2014 IEEE/RSJ International Conference on Intelligent Robots and Systems
Workshop on Assistive Robotics for Individuals with Disabilities: HRI Issues and Beyond
September 14, 2014, Chicago, Illinois, USA

A Wizard-of-Oz Intelligent Wheelchair Study with Cognitively-Impaired Older Adults: Attitudes toward User Control

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***Abstract*— Intelligent wheelchairs can increase mobility and independence for cognitively-impaired older adults by compensating for their cognitive deficits using automatic safety features. The level and/or type of control desired by the target population during intelligent wheelchair use have not been previously explored. In this paper, we present findings from a study conducted with a mock intelligent wheelchair offering different modes of user control. We discuss both participant attitudes related to control and the implication of these findings for future intelligent wheelchair design.**

I. Introduction

Powered wheelchairs (PWCs) can improve the quality of life of older adults who are unable to propel themselves in manual wheelchairs. Safe operation of these PWCs, however, can be difficult or even impossible for drivers with cognitive deficits. It is reported that 60-80% of long-term care residents have dementia [1]. When determining eligibility for PWC use, prescribers (therapists) are faced with the difficult decision of weighing their clients' need for independent mobility against the safety of the driver and others in the environment [2]. Cognitive impairments often lead to decisions of PWC exclusion, which in turn lead to reduced mobility and independence for a large number of long-term care residents.

In order to address the issues above, several researchers have developed intelligent wheelchairs capable of compensating for cognitive deficits by providing collision avoidance and wayfinding support [3]. Only a few of these systems, however, have been tested with cognitively-impaired older adults and have led to the identification of specific usability issues and areas for improvement [4]. In addition, interviews with users and caregivers have explored perceptions on intelligent wheelchair use [5]. All of the above studies have suggested that further testing with the user population is imperative in order to determine user needs and preferences, and to develop a system that is eventually adopted by the intended users. Specifically, attitudes related to user control while driving intelligent wheelchairs have not been explored in previous studies, and are important to consider in the design of this technology.

The study described in this paper is informed by quantitative and qualitative results acquired during studies conducted previously by the authors. This study uses a mock intelligent wheelchair, implementing a Wizard-of-Oz approach that allows researchers to circumvent engineering challenges in building a fully functional system, and yet obtain feedback from the users on issues related to usability and satisfaction [6]. The study described is one of the first to test different modes of control in a (mock) intelligent wheelchair with cognitively-impaired older adults. The system in [7] was also tested with residents with varying levels of physical and cognitive impairment; however, the system implemented a single shared control strategy. This paper presents details about our study protocol, data collection and analysis approaches, and some findings related to the user population's attitudes toward control when using an intelligent wheelchair that provides three different modes of driving assistance.

II. System Setup

The study used a commercial PWC modified by AT Sciences, LLC (http://www.at-sciences.com/) such that it could be controlled normally through the joystick on the wheelchair or through a laptop. The software provided by AT Sciences was further modified by our research team to allow the wheelchair to be controlled through a separate wireless joystick held by a tele-operator. Specifically, the wheelchair controllers were modified so that the user's joystick input could be overridden by the tele-operator's commands. This allowed the tele-operator to simulate a shared or autonomous control strategy through the use of a second driving interface. For example, if the user drove towards an obstacle, the tele-operator could slow down or stop the wheelchair to prevent a collision. In addition, the tele-operator could change the wheelchair heading to enable the user to steer away from obstacles. The tele-operator's interface consisted of a joystick for direction control, buttons for speed adjustments, and a stop button. Audio and haptic feedback was also provided in some cases. More details on the tele-operator's capabilities can be found in [8].

III. Recruitment

Following ethics approvals, potential participants were contacted by designated caregiving staff for informed consent. A purposive sampling method was used. Ten participants from three different long-term care facilities in the city of Vancouver were recruited over a period of three months. To be included in the study, participants had to:

*Research supported by CANWHEEL (the Canadian Institutes of Health Research (CIHR) Emerging Team in Wheeled Mobility for Older Adults Grant #AMG-100925), the Alzheimer's Society Research Program and the Alzheimer's Society of Canada, the National Sciences and Engineering Research Council (NSERC) of Canada grants, British Columbia Knowledge Development Fund Grant #13113, the Institute for Computing, Information and Cognitive Systems (ICICS) at UBC, and TELUS.

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- be over the age of 50
- have mild-to-moderate cognitive impairment (as determined by clinical assessments)
- provide written consent
- be able to sit in a PWC for an hour per day
- be able to operate a joystick
- have basic communication skills in English
- have difficulties walking or self-propelling a manual wheelchair

IV. Experimental Setup

Participants completed five driving sessions (one session per day, over two weeks), lasting approximately 90 minutes each, during which he/she navigated in various realistic scenarios (ordered randomly) based on the Power Mobility Indoor Driving Assessment (PIDA) [9]:

1) Getting in and out of an elevator (elevator)
2) Docking under a table (docking)
3) Back-in parking against a wall between two chairs (back-in parking)
4) Driving down an L-shaped hallway, turning around (180 degrees), and driving back to the starting point, while avoiding unexpected obstacles in both directions (hallway)
5) Maneuvering through an obstacle course (maneuverability)

Participants initially completed up to two 20-minute training sessions on basic PWC maneuvers and the driving modes. During each session, participants completed one scenario in the three different driving modes. These modes each simulated a different strategy for driving assistance, resulting in three different levels and/or types of user control. The following guidelines were used by the tele-operator during each mode:

Basic safety mode – The maximum speed of the wheelchair was decreased when the user was within 0.6 m (2 ft) of the obstacle and was stopped when the user was within 0.3 m (1 ft) of the obstacle. Once the user was stopped, he/she was not permitted to drive towards the obstacle and had to drive away from it, except for scenarios where the user was required to approach objects closely (such as the table in scenario 2 and the wall in scenario 3). In these cases, after the user was stopped, he/she could proceed towards the object at a very slow "docking" speed. An audio prompt was played when the wheelchair was slowed down or stopped (e.g., "Slowing down", "Stopping"). Vibration feedback was also provided on the joystick when the speed was being capped.

Steering correction mode – If the user was within 0.3 m (1 ft) of an obstacle, the wheelchair automatically steered away from it (without slowing down or stopping). Speed correction was only used as in the basic safety mode above if: 1) the user approached objects that were parking destinations (as in scenarios 2 and 3), 2) no free space was found ahead of the wheelchair, or 3) the user moved outside of the designated test area. A notification audio prompt was played upon system intervention (e.g., "Turning away"). Just-in-time audio direction prompts were offered to signal upcoming turns (e.g., "Turn right") when the user was off-route. Vibration feedback was also provided on the joystick when the heading and/or speed were corrected.

Automatic mode – The wheelchair completed the driving task, avoiding all obstacles in its path automatically. The user could stop the chair by pulling back on the joystick or by telling the researcher to stop. An audio prompt was provided at the beginning (e.g., "Driving in auto mode").

The ordering of modes was randomized for every scenario and participant. Additionally, each mode was tested three times consecutively in every scenario to allow participants to become comfortable with the technology and driving task. One researcher tele-operated the wheelchair while standing in a relatively inconspicuous position such that he did not interfere with the driving task, but remained aware of the obstacles around the chair. A second researcher supervised the sessions and interviewed the user using qualitative data collection approaches throughout the driving session, and quantitative surveys after every scenario-mode combination. A third researcher video-recorded the sessions.

Each participant also completed one-hour semi-structured interviews before and after the driving sessions. This paper reports preliminary analysis of the interviews conducted during the driving sessions, while findings from the pre- and post-driving interviews are reported in [10].

V. Results and Discussion

Participants (6 female and 4 male) had mild to moderate cognitive impairment and were 62 – 98 years old. Three were PWC users and seven were manual wheelchair users.

Several open-ended questions were asked during and after each trial, and participants were asked to rank all modes in order of preference at the end of every scenario tested. Initial coding of transcripts was performed by the first two authors independently. Codes and rankings were then collaboratively reviewed and compared to ensure agreement, and cases of ambiguity or disagreement were noted. A set of prevalent themes specifically related to the attitudes of users toward control was identified by the first two authors, and subsequent discussion of the identified themes with the third author resulted in the three overarching themes presented in this paper. Relevant ranking information is included to supplement and contextualize the thematic discussion. Although preferences for specific modes varied across participants and even across scenarios for the same participant, some interesting tendencies were found.

A. The desire to be in control

In the first theme, participants clearly indicated their desire to be in control of some aspect of their mobility such as wheelchair operation and/or decision-making. The extent, mechanism, and timing (i.e., scenario-dependent vs. persistent) of desired control was found to vary between participants.

Participant 1 rated the automatic mode as his most preferred mode in the hallway, elevator and back-in parking tasks, which he rated as the most difficult tasks. However, he noted that the automatic mode would need to be able to allow him to change his mind regarding his desired destination (in the hallway task), which was a feature he liked about the other modes. These remarks implied that he wanted to be in control of the decision-making process. He also mentioned that although he did not mind the reduced control in the steering correction mode during familiar tasks, he wanted more specific prompts during the (less familiar) back-in parking task to inform him about what the chair was doing and why. He mentioned the importance of having some control in the maneuverability task, where he preferred the steering correction mode, and liked the ability to make small adjustments himself while docking under the table. Participant 3 was "somewhat frustrated" with the automatic mode during the back-in parking task since she felt comfortable driving herself, and later mentioned that she "always" prefers to be driving on her own. Participants 4 and 6 always preferred to have some control (in either steering correction or basic safety mode) rather than being driven automatically, both showing signs of anxiety during the automatic mode. Specifically, Participant 4 preferred the basic safety mode in three out of five scenarios, and steering correction in the remaining scenarios. Participant 6 preferred steering correction over other modes in all scenarios, emphasizing that she "wanted [the system] to go where [she] wants it to go and not where it wanted it to go, even if it was the wrong thing", as long as the wheelchair did not hurt anyone. Although Participant 7 initially preferred the automatic mode and was "not a confident driver", over time she became more comfortable and commented that she would rather drive on her own with safety features than have the chair drive automatically. Participant 8, who was initially nervous about the automatic mode, also expressed the desire to have "some control" in four out of five scenarios, and was confused or frustrated when wayfinding prompts were issued, saying "but I do not want to go back that way". He often questioned why the system was telling him to go in a different direction, and later explained, "sometimes I would like to go my own way". Participant 9 rated the automatic mode as least preferred in three out of five scenarios where he wanted to drive on his own.

These findings suggest that a fully autonomous system that does not offer the user any control over higher level route planning or lower level driving behaviors might be unacceptable to target users, and cause frustration and anxiety.

B. *The pros and cons of different levels of control*

This theme highlights that users actively considered the advantages and disadvantages of each mode. There were several cases of conflicting attitudes and ambivalence about the different modes of control, possibly because of specific user characteristics and personal preferences. Results indicated that participants might want to be able to choose different levels of control depending on their cognitive and/or physical state, and/or the specific scenario.

For example, Participant 1 mentioned that it was more difficult to control the chair in basic safety mode because it "stopped a lot", but appreciated the fact that, unlike with the automatic mode, he was still in control. In addition, although he preferred the automatic mode in crowded situations where he trusted the system more than himself, he referred to the other modes as "fun" since they offered him a higher level of control. Participant 2 said she would use automatic mode especially when she was tired, sore and wanted to move around, but felt concerned that "your mind can wander onto something else and maybe you should still pay attention". Participant 3 similarly expressed that she liked that she "didn't have to do anything" in the automatic mode but was simultaneously frustrated by the fact that she was not doing the task herself in this mode. Participant 5, who often fell asleep during the automatic mode, appreciated the fact that she could relax while the chair drove, but was concerned that she would forget how to drive if she always used the automatic mode. Participant 6 mentioned that while she preferred to remain in control, the automatic mode would be useful in complex or new environments where she could get lost or anxious. Although Participant 8 felt like the wayfinding directions could be useful, he was frustrated when the directions conflicted with his intentions. Participant 10 commented that the basic safety mode made her feel safer than "doing it herself" (without the safety features), but also expressed frustration with the stopping behavior, saying "it takes hours to get in here".

These findings help to understand the contexts (user characteristics and driving scenarios) where different levels and/or types of control might be beneficial. Thus, a system that implements a single control strategy as in [7] might ultimately restrict the users' function and acceptance of the technology.

C. *"Steering away" vs. "stopping"*

This theme highlights the difference in user acceptance between a system that prevents motion toward obstacles and one that allows the user to move around obstacles by steering away from them. It is important to note that steering corrections were not made to avoid objects that were parking destinations in scenarios 2 and 3, since participants were required to eventually stop at the destination in these scenarios. Instead, steering correction (in all scenarios) was only offered for en-route obstacles that the participant needed to drive around. While participants appreciated being stopped in front of the table or wall, and it seemed in these cases that the system behaved as the participants expected/desired, dissatisfaction with the basic safety mode while avoiding en-route obstacles was expressed clearly.

Steering correction was preferred to the basic safety mode in a total of 28/50 rankings across all scenarios and participants. The basic mode, on the other hand, was preferred over steering correction in only 6/50 rankings. Other rankings included cases of contradiction and/or ambivalence. Participant 1 mentioned that he liked steering correction since he could "move away smoothly" as opposed to having to "regain momentum" when stopped, implying that smoothness of speed and trajectory could be important system features. Participant 3 said that a system that just stopped her and did not correct her steering for her would be "frustrating". Participant 5 felt that the steering correction mode was easier because she "didn't have to do any maneuvering [herself]". Participants 8 and 10 both mentioned that the steering correction was helpful and made avoiding obstacles easier, and Participant 10 expressed frustration when the basic safety mode stopped her in front of a wall during the hallway task.

The above findings suggest that most of the time, participants were willing to give up some control over their direction in order to preserve their driving speed, while still feeling as though they were driving themselves rather than the wheelchair driving on its own, or in some cases that they were driving "with" the wheelchair. Their preference for maintaining wheelchair speed rather than being stopped corroborates reports of user frustration when the system stopped the wheelchair to prevent collisions in this study and previous studies [4]. Since a key benefit offered by powered mobility is the ability to move faster than while using a manual wheelchair or walker, it is reasonable that some drivers might want an intelligent wheelchair that ensures safety without compromising speed. In this case, a steering correction approach might lead to higher satisfaction and usability than simply stopping the driver, although issues reported by some participants related to "jerkiness" (caused by disagreements between the driver's and tele-operator's joystick direction inputs) would need to be addressed to ensure a positive user experience. Additionally, automatic steering correction could take away opportunities for the driver to learn and/or practice how to steer independently. An alternative approach would be to test a version of the basic safety mode that provides richer feedback on the correct steering direction and the environment, as suggested by three participants. Developing a more intuitive feedback interface could improve usability for users such as Participant 9, who wanted to be able to steer the wheelchair on his own even though he found the joystick "hard to control" in the basic safety mode.

VI. IMPLICATIONS FOR SYSTEM DESIGN

The findings presented in this paper demonstrate that users, despite their cognitive impairment, are able to articulate some needs and preferences clearly. Instances of ambiguity and contradiction seen in user responses could be attributed to various factors: users may not have fully understood how the technology worked, they were unable to articulate specific thoughts, they were unsure of, confused about, or did not remember details related to the trial in question, they were hesitant to express how they truly felt, they changed their mind, or they simply had mixed feelings. Although the above factors present challenges in data collection and interpretation, given that all of these users were cognitively impaired and many are likely to deteriorate with time, these ambiguities and contradictions themselves need to be accounted for in the system design process. For example, a user with memory impairment might need a system that continuously reminds him/her of what it is doing in order to prevent confusion or anxiety, as suggested by Participant 6. Alternatively, a user who is easily agitated might prefer a system that simply intervenes without providing any feedback, and this preference might change from one day to the next as seen with Participants 3 and 8.

In addition, both preference and ability need to be considered during system design. While Participant 4 had high driving performance, thus justifying his perceived lack of need for intervention, Participant 6 had poor short-term memory and was not able to drive without a lot of verbal feedback from the researcher. Thus, although the basic safety mode would likely be sufficient to increase safety for drivers such as Participant 4, Participant 6 would require richer feedback from the system in order to maintain some control over lower level driving behaviors while being safe.

The above features would therefore need to be implemented in a system that is not only customizable to the user, but is also dynamic and can adapt appropriately based on the user's cognitive and/or physical state as well as the environment at any given time. Future work involves using machine learning techniques to determine the optimal control strategy for each user based on sensor data collected (e.g., distance to obstacles) [8] and known user preferences.

VII. CONCLUSION

The results from this study have provided several insights into users' attitudes toward intelligent wheelchairs, specifically related to user control. We hope that continued development and testing will help to create a system that increases the independence and mobility of the target users, while satisfying their specific needs and preferences.

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