Older Adults' Medication Management in the Home: How can Robots Help?

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***Abstract*— Successful management of medications is critical to maintaining healthy and independent living for older adults. However, medication non-adherence is a common problem with a high risk for severe consequences [5], which can jeopardize older adults' chances to age in place [1]. Well-designed robots assisting with medication management tasks could support older adults' independence. Design of successful robots will be enhanced through understanding concerns, attitudes, and preferences for medication assistance tasks. We assessed older adults' reactions to medication hand-off from a mobile manipulator with 12 participants (68-79 years). We identified factors that affected their attitudes toward a mobile manipulator for supporting general medication management tasks in the home. The older adults were open to robot assistance; however, their preferences varied depending on the nature of the medication management task. For instance, they preferred a robot (over a human) to remind them to take medications, but preferred human assistance for deciding what medication to take and for administering the medication. Factors such as perceptions of one's own capability and robot reliability influenced their attitudes.**

***Index Terms*—Aging, assistive robots, delivering medication, home environment, medication management, older adults.**

I. Introduction

A. Medication Management in the Home

There is a growing need in society to enable older adults to remain in an independent living environment. Many older adults fear losing their independence and being required to move to an assisted living environment. Difficulty in efficiently managing medications is one of the main predictors of older adults' transitions into assisted living facilities [1].

Difficulty with medication management arises from the complexity of the regimen many older adults have to follow (e.g., multiple medications, side-effects, schedules) [2]. Five of six adults aged 65 and older take at least one medication; nearly half take three or more [3]. Additionally, deficits in cognitive and physical capabilities (e.g., working memory and movement control) impede skillful medication management among older adults [4]. Consequences of improper medications can be serious. Preventable errors contribute to 33-69% of hospital admissions [5]. Technology, such as robots, can assist older adults with managing their medications.

Fig. 1. PR2 handing off medication bottle to the participant.

Many approaches for medication-adherence have been researched: convenient care, education programs, counseling, reminders, self-monitoring, and family therapy [6]. Short-term approaches to medication adherence can be effective, particularly counseling, written information, and personal phone call reminders; however, for long-term medication adherence, no simple intervention, and only some complex ones, can improve health outcomes. Innovative approaches to assist patients in medication management are needed [7].

B. How Robots can Assist with Medication

From a societal perspective, it is cost-effective to support older adults' preference to age in their own homes. Economic implications of transitioning to full-time residential care settings are substantial to individuals and society. Given current demographics, the projected costs will exponentially increase [8]. Mobile robots that manipulate the world (mobile manipulators) have potential to support older adults in their homes; including assistance with medication management. Mobile manipulators are an emerging class of robots with potential to assist diverse users with a wide variety of tasks.

Autonomous mobile manipulators presenting timely, in-person reminders could provide both the motivation and the means to improve adherence without significant caregiver or care-receiver burden [9]. In essence, an autonomous mobile robot could be tasked with delivering the right medication to the right person at the right time. Along with the medication, the robot could also provide the means to take the medication (e.g., a glass of water) and motivation through established psychological bonds (e.g., reciprocity) that are commonly developed between social robots and their owners [10].

Although researchers have started to note opportunities for mobile manipulators to help older adults with health-care tasks (e.g., [11, 12]), application of such robots for medication support in the home is not well researched. A recent exploratory study examined the feasibility of a touch-screen based robotic system for medication assistance for older adults and reported positive reception of the robot [9]. However, to be successful in supporting older adults with medications in their homes, the development of the robotic technology will have to involve a more in-depth understanding of older adults' needs and attitudes, and interaction challenges that arise in the home environment. Despite needs for assistance, older adults have concerns for becoming overly dependent on assistance[13]. Independently living older adults prefer compensatory support that can help them with the difficult aspect of the task while allowing them to do what they still can and want to do[14]. The same may be true for tasks specific to medication management; older adults may want to continue to perform certain aspects of medication management tasks.

Perceptions of and attitudes toward robots have been suggested to predict robot acceptance [11]. Older adults may not be uniformly open to robot assistance for all home-based activities but may prefer human assistance for some activities [15]. Thus, it is important to understand preferences for specific tasks and task demands. For example, medication management is an instrumental activity of daily living required for living independently [16], yet it comprises multiple aspects including cognitive and physical. Assistance with cognitive aspects includes reminding the person to take medication, deciding the right medication to take, and researching medications and health conditions. Assistance with physical aspects includes delivering medication, opening/closing the bottle, and administering the medication. Preferences for assistance may vary across and within these aspects. Other variables such as motivation and self-efficacy also affect medication adherence [6, 17] but in this study, we primarily delved into the cognitive and physical aspects.

C. Goals of Current Research

Incorporating end-users' perspectives into design of robots could benefit from collaborative efforts from roboticists and human-factors specialists. Through such an interdisciplinary collaboration, we designed a mixed-methods exploratory study to gain insights into factors that influence older adults' attitudes toward a mobile manipulator for supporting medication management. We focused on three specific goals:

- Investigating older adults' reactions to medication delivery by a mobile manipulator in a home environment.
- Understanding older adults' preferences and attitudes toward a robot assisting them with general medication management tasks.
- Specifying implications for the design of assistive robots for older adults.

II. METHOD

We combined quantitative and qualitative methods: quantitative data from questionnaires to provide an indication of participants' preferences for robotic assistance and qualitative data from structured interviews to understand the underlying reasons for specific preferences (i.e., the *why*).

A. Participants

Participants were 12 independent living older adults (6 males) aged 68-79 years (M=72.58; SD=3.87) recruited from the community of Atlanta, GA, USA. The sample was racially diverse: half the participants reportedly White/Caucasian and the other half Black/African American. Additionally, they were educationally diverse; half the participants reported holding a Bachelor's degree or higher. Participants reported taking five medications on average and their 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). Most familiarity was reported for entertainment/toy robots (e.g., Aibo, Furby) and least for remote presence robots (e.g., Texai, Anybot). However, participants reported little to no experience in using them.

B. Materials and Apparatus

1) Robotic Platform - Willow Garage's Personal Robot 2 (PR2): We used the PR2 to gauge older adults' reactions to a robot assisting them with medication management. The PR2 is a human-sized commercially available mobile manipulator but is primarily used in research. Characteristic features of the PR2 include an omni-directional wheeled base, two 8 DOF arms/grippers, a telescoping spine, and a pan-tilt head carrying two stereo camera pairs and a LED texture projector. The robot is capable of manipulating objects (with its grippers) and autonomously navigating around human environments.

2) Aware Home Research Facility: The Aware Home Research Facility at Georgia Tech is a unique three-story, 468 square meter home-like laboratory designed to facilitate research with home-based assistive technologies (www.awarehome.gatech.edu). This facility provides a home-like venue to better understand older adults' interactions with a robot in an authentic home environment.

3) Medication Hand-off Demonstration: The PR2 was programmed to execute a medication hand-off task to the participants (Figure 1). We developed custom hardware and robot behaviors to interact with long-range ultra high frequency (UHF) radio frequency identification (RFID) tags which are small, thin, low-cost (sub-$0.25), passive (battery-free) tags that can be affixed to locations, objects, and people [18, 19]. By tagging medication bottles and having people carry UHF RFID tags, a robot could use RFID search to acquire a medication and then discover, approach, and deliver it in a timely fashion. Several properties of UHF RFID make it particularly beneficial in this scenario. Human environments contain a wide variety of objects, which can move within the environment and are often hidden by other objects. This makes identification and localization via cameras and other line-of-sight sensors difficult for robots. By affixing UHF RFID tags to important objects in an environment, robots can use each tag's unique identifier (ID) and signal strength from each tag (RSSI) to identify and localize objects. For a medication delivery task, a robot in a home environment could retrieve a tagged medication and deliver it to a user wearing a tag. The extremely low false positive rate in identifying an RFID tag reduces the odds of the robot retrieving the wrong medication or delivering to the wrong person.

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:

- The medication delivery algorithm started with a navigation step, where the PR2 moved from any (initial) starting location in the Aware Home to the center of the living room. Navigation was performed using a variant of FastSLAM localization coupled with an A∗ global planner and dynamic window local planner from the open source Robot Operating System (ROS) navigation stack [20].
- From this vantage in the center of the living room, the PR2 panned its directive antennas back and forth to search for the tag ID being worn by the recipient. If the intended recipient was detected, the robot used the resulting signals to estimate the bearing toward the individual, and then oriented itself to face him or her [18, 19].
- Making continuous readings of the UHF RFID tag worn by the recipient, the robot slowly moved forward (at 10 cm/sec). The robot used the difference between the RFID signals from its two antennas to adjust its heading, stopping within 10 cm of an obstruction - either nearby furniture or the intended recipient [18, 19].
- The robot reached out its hand (with the medication bottle) to a fixed position and monitored the values of its finger-mounted tactile sensors. When the recipient 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.

4) Questionnaires: We report only questionnaires relevant for the scope of this paper. Additional questionnaires were administered as part of the larger study (see Table I).

a) Demographics Questionnaire: Participants provided demographics, general health, and technology experience information before the study via a questionnaire [21].

b) Robot Familiarity and Use Questionnaires: Prior to the study, participants indicated familiarity with 13 different robot types. The response scale was 5-point (0= not sure what it is, 4= have used or operated this robot frequently).

c) Assistance Preference Checklist: An Assistance Preference Checklist revised from a previous study [14] 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 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 five-point scale (1=only a human, 3=no preference, 5=only a robot). This checklist was administered both before and after participants interacted with the robot.

d) Medication Hand-off Questionnaire: This questionnaire assessed experience with the robot during the medication hand-off demonstration. To mitigate memory limits they were reminded of the robot delivering a medication bottle to them and then responded to 6 questions (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?) on a 5-point scale (1= not at all, 5=completely).

5) Structured Interview: We developed a 5-part interview script for an in depth qualitative assessment of older adults' attitudes toward assistance from a robot in their homes. 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 into opinions on the tasks demonstrated by PR2 (i.e., assisting with medication-management, learning new tasks, and helping with cleaning and organizing). Part 5 comprised concluding questions. In this paper, we focus on Part 2 of the structured interview: the medication management task. We gauged participants' reactions specific to the hand-off (e.g., where the robot stopped and handed the medication) and attitudes about assistance with general medication management.

C. Procedure

After arriving at the Aware Home, participants signed an informed consent and then completed questionnaires prior to being introduced to the PR2 robot (see Table I). At different points during the study, participants witnessed from close proximity three different task demonstrations from the robot in the living room area: the robot handing-off medication to the participant; the robot turning off a light switch with at least one failed attempt; and the robot picking items from a table and placing them in a basket. Participants were informed that these demonstrations were autonomously performed by the robot.

In general, the older adults had little experience with robots and the demonstrations provided a context for how an assistive home robot might function. We made clear the robot was not limited to what the older adults witnessed. Thus, the medication hand-off task served to enable older adults to imagine robot assistance with medication management tasks.

Prior to interaction with the robot, participants were given a brief overview of the functioning of the robot in lay terms. They were also assured of the robot being safe and that it could be stopped anytime they felt uncomfortable. To minimize demand characteristics, participants were made aware that the 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.

After each demonstration, participants were taken to a private room where they were interviewed. When responding to interview questions, participants were encouraged to think of their present and future needs. The entire interview, along with the demonstrations, lasted about 2.5 hours. At the end, participants completed more questionnaires (Table I), were debriefed, and compensated for their time.

TABLE I. PROCEDURAL FLOW OF THE STUDY

Procedural flow	Methods used
PRE-Questionnaires	Demographics Questionnaire***** Robot Opinions Questionnaire-PRE Assistance Preference Checklist-PRE***** Robot Familiarity and 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*****

**Data discussed in this paper*

III. RESULTS

The interviews were transcribed verbatim and analyzed by a primary researcher for systematic identification and organization of underlying themes [22]. Transcripts were first segmented by a primary researcher based on responses relevant to medication management. The primary researcher developed an initial categorization scheme by identifying salient categories (e.g., person capability, robot reliability) based on the HRI and medication management literature. The transcript segments were then categorized using this initial scheme. If a response did not map to the top-down categories, a new category was generated to represent that class of response, and thus the scheme was refined through a bottom-up approach. A secondary researcher independently re-categorized the segments using the scheme developed by the primary coder. Discrepancies were discussed and the scheme was revised until complete consensus was reached between the two coders.

A. Reactions to the Medication Delivery Task

Immediately after the robot delivered medication, we interviewed participants about their reactions to the task. The first question was about the speed of the robot in performing this task. Seven participants reported the task to be rather slow; however, for the other five participants, the speed was perceived to be adequate. Suggestions were made to speed up the process later on, with one older adult stating "I think there would be later phases where it could be changed once the person gets more used to interacting with the robot."

We asked participants' opinions about the speed at which the robot approached them. The majority of participants (8 of 12) were comfortable with 10 cm/s. The fact that the robot did not move too fast was, in fact, considered "desirable" by some participants (4 of 12), because it made the robot less intimidating and they felt more at ease. However, some participants wanted it to move faster, particularly if more immediate assistance was required or once the person became more familiar with the robot.

Participants' opinions were mixed on the distance at which the robot stopped in front of them. Although more than half the participants were fine with the current distance, some participants would have liked it to stop closer to avoid having to lean forward to grasp the bottle from the robot's gripper. Differences for preferred distance for interaction with the robot may depend on individual perceptions of personal space [23], as is reflected in the comment - "whether it was a human being or in this case the robot, closer would have felt violating that comfort zone that people talk about all the time…".

None of the participants expressed strongly negative opinions about the amount of strength they had to use to take the medication bottle from the robot's gripper. However, how and when the robot released the bottle was not intuitively understood by all participants. For example, "At first I thought it had not released it because there was some friction involved of gripping it, but then I was told to go ahead and take the bottle. After I learned… then it wasn't a problem."

The next interface-related question was about where the robot handed the bottle (i.e., too close, too far, too high, or too low). The majority (8 of 12) found the distance to be appropriate. Some participants found it to be slightly far away though the height was considered appropriate. The concern was for situations when "I can't get my hand out of the bed even," in which case the distance should be adjustable.

During the interview, we also asked opinions about wearing a necklace with an RFID tag. Participants did not mind wearing the necklace; some even mentioned having forgotten that they were wearing one. We further assessed their willingness to wear this necklace as well as their willingness to label their medication bottles in the demo-specific questionnaire on a scale from 1 (not at all willing) to 5 (completely willing). Participants were mostly to completely willing (M=4.67; SD=0.49) to wear the necklace if it allowed the robot to perform a lot of tasks for them. They were also mostly to completely willing (M=4.50; SD=0.80) to label their medication bottles so the robot could identify them.

B. Preferences and Attitudes for Assistance with General Medication Management Tasks

Through the Assistance Preference Checklist administered before and after the robot interactions, we analyzed preference changes for human versus robot assistance for medication management tasks: reminding to take medication; deciding what medication to take; delivering medication; taking medicine; and researching health and medical conditions. For each task, we performed Wilcoxon signed-rank tests to analyze whether preferences for human versus robot assistance changed after viewing the demonstration. Additionally, we conducted 1-sample Wilcoxon test on the post-demonstration data to examine if participants' preferences for assistance were significantly different from no preference (=3.0).

Overall, older adults showed selective preference or no preference for robot assistance for certain aspects of medication management. There were some aspects for which human assistance was preferred. The structured interview provided additional insights into older adults' attitudes toward robot assistance with medication management.

1) Reminding to Take Medication: Participants were positive overall about a robot reminding them to take medication. (Figure 2). After exposure to the robot, there was a significant increase in preference toward robot assistance for being reminded to take medication (Z = 2.33, p < 0.05). Additionally, after the demonstration, participants had a significant preference for robot assistance for reminding (Z = 2.24, p < 0.05), compared to no preference.

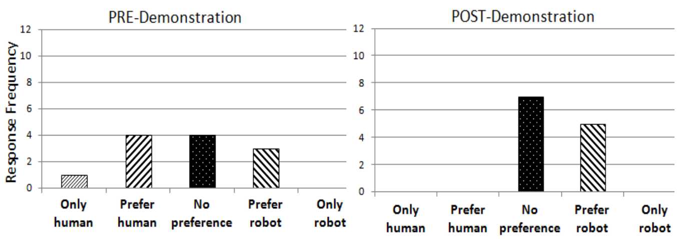

Fig. 2. Human versus robot assistance with reminding.

Other aspects of assistance with reminding were assessed in the structured interview. Participants were asked if they wanted the robot to remind them to take medications, even if it interrupted them. A majority of participants (9/12) responded positively, although some mentioned that it would depend on the situation (e.g., "I could see on the one hand if you need to take it, you need to take it, but it's not you need to take it within a certain degree of minute and if I were doing something I really like to do or watching a show I really want to watch, do I really want to be interrupted? So, it would depend.")

The task of reminding can be graded based on the level of insistence offered. Half the participants wanted the robot to be very insistent in reminding them to take the medication, as expressed in the remark "I would want the robot to stand right there until I took the medication...if you needed to have your medication at a certain time, it needs to make sure that you take it at that time." However, some participants opted for less insistence and would rather have "just a friendly reminder."

2) Deciding What Medication to Take: Exposure to a robot did not significantly change participants' preference for assistance with deciding what medication to take (Z = 0.79, p > 0.05). Even after the demonstration, there was a significant preference for human assistance (Z = 2.33, p < 0.05).

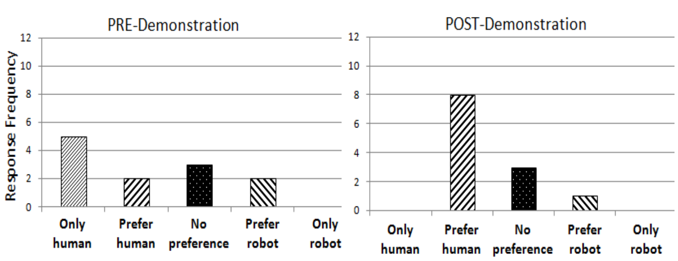

Fig. 3. Human versus robot assistance with deciding medication.

Participants' preference for human assistance for deciding could be due to lack of clarity about how a robot would know what medication the user should take and when. Participants were also concerned about the possibility of a robot making a mistake (i.e., reliability of the robot). This was reflected in multiple comments during the interview:

- "if it's programmed that I have 6 medications to be taken at certain times of the day, my first question to be answered would be does it know that to go and get the correct medicine and bring it to me?"
- …if the robot is going to get your medication, you have to have it put in a specific place and arranged in a specific order so…they don't bring the wrong medication at the time you tell it to bring the medicine."
- "I take two medications and would the robot give me the right medication? There are people who take more…And with the robot, how would the robot know to give me the right medication at the right time?"

3) Delivering Medication: After the medication hand-off demonstration, older adults were less likely to say prefer a human (Z = 1.99, p < 0.05); however, the post-demonstration data did not show significant preference either for human or robot assistance (Z = 1.00, p > 0.05). Thus, after the demonstration, participants were more open to the idea of a robot and did not express a preference one way or the other.

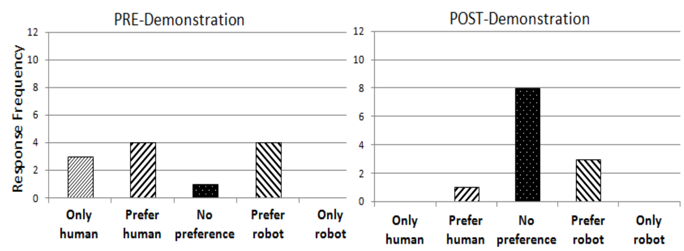

Fig. 4. Human versus robot assistance with delivering medication.

During the interview, participants were asked if they would prefer the robot to fetch a single pill or the bottle of pills. All participants expressed a preference for the robot delivering the bottle for one of three main reasons (see Table II for example quotations): First, they would have the robot deliver the pill only under special circumstances such as when they could not open the bottle themselves to take the pill out. Second, preference to have a bottle delivered also emerged from perceptions of the robot's reliability (e.g., belief that a robot can make mistakes). Finally, familiarity-based preferences also contributed to this trend.

Participants were informed there could be two methods for the robot to bring their medication– it could be programmed beforehand or it could bring the medication when asked. Seven (7/12) participants chose the robot being programmed beforehand as their preferred method. This way the robot could support their memory for better medication adherence. Four participants preferred the robot to bring medication when asked, with two primary reasons: person factors (e.g., one's personality, preferences, attitudes) and external factors (e.g., change in situation, circumstances). Only one person had no preference. These trends are illustrated in Table III.

TABLE II. PREFERENCES FOR BOTTLE DELIVERY OVER A SINGLE PILL

Reason	Example quotations
Person's current capability	"...it all depends on my manual dexterity… if I was capable of extracting one pill from the bottle, then I could manage it. If I did not have that capability then the robot could handle it" "Today, the bottle would be fine. If the roles change and the robot is thinking more clearly than I about how many do I take, then yes, ideally it would be programmed to give the dosage as well"
Perceptions of reliability	"robots are supposed to kinda be designed like humans, which means that robots can drop a pill." "I think there is a trust that we would have to have... I would rather have the bottle and be able to say, 'Oh yeah, this is my high cholesterol medicine.'"
Familiarity-based preferences	"…the whole bottle is so natural, just like a friend giving it to you, an associate giving it to you."

TABLE III. WHEN SHOULD THE ROBOT BRING MEDICATION?

Preference	Reason	Example Quotations
Programmed beforehand	Memory issues	"…sometimes we as humans forget to take medication at a certain time. And if you program into a robot, he's gonna remind you it's time for you to take your medication." "Then I don't have to be concerned about it and as I age and may forget."
When asked	Person-factors	"That's just my personality. I'm not too punctual and I'm not too exact." "I would probably prefer telling it when to get it and what to get… because I didn't want to be a complete vegetable just sitting there waiting to be served."
	External-factors	"Because at the present time… I might go out of the house and don't take it. Let me see. 'Would you bring my pill for me, please?' Because I'm on my way out the door."
No preference	It depends	"If I'm at the point where I have maybe forgotten a medication and I need it right away, then I - I - I would go for the robot right away bringing it to me. But if not, if I'm just on a normal schedule, then I'd program it and it - I could do either/or."

4) Taking Medication: Assistance with taking medicine involves help with taking, or administering, the medication (e.g., putting the medicine in the mouth). Participants' preference for assistance with taking medicine did not change after the demonstration (Z = 0.0, p > 0.05). The post-demonstration data showed significant preference for human assistance for this task (Z = 2.11, p < 0.05).

Although we did not specifically interview participants about their attitudes toward robot assistance for taking medicine, some participants spontaneously raised concerns for this type of assistance. One participant said, "Fine for handing me, you know, or getting the medication for me and bringing it to me. I don't know how comfortable I would be with the robot actually… administering it."

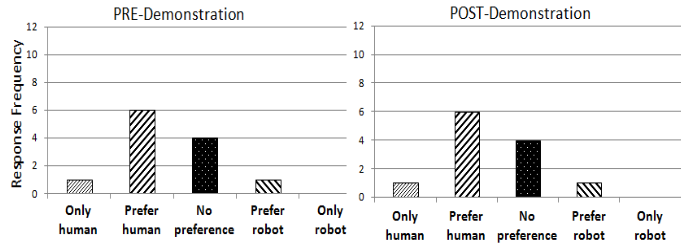

Fig. 5. Human versus robot assistance with taking medication.

5) Researching Medications and Health Conditions: Robots can also assist in other aspects of medication management such as finding up-to-date information about medications and health conditions. Participants' preferences for human versus robot assistance for this task did not change significantly after the demonstration (Z = 0.90, p > 0.05). Additionally, post-demonstration, they did not have a significant preference toward a robot or a human (Z = 1.81, p > 0.05).

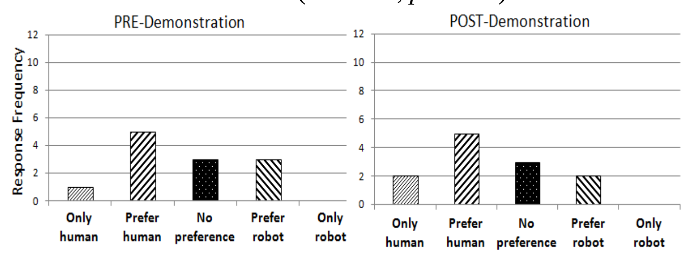

Fig. 6. Human versus robot assistance with researching medications.

TABLE IV. OTHER DESIRED ASSISTANCE

Assistance	Example Quotations
Fetching/Putting back	"…it could get the water for me or juice or whatever I need to take it with. " "…we really didn't test whether it would go back and put it back where it was."
Health Monitoring	"I'm a diabetic, so I would need for the robot to be able to do my blood sugar tests."
Managing Inventory	"The only thing I can think of is to keep track of an inventory and reordering the medications."

During the interview, participants were also asked if there were any other aspects of medication management with which they would want robotic assistance. One third of the participants (4/12) offered suggestions (Table IV).

IV. DISCUSSION

A. Review of Findings

Maintaining good health in old age is partially contingent upon the ability to successfully manage one's medications. Increased demands in the environment (e.g., complex medication regimen) and age-related changes in cognitive and physical abilities can create challenges in adhering to one's medication regimen [4]. Robots have the potential to support older adults' medication management needs. An important challenge, however, is to design robotic systems that are aligned with older adults' preferences and concerns.

The older adults had specific preferences for assistance from a robot. Our aim was to capture older adults' preferences based on their sparse mental-models of robots via the pre-questionnaires. By administering the same questionnaire later on, we assessed whether preferences changed after a 2.5 hour long HRI study. We minimized demand characteristics by making clear the interviewers did not design the robot, and by carefully wording the questions to avoid bias. As is clear from the results, the older adults were selective in their preferences for robot assistance, and did not hesitate to state aspects of robot assistance they were not comfortable with.

Medication management comprises a variety of tasks differing in cognitive and physical components. In the next sections we discuss how our findings on older adults' preferences for robot assistance varied within and across these two aspects of medication management:

1) *Cognitive Assistance:* Cognitive assistance with medication management includes reminding to take medication on time, assistance in deciding which medication to take, and researching medications and health conditions. Older adults' attitudes toward and preferences for assistance varied across these cognitive components.

Memory issues can lead to drug overdoses or missed doses, which have consequences detrimental to one's health. Robots can serve as memory support systems for medication adherence. After their interaction with the robot, older adults preferred robot assistance over a human assistance for reminding them to take medications. However, there were differences in opinions on how insistent the reminder should be. Adapting the level of insistence to the needs and preferences of the user can improve the adoption of robots.

Managing multiple medications can also be cognitively demanding. Robots may be able to reduce cognitive burden on the user by assisting in deciding the right medication to take and when. However, older adult participants expressed doubts about the capability and reliability of the robot for this task. They also responded that they would prefer human assistance for deciding which medication to take.

Medication non-adherence for some older adults could be due to inadequate information or beliefs about effectiveness of a drug [2]. Robots may facilitate medication adherence by informing users about benefits of the drug, its side-effects and other relevant information. However, participants in our study did not have significant preference for human or robot assistance for *researching* medications and health conditions.

2) *Physical Assistance:* Robots can offer physical assistance with medication management, for instance by delivering the medication to the person, or by assisting in taking the medication. After physically interacting with the robot (in the medication hand-off task), older adults did not have a preference for human or robot assistance for medication delivery. If a robot were to deliver the medication, preference was for it to deliver the bottle of pills over an individual pill. However, it should be noted that during the medication delivery demonstration, the robot delivered a medication *bottle*. Participants did not have the opportunity to witness the robot delivering individual pills which may have biased their reported preferences towards bottle delivery. Additionally, older adults had mixed opinions about *when* the robot should deliver the medication. The majority of participants wanted the robot to be pre-programmed for medication delivery, whereas some wanted the medication to be brought only when asked. Participants were not as open to assistance from a robot for physically taking the medication (e.g., oral administration) and preferred human assistance for this task.

B. Study Limitations and Future Directions

We designed this study to better understand the potential for a mobile manipulator to support older adults' medication management in their homes. We limited our sample to independently living older adults, because about 80% of older adults live independently in their home [24]. While our sample size of 12 was sufficient for qualitative interview analysis [25], it was relatively small for *quantitative* assessments. Nonetheless, our analyses were within-participants which increased the power of the statistical test assessments.

Moreover, this was a self-report study that captured older adults' attitudes and intentions for robot use after a brief interaction with the robot. Attitudinal and intentional acceptance of technology are positively correlated with behavioral acceptance (i.e., actual use of the technology [26]). Yet, one must be wary that attitudes and intentions are not perfect predictors of technology adoption. In the future, more definite insights can be gained by conducting field-studies that evaluate long-term behavioral acceptance.

Limitations of the study include use of a single robot. Responses may have been limited by perceptions of the PR2. Future studies should assess if assistance preferences for medication management are influenced by robot features (e.g., size, appearance, voice). Additionally, during the design of this study, we recognized the potential impact of robot reliability on perceptions and therefore controlled it across participants for the medication task (i.e., the robot performed autonomously without error). It is informative that participants raised concerns about robot reliability despite its non-erroneous performance. This would be an interesting variable to manipulate in a follow-up study.

C. Implications for Design of Assistive Robots

Although the PR2 is a human-sized research robot, not specifically designed for medication support in the home, in general it was positively evaluated by the older adults for medication delivery. Thus older adults are open to the idea of receiving medication support from a mobile manipulator. Moreover, interaction with the robot strengthened preference toward robot assistance for certain tasks.

Participants' willingness to wear a necklace with the RFID tag and to label their medication bottles suggests older adults may be willing to make accommodations in their homes to support robot operation. Wearing an RFID tag is one possible form of accommodation that may enable robots to be more helpful. There are examples of items worn by older adults for medical reasons such as allergy bracelets, medical alert bracelets and necklaces, and hospital ID bands. An RFID tag could potentially be added to any of these devices or be carried unobtrusively in one's wallet. Similar capabilities may be achievable without RFID, but our study suggests that RFID could be valuable to robots that help older adults age in place.

To increase participant safety during the study, the robot was programmed to move at a slower speed and extend its arm out less than it has during informal demonstrations of object delivery. Even though the robot developers would have liked the robot to move more quickly, some older adults explicitly stated that they liked its slowness. Thus, fast operation may not always be a desirable characteristic for tasks where humans and robots interact in close proximity. Many opportunities exist for potentially enhancing this interaction, including considering human proxemics [26], but participants had a generally favorable response to the current system.

In this study, the PR2 was not equipped to demonstrate any social capabilities. However, future robots displaying social behaviors may influence older adults' motivation and self-efficacy and further enhance medication adherence [27].

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