- One participant related to the robot as a social presence demonstrated by her calling the robot "Jim".

C. Design Guidelines

Considering the current design of the deployed robot and its considerations (Section III), improvements relating observations with possible design guidelines can be inferred. Table III presents some insights on possible design modifications for future robot deployments of the robot based on these observations from both deployments.

TABLE III: Design Guidelines based on observations during both deployments

OBSERVATION	DESIGN GUIDELINE
Tendency to read instead of listen to instructions.	Use larger fonts for written text
Difficulty in touching on screen buttons for 0-10 scale for pain assessment	Bigger buttons on the screen, or physical buttons on the robot instead
Older adults requested the robot to repeat the instructions	Add "repeat" function or button
Tendency to answer YES/NO questions verbally instead of choosing on-screen options.	Implement YES / NO voice recognition
Low volume complaint (High pitch voices for older adults represents the most difficult hearing frequency in the vocal range [20])	Louder speakers, or change location to front of the robot.
Elders in walkers or wheelchairs could not easily reach the bin	Bin opening to the side (not the top) of the robot
Elders in walkers or wheelchairs could not touch buttons on the screen	External physical buttons and PAN/TILT tablet mount
Elders confused robot eyes with screen buttons	Better user interface design or physical buttons

VII. Conclusion

This study describes robot interactions with elders in a low income SAL facility, presenting guidelines for the design of the robot hardware based on human-robot interactions using tasks determined to be important from previous stakeholder focus groups and surveys.

Two highly rated tasks requiring a mobile-only robotic base were chosen for study and the robot was adapted to perform both. Data was collected on the robot performance including aspects of human-robot interaction to help in the design of robots and interaction in future deployments, where we plan to integrate an arm onto the mobile base. We will then be able to address a wider range of highly ranked tasks (according to our need finding study). Tasks such as fetching objects on the floor and in cabinets or opening doors emerged on the focus groups and surveys, as in other studies [19], [15], [4] and future deployments will evaluate the usability and acceptance of the robot in performing those tasks.

APPENDIX A: Participant Demographics for All Deployments

Gender	Male 9	Female 7	**Total** **16**
Age	55-65 1	66-79 13	80 or older 2
Race	African American 15	Other 1	**Total** **16**

APPENDIX B: Top 14 Tasks from Confidential Surveys and Member Checks identified for Elders

ELDERS	**CONFIDENTIAL SURVEY (N=42)**			**MEMBER CHECK (N=4)**		
	Rank	X_i	F_i	Rank	X_i	F_i
Having additional assistance when pain flares up	1	2.89	0.52	5	2.5	1
Outings (casino, theater, shopping)	2	2.42	0.42	1	3	1
Having your food preferences known	3	2.41	0.44	9	2.33	0.67
Getting a drink	4	2.27	0.18	1	3	1
Being asked about your preferences	5	2.26	0.47	6	2.5	0.75
Having assistance with being in bed (changing position, putting on blankets)	6	2.26	0.26	5	2.5	1
Having caretakers help keep your spirits up	7	2.26	0.206	5	2.5	1
Reaching things on high shelves	8	2.24	0.48	6	2.5	0.75
Getting around in a wheelchair	9	2.21	0.29	1	3	1
Walking	10	2.12	0.4	7	2.5	0.5
Games, including bingo	11	2.08	0.208	8	2.5	0.25
Caretakers working to increase your socialization opportunities	12	2.07	0.25	3	2.75	0.75
Having clothing taken out	13	2.04	0.36	9	2.33	0.67
Having assistance finding items in the closet	14	2	0.44	4	2.67	0.67

APPENDIX C: Top 11 Tasks from Confidential Surveys and Member Checks identified for Clinicians

CLINICIANS	**CONFIDENTIAL SURVEY (N=14)**			**MEMBER CHECK (N=8)**		
	Rank	X_i	F_i	Rank	X_i	F_i
Providing Input	1	3.0	0.3	21	2.75	0.13
Evaluating Homes for Safety	2	3.0	0.25	2	3.0	0.43
Coming up with ways to keep someone safe at home	3	2.93	0.62	2	3.0	0.43
Toileting	4	2.92	0.25	15	2.8	0.60
Matching cognitive ability to tasks	5	2.92	0.36	6	2.88	0.38
Confirming that members have taken medications	6	2.91	0.6	4	3.0	0.33
Reminding members to drink (water, health drink)	7	2.91	0.36	8	2.86	0.33
Checking weights	8	2.90	0.56	11	2.86	0.14
Providing a listening ear	9	2.85	0.25	21	2.75	0.13
Providing companionship to members when they are upset	9	2.85	0.25	16	2.88	0.13
Having small conversations with members	10	2.85	0.17	21	2.75	0.13

APPENDIX D: Top 14 Tasks from Confidential Surveys and Member Checks identified for Caregivers

CAREGIVERS	**CONFIDENTIAL SURVEY (N=15)**			**MEMBER CHECK (N=4)**		
	Rank	X_i	F_i	Rank	X_i	F_i
Making sure members ate and are not missing meals	1	3.0	1.0	5	3.0	0
Providing a listening ear	2	3.0	0.11	4	3.0	0.25
Assisting members with taking medications	3	3.0	0	5	3.0	0
Helping members get ready for the doctors /providers apt.	3	3.0	0	4	3.0	0.25
Preparing meals	3	3.0	0	4	3.0	0.25
Working with members with physical challenges and need extensive assistance	3	3.0	0	4	3.0	0.25
Assisting with morning routines	3	3.0	0	3	3.0	0.33
Helping members comply with care plans	3	3.0	0	2	3.0	0.5
Encouraging members to see nurses when not feeling well	3	3.0	0	1	3.0	0.67
Providing companionship to members when they are upset, depressed or lonely	3	3.0	0	4	3.0	0.25
Matching cognitive ability to task	3	3.0	0	5	3.0	0
Providing comfort measures to members	3	3.0	0	5	3.0	0
Reminding members to use their walkers	3	3.0	0	5	3.0	0
Helping members reach things on high shelves	3	3.0	0	5	3.0	0

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