Designing a Social Robot to Assist in Medication Sorting

Jason R. Wilson[1], Linda Tickle-Degnen[2], and Matthias Scheutz[1]

[1] Tufts University, Human-Robot Interaction Lab,
[2] Tufts University, Department of Occupational Therapy,
Medford, MA 02155 USA

Abstract. Being able to sort one's own medications is a critical self-management task for people with Parkinson's disease. We analyzed the medication sorting task and gathered design considerations. Then we developed an autonomous robot to assist in the task. We used guidelines provided by occupational therapists to determine the level of assistance provided by the robot. Finally, an evaluation of the effectiveness of the robot with student evaluators determined that people trusted the robot to reliably assist and that people had a positive emotional experience completing the task.

1 Introduction

Medication adherence, defined as the extent to which patients take medications as prescribed [9], can be a great challenge for many people that rely on a daily regimen of medications. It requires successful "medication management", i.e., the ability to develop, schedule, and implement a plan to take medications, as well as to remember if medications have been taken and when to take them [16]. Adhering to a successful medication management schedule is often critical for managing and delaying the progression of chronic diseases.

Parkinson's disease (PD) is a progressive and neurodegenerative condition that reduces the amount of dopamine produced in the brain [8, 10]. PD currently has no cure, but symptoms can be dramatically reduced with antiparkinsonian medication. Optimizing adherence to oral medication regimens is critical to managing the symptoms of PD [6, 7], but many challenges impede good medication adherence [14].

While most existing assistive technologies remind a person when it is time to take a particular medication [2, 5], there are few assistive technologies that address the important problem of planning, scheduling, or sorting of medications. We believe that a social robot assisting in a medication sorting task could serve an important role in the self-management of Parkinson's disease, and we present the first steps towards developing such a system. To our knowledge there are currently no other technologies that can interact with the person to develop an ideal medication schedule that is also adherent to how the medications are prescribed. In the following, we first analyze the medication sorting task and gather design considerations, then we present on overview of the development of the autonomous robot to assist in the task, and evaluate the effectiveness of the robot in a human-robot interaction experiment.

2 Background

People with PD are often referred to occupational therapists to assist in activities of daily living (e.g., dressing, bathing) as people with PD that are early in the disease progress may experience difficulties with instrumental activities of daily living (IADLs) [15]. These activities include physically demanding ones like sweeping or carrying groceries, but more cognitively demanding IADLs often present challenges to people with relatively early PD [4]. Using an objective performance-based metric, Foster found measurable deficits in performance of cognitively demanding IADLs [3]. On activities such as shopping, sharp utensil use, and medication management a larger proportion of people with PD required assistance or required more assistance than people without PD [3].

Adherence to a medication regimen is critical to treatment outcome and quality of life for people with PD. In addition to general issues elderly patients may have (e.g., age-related physical decline, economic factors), people with PD often require complicated dosing or titration schedules and may have co-morbidities that require the coordination of therapies from multiple drug classes. Disease progression can also introduce cognitive impairments that can affect adherence. Additionally, responses to antiparkinsonian agents can cause variable responses interfering with medication adherence. [1].

To achieve optimal adherence in elderly patients with Parkinson's disease, a combination of approaches is the best strategy for success. Suggestions include educational intervention, simplified dosing and administration schedules, management and understanding of medication adverse events, and the use of adherence aids such as pill boxes and hour-by-hour organizational charts [1].

3 Development & Assessment of Medication Sorting Task

To get a thorough understanding of the medication sorting task, the importance of the task, and how a robot could assist with this task and others, we developed a pill sorting task that was subsequently performed by two humans and then evaluated by a *focus group* consisting of four occupational therapists (OT). The standardized task involves one person sorting two medications onto a grid while the other person provides assistance [12]. The focus group was specifically charged to assess task performance and analyze the various activities performed as part of the task, discussing the possible roles and design considerations for a social robot assisting in this task.

The standardized medication sorting task of the Performance Assessment of Self-care Skills [12] was the basis for a simulated performance of the task. The video of this task showed an actor, who simulated a person with PD, placing two medications on a sorting grid while being instructed by an actor who simulated the caregiver. Research assistants created a written activity analysis of the recorded performance [11]. In an evaluation and focus group session, OT experts viewed the recorded scenario, read the activity analysis, and independently completed 17 Likert-scaled questions about the realism, comprehensiveness, and relevance of the content of the scenario and analysis.

The OT experts agreed that the medication sorting task was valuable for daily life with PD and that the content of the activity analysis was comprehensive and accurate. They also agreed that the video of the simulated task performance was not as complex as would typically occur in the home (e.g., there would be more medications with more constraints, and the environment in which the task is being done, often a kitchen table, may be cluttered and have other distractions). The experts also suggested that more safety concerns needed to be included in the activity analysis. We concluded that with these minor improvements the activity analysis of the medication sorting task has been validated as to its significance to a person with PD, and that the task has been sufficiently described for designing a social robot to assist in the task.

4 Autonomous robot design

Based on the task analysis and the outcome of the focus group, we have begun the development of a social robot to assist in the medication sorting task. An important design concern was for the architecture to be extendable to potentially incorporate additional tasks that are important for the daily activities of a person with PD.

4.1 Architecture

The components of the system have been developed using the DIARC architecture [13]. For this medication sorting task, the necessary components are the vision system, script execution, medication management and assistance, and robot control. Each of these components are described in the following sections.

4.2 Vision system

The vision system is responsible for perceiving the state of the environment so that other components can infer the state of the task. In addition, changes in state are used by other components as an indication that a human action might have occurred. In determining the state of the medication grid and the sorting tray, the vision system reports how many pills of each type are in each cell in the grid. The sorting tray, which is a small circular tray, is treated as a separate grid with one cell. The vision system can also report how many pills of each type are in the tray.

4.3 Script execution

Script execution is conducted by the *Goal Manager* component in the DIARC architecture. A script here defines the sequence of actions the robot is to perform. A script may be defined using a hierarchical structure in which high-level actions have their own scripts. The high-level sequence of actions we use for the medication sorting task is introduce the robot and the task, assisting in sorting the first medication and then the second, then indicate that the task is complete. The action for sorting a particular medication takes a parameter that indicates which medication is to be sorted next. The script for that action is the following:

1. Robot announces which medication is next
2. Robot instructs person to pour medications into tray
3. Robot waits for medications in tray
4. Provide instructions for medication
5. Wait for an event
6. Respond to event
7. If not done sorting this medication, return to step 5

4.4 Medication management and assistance

A medication management component assesses each event. It selects the appropriate response to be made by the robot based on details of the event. The decision process is mostly a binary decision tree where decisions are based on characteristics of the event. The analysis of the event determines the following information:

- grid correctness: current state of grid is consistent with the goal
- correction event: last event fixed a grid inconsistency
- hesitation event: last event has no state change and simply is a timeout, possibly due to human partner moving slowly
- number of recent errors: number of recent events that were errors
- current errors: total number of misplaced pills
- too quick: user is moving too quickly

Based on the analysis of the event, the component then uses the decision tree to determine how to react. Reactions are intended to provide an appropriate level of assistance, where the basic characteristics of each level is based on the "Hierarchy of Types of Assistance". This hierarchy, specified in the Performance Assessment of Self-Care Skills (PASS) 3.1 [12], defines the minimal type of assistance a therapist is to provide to facilitate task performance. Of the nine defined levels, we use only the first four levels. Assistance at level 5 and higher requires greater physical intervention and the current robotic system does not have the necessary manipulation capabilities.

Figure 1 shows the four levels of assistance (plus a level 0 that we have added) laid out in a binary decision tree. The PASS defines the four levels of assistance that we use as the following. Level 1 is *verbal supportive* and includes verbal affirmations to encourage the person it continue the task. Level 2 is *verbal non-directive* and encourages task continuance without telling the person exactly what to do. Level 3 is *verbal directive* and uses statements that direct the person on what to do or how to proceed with the task. Level 4 is *gesture* and includes pointing to objects and may be accompanied by verbal statements.

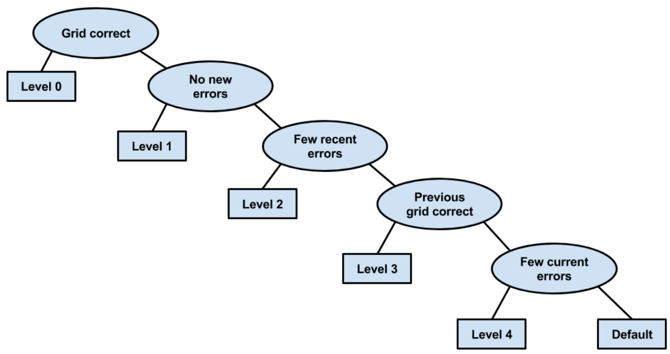

Fig. 1. The type of response that the robot gives to an event is determined by this binary decision tree. Levels 1-4 are designed to reflect the minimal level of assistance a therapist would provide on this task, as defined by the PASS manual [12].

Level 0 responses are minimal feedback given to the human partner to indicate that the task is progressing correctly and to confirm that the robot is paying attention to the actions. The PASS does not have a level 0 type of assistance, but reviewing the video recording of the scripted interaction and consulting with OTs with experience in the task indicated that simple back-channeling was common and possibly necessary. However, the robot must not always give positive feedback as this could introduce dependence on this positive reinforcement signal from the robot. Since a main aim of our system is to support human autonomy, feedback must be minimal, intermittent, and mostly confirm that the robot is working and paying attention.

The system distinguishes between three types of events that merit different types of level 1 responses. If the last event is correcting a misplaced pill, then the response generated recognizes this and confirms the correct action. If the event is the result of a timeout, possibly indicating that the human partner is moving slowly, then an encouraging remark is generated. If the last event is the result of a correctly placed pill but there remains another pill that is incorrect, then a level 1 response is generated to confirm the correct action but a level 2 response is also necessary to indicate that there is still a mistake somewhere on the sorting grid.

A level 2 response indicates that a pill may be misplaced but does not provide direct indication as to what or where the mistake is. The intent is for the human partner to identify the incorrectly placed pill and fix it without further assistance. If the human needs further assistance, then the feedback gets escalated to level 3. The feedback is more direct in this case. The current implementation repeats the instruction for the medication currently being sorted. If this is still not sufficient, then the level 4 feedback includes a gesture. The robot will then point to a misplaced pill on the grid. If there are too many misplaced pills, then further intervention beyond the currently implemented capabilities will be necessary. For the purposes of our evaluation, the robot simply suggests that the person slow down and think more carefully.

5 Evaluation

We evaluated the initial implementation of the system by having student subjects complete the task with assistance provided by the robot. The goals were to ensure the task can be correctly completed with the robot assisting and that people find the robot to be helpful, supportive, reliable, trustworthy, and create an overall positive experience. In preparation for future studies with the target population, we were also interested in how the robot may be perceived (by one's family or care providers) and other factors contributing to the desired experience (e.g., the person feeling in control and responsible).

5.1 Method

Participants: Students (N=11) from Tufts University participated in a human-robot interaction study. No demographics were collected from the participants. There were three participants who were involved in the preliminary study but did not know any details about the present experiment.

Materials and design: A Nao robot was on the table when the participant entered. In front of the robot was a medication sorting grid, two cups of simulated medicines (candies), and a tray. The experimenter informed the participant that the robot will be assisting in a task involving placing the medications onto the sorting grid. Also, each participant was instructed to follow the instructions of the robot but also make two types of mistakes. The first mistake is to act slowly, to take more than 3 seconds to place the next pill. The other mistake is to misplace a pill. Any mistake may be made more than once if the participant chose. We recorded a video of each participant completing the task with robot.

Procedure: The participant sat directly in front of the robot. Once the experimenter left the room, the experimenters in the other room initiated the robot's execution. The fully autonomous robot then followed the script described above. As part of this script, the robot would say the following:

- Introduction: "Hello. ⟨opens hands⟩ My name is Shafer. ⟨left hand closes and moves towards chest⟩"
- Describing the task and materials: "Today we will be sorting medications onto this grid. ⟨points with left hand at grid⟩ There are pills in these containers ⟨points with right hand at cups of pills⟩. Let's begin."
- Instructing placements: "One ⟨color⟩ pill is to be taken each ⟨time of day⟩." See section 4.4 for assistance given by robot during this phase.

– Completion: "Congratulations! You have successfully completed the task."

Once the task was completed, the experimenter returned and provided the participant with a questionnaire, which had 19 Likert-scaled questions (see Table 1) and 1 question for comments.

Table 1. Questions had 5 options from "Strongly disagree" to "Strongly agree".

1. The robot is able to provide you with assistance in the task.	11. The robot helped me understand how to complete the task.
2. The assistance the robot provides is correct.	12. The robot acted in a manner that ensured my safety.
3. I am able to complete the task more efficiently with the assistance of the robot.	13. The robot is able to warn me of potentially unsafe medication administration.
4. When the robot corrects me I feel included to follows its instructions.	14. My family would approve of the way the robot assisted me.
5. I trust the robot to (correctly) provide assistance.	15. My care providers would approve of the way the robot assisted me.
6. I expect the robot to act in a consistent and predictable manner.	16. I felt pleasant during the task.
7. The robot is able to provide physical support.	17. I felt in control of what was happening during the task.
8. The robot is able to provide emotional support.	18. I felt I understood what was happening during the task.
9. The robot paid attention to me.	19. I felt responsible for completing the task.
10. The robot used action and words that did not make sense.	

5.2 Results

All participants successfully completed the task and answered 19 questions about the robot. The average scores of these categories are in Table 2. The highest rated questions were 18 and 19, and the lowest (after inverting question 10 for being negatively framed) was 7. It was anticipated that 7 would be rated lowly since the robot has limited physical capabilities. A principal components analysis (PCA) showed that two of the questions did not correspond with any of the composites. The three composites that were formed are related to effectiveness, support and assistance, and emotion. The resulting scores of the three composites are given in Table 2 (note that Support 7 and Rapport 10 were removed from the PCA).

Since some participants had previous experience with the project (though not with the robot), we compared the results of those participants with the rest to see if there was any difference. Only Support had a statistical difference between the groups: questions 7 ($t(7)=3.33$, $p=0.01$) and 8 ($t(7)=-2.57$, $p=0.04$).

We performed an additional post-hoc analysis since some participants interacted more with the robot than others (i.e., when the robot introduced itself, some would reply with some form of greeting). We analyzed the video of each participant and coded whether the participant greeted the robot. Two coders reviewed each video and classified each of the participants as greeters or non-greeters. Of the 11 participants, 5 had some form of greeting toward the robot.

Using an independent sample t-test, we compared the scores from the questionnaire for the greeters and non-greeters. The non-greeters reported higher means on all of the social robot questionnaire items ($M=3.84$, $SD=0.42$) compared to greeters ($M=3.69$, $SD=0.36$), but the difference was not significant ($p=0.55$). We used an independent two-sample t-test to find that between greeters and non-greeters there were no significant differences across any of the three components from the PCA: 1 ($t(9)=-0.2$, $p=0.91$, 95% CI[-1.28, 1.16]; $d=.07$]), 2 ($t(9)=-0.35$,$p=0.73$, 95% CI[-0.89,0.65]; $d=0.22$)), 3($t(9)=-1.25$, $p=0.24$, 95% CI[-1.36, 0.39]; $d=0.74$). The third dimension, emotional support, was found to have a large effect size ($d=0.74$).

Table 2. The means and standard deviations for each question, means for each category, and relation to each dimension based on a principal component analysis.

		M	SD	M	Trust to safely and correctly assist	Supportive and considerate	Emotional support
1	Function	4.00	1.00	3.86		.845	
2		3.64	1.03		.809		
3		3.45	0.82		.571		
4		4.36	0.92				.692
5	Trust	3.73	1.35	3.91	.769		
6		4.09	1.22		.924		
7	Support	2.27	1.49	3.00			
8		3.73	1.10				.723
9	Rapport	4.27	0.79	3.82	.695		
10		3.09	1.04				
11		4.09	1.04			.646	
12	Safety	3.73	1.19	3.41	.812		
13		3.09	1.30		.777		
14	Social Perception	3.82	1.08	3.82	.645		
15		3.82	0.98		.602		
16	Mood	4.09	0.83	4.43			.484
17		4.27	0.65				.805
18		4.45	0.52			.803	
19		4.91	0.30			.539	

5.3 Discussion

Overall, participants had a positive experience with the robot and felt that the robot performed well. Participants most highly rated their emotional experience with the robot. This is apparent in the two questions with the highest mean score (Mood 4 and Mood 3), the category with the highest mean score (Mood), and the component with the highest score (Emotional Support). Future work will help determine how much the robot contributed to these ratings.

The physical support question had the lowest score, and this was anticipated since the robot does not appear to be able to provide any direct physical support. It is too small to help a person move. Participants did not witness the robot manipulating even small objects, and it has limited capability to do so. Given these limitations, the mean score we report here perhaps should be lower if the participants really knew the limitations of the robot.

6 General discussion

The focus group with the expert occupational therapists provided important design considerations, most importantly confirming the significance of the medication sorting task we developed to a person with PD. The results showed that the developed robotic system is capable of detecting incorrectly sorted pills and provide appropriate escalating feedback according to the PASS hierarchy. Yet, the current system is clearly only a first step and several improvements are necessary before such a social robot can find application in an occupational therapy setting. For one, the decisions on how and when to assist need improvements as the current reasoning by the robot for determining which level of assistance to provide is fairly simple. Modeling the mental and emotional state of the human partner will allow the system to appropriately react to the person's feelings of frustration, boredom, confusion, joy, or pride. We also limited the robot's assistance to just the first four levels as defined in the PASS [12], but at least a level 5 (affecting the environment) should be possible with the current robot form factor. Going beyond level 5 may require physical contact between the robot and the person. There are many ethical concerns when it comes to personal touch. In order for the robot to ethically perform these levels of assistance, the robot architecture must include reasoning capabilities that incorporate the ethical considerations.

A more thorough evaluation of the robot is also important as we have not controlled for any preconceived notions of robots, eldercare, or medication adherence. Factors that influence the function, trust, safety, rapport, social perception, and mood have not been explored. It is currently also unclear what prompted some of our subject to greet the robot and how this is related to the lower scores of greeters compared to non-greeters. In a larger evaluation we could further examine if greeters continue to rate the system lower and begin to investigate the reasons for this. It is possible that some people have preconceived notions of how a robot should behave that then affects people's willingness to engage with the robot initially but then the robot's minimal interaction during the task could disappoint the user and lead to a poorer evaluation.

7 Conclusion

We introduced a socially assistive robot and evaluated its ability to assist a person in completing a medication sorting task. A focus group of four occupational therapists specifically formed to evaluate the task determined it to be an important task for health management of people with Parkinson's disease, which can also serve as a tool for monitoring and assessing the physical and cognitive abilities of the individual. Unlike other assistive technologies, the social robot is designed to assist the person and not do the task for them and can thus support the person in feeling included and responsible for managing their own health, while maintaining the person's autonomy. Results from the first HRI experimental evaluations of the robotic system with student subjects showed that the robot is found to trusted to reliably assist and supports a positive emotional experience during the task.

Future work will improve the robot's ability to correctly and reliably operate in this task and possibly others. This will hopefully lead to an assistive technology that maintains the autonomy of people with PD and thus contribute to a better quality of their life.

Acknowledgments. This project was in part supported by NSF grant #IIS-1316809. A special thanks to Grace Lee and Annie Saechao for their significant help in running the evaluation and analyzing the data.

References

1. Bainbridge, J.L., Ruscin, J.M.: Challenges of treatment adherence in older patients with parkinson's disease. Drugs & aging 26(2), 145–155 (2009)
2. Dayer, L., Heldenbrand, S., Anderson, P., Gubbins, P.O., Martin, B.C.: Smartphone medication adherence apps: potential benefits to patients and providers. Journal of the American Pharmacists Association 53(2), 172–181 (2013)
3. Foster, E.R.: Instrumental activities of daily living performance among people with parkinson's disease without dementia. Am J. Occup. Ther. 68(3), 353–362 (2014)
4. Foster, E.R., Bedekar, M., Tickle-Degnen, L.: Systematic review of the effectiveness of occupational therapy–related interventions for people with parkinson's disease. Am J. Occup. Ther. 68(1), 39–49 (2014)
5. Granger, B.B., Bosworth, H.: Medication adherence: emerging use of technology. Current opinion in cardiology 26(4), 279 (2011)
6. Grosset, D., Antonini, A., Canesi, M., Pezzoli, G., Lees, A., Shaw, K., Cubo, E., Martinez-Martin, P., Rascol, O., Negre-Pages, L., et al.: Adherence to antiparkinson medication in a multicenter european study. Movement Disord. 24(6), 826–832 (2009)
7. Kulkarni, A.S., Balkrishnan, R., Anderson, R.T., Edin, H.M., Kirsch, J., Stacy, M.A.: Medication adherence and associated outcomes in medicare health maintenance organization-enrolled older adults with parkinson's disease. Movement Disorders 23(3), 359–365 (2008)
8. McCance, K.L., Huether, S.E.: Pathophysiology: The biologic basis for disease in adults and children. Elsevier Health Sciences (2015)
9. Osterberg, L., Blaschke, T.: Adherence to medication. New Engl. J. Med. 353(5), 487–497 (2005)
10. Pavon, J., Whitson, H., Okun, M.: Parkinson's disease in women: a call for improved clinical studies and for comparative effectiveness research. Maturitas 65(4), 352–358 (2010)
11. Radomski, M., Trombly, C.A. (eds.): Occupational Therapy for Physical Dysfunction. Lippincott Williams & Wilkins, seventh edition edn. (2013)
12. Rogers, J., Holm, M.: Performance assessment of self-care skills (pass-home) version 3.1 [unpublished assessment tool] (1994), pittsburgh, PA: University of Pittsburgh
13. Scheutz, M., Schermerhorn, P., Kramer, J., Anderson, D.: First steps toward natural human-like HRI. Autonomous Robots 22(4), 411–423 (May 2007)
14. Shin, J.Y., Habermann, B., Pretzer-Aboff, I.: Challenges and strategies of medication adherence in parkinson's disease: a qualitative study. Geriatric Nursing 36(3), 192–196 (2015)
15. Shulman, L.M., Gruber-Baldini, A.L., Anderson, K.E., Vaughan, C.G., Reich, S.G., Fishman, P.S., Weiner, W.J.: The evolution of disability in parkinson disease. Movement Disorders 23(6), 790–796 (2008)
16. Steinman, M.A., Hanlon, J.T.: Managing medications in clinically complex elders: "there's got to be a happy medium". Jama 304(14), 1592–1601 (2010)