CLINICAL EVALUATION OF THE INTELLIGENT WHEELCHAIR SYSTEM

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ABSTRACT

Cognitively impaired older adults may be prevented from using a powered wheelchair due to safety concerns. This paper presents an Intelligent Wheelchair System (IWS) aimed at helping these adults drive a powered wheelchair safely. A clinical study was conducted to compare the safety and usability of driving a powered wheelchair with and without the IWS. Results showed that the IWS has the potential to increase safety for cognitively impaired older adults; however the IWS may also increase the complexity of powered wheelchair use.

INTRODUCTION

Powered wheelchairs are known to provide benefits for older adults by enabling them to have a means of independent mobility. Some of these benefits include: participation in self-care, productivity and leisure occupations, and social opportunities [1]. Overall powered wheelchairs are linked to an improved quality of life for older adults who have a reduced ability to walk, and do not have the physical ability to propel themselves in a manual wheelchair.

Unfortunately, not all older adults who require a powered wheelchair for independent mobility are able to obtain one. The barriers to powered wheelchairs are complex, and range from physical and cognitive impairments, to cultural stigmas, and institutional concerns. Cognitive impairments in particular, present a large concern for Canadian institutional settings. From a national survey it was estimated that 65% of older adults in these settings have some form of cognitive impairment [2]. Often older adults with cognitive impairments are denied powered wheelchair use because of concerns that they will cause accidents/collisions that harm themselves, bystanders, or property [3].

The safety of bystanders is a serious concern. Approximately 73-80% of older adults experience a trip or fall after being hit by a wheelchair [4]. And from this, 5-10% of falls lead to hip fractures [5], which with further complications could result in death.

BACKGROUND

In an effort to promote access to independent mobility, while addressing safety concerns, researchers have been developing intelligent powered wheelchairs. These powered wheelchairs are equipped with technology to make the wheelchair safer to drive and more accessible to use. A number of these wheelchairs have been developed and tested with cognitively impaired individuals, including: UK Call Centre's Smart Wheelchair [6], PALMA [7], and University of Zaragoza's Intelligent Wheelchair [8]. However, only one project (anti-collision skirt) has been known to be clinically evaluated with cognitively impaired older adults [9]. In light of this, there is a pressing need for the field of intelligent wheelchairs to better understand its potential impact on cognitively impaired older adults.

The goal of this research was to clinically evaluate if an intelligent wheelchair system could benefit its target population of older adults with cognitive impairments.

SYSTEM OVERVIEW

The Intelligent Wheelchair System (IWS) is the newest iteration of intelligent wheelchairs developed by IATSL (Intelligent Assistive Technology & Systems Lab) for cognitively impaired older adults. Previous versions of the system have examined its potential use in long-term care homes [10], and compared different external sensors [11].

The IWS is designed as an add-on system to existing powered wheelchairs. It adds two functions to promote safety and ease of use: 1) anti-collision – to gently stop the powered wheelchair before it collides into an obstacle and then to prevent further wheelchair movement towards that obstacle; and 2) semi-autonomous navigation – to give audio prompts that will help users navigate around obstacles if they remain stopped for a certain period of time (i.e. "try turning left", "try turning right").

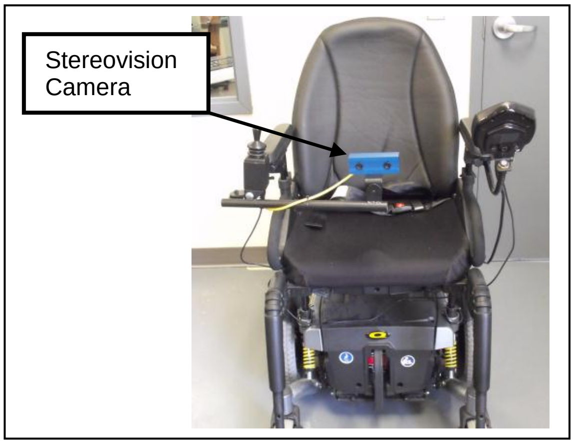

Figure 1: IWS mounted on a Pride® Mobility Q6000z Powered Wheelchair.

For operation, the IWS consists of a *stereovision camera* (FocusRobotics nDepth™), an *onboard computing unit* (PC/104 form factor), and a *joystickDCLM* (Direction Control Logic Module). The *stereovision camera* has the capability to perceive the distance of objects from the front of the wheelchair. From real-time analysis of this depth information, the *onboard computing unit* is able to interpret when objects are too close to the wheelchair, and also the free space surrounding objects. When objects are too close, commands will be sent to the *joystickDCLM* to stop the wheelchair. The *joystickDCLM* interfaces directly with the powered wheelchair's controls and will prevent "unsafe" joystick signals (i.e. inputs that cause the wheelchair to hit an obstacle) from reaching the wheelchair's motors. Free space information is used to determine which audio prompt to be played. The prompt asks the user to drive in the direction of greatest free space around an obstacle. This prompting approach allows the user to retain navigational control of the wheelchair (for their individual exploration), while still being aided (prompted) by the IWS if the navigation task becomes too difficult.

OBJECTIVE

The focus of this research was to evaluate if the IWS could have a positive impact on the *safety* and *usability* of a powered wheelchair when driven by cognitively impaired older adults. Within this population, a subset was selected for practicality: older adults with dementia living in an institutional setting.

METHODS

A single-subject research approach was conducted to identify the effects of the IWS on the individual. In single-subject research each participant acts as his/her own control [12]. For this experiment, there were two phases of testing: A, driving a powered wheelchair without the IWS; and B, driving with the IWS.

To standardize the testing procedure for driving, an obstacle course with six essential powered wheelchair movements was created. These movements were based from the PIDA (Power-Mobility Indoor Driving Assessment) [13], and the Wheelchair Skills Test [14], two current assessments related to powered wheelchair mobility. The six essential movements were: 1) 90º left turn, 2) 90º right turn, 3) straight line path, 4) weaving maneuverability, 5) stopping, and 6) 180º turning on spot. Participants were asked to drive through the obstacle course five times (or runs) in each phase. For each run, the order of the movements was randomly assigned to minimize the effects of learning on the internal validity of the study. With the exception of the 180º turn, all movements were driven through twice per run. A run was done once a day.

Participants were recruited from a long-term care home following ethics approval from the University of Toronto Research Ethics Board. The inclusion criteria for this study were that participants: are over age 60, have minimal experience with powered wheelchairs (to minimize historic effects), have mild-to-moderate dementia (11-26/30 on MMSE), be able to identify joystick directions, be able to speak English, and have written consent from their substitute decision maker.

Two participants were recruited for the study (Table 1).

Table 1: Participant Data

Inclusion Criteria	Participant 1	Participant 2
Age	69	62
MMSE Score	25 (Mild)	13 (Moderate)
Prior Wheelchair Experience	~6 hrs	No

Training occurred before the start of each phase until the participants demonstrated cause-effect understanding between joystick directions and wheelchair movements. Before each run, training was reiterated if participants had difficulty demonstrating this cause-effect understanding. For the phase/runs with the IWS, a demonstration of how the system operates was given before each run.

Outcome measures for *safety* were: the front collisions that occurred within the stereovision camera's field of view (FOV), and the successful completion of an essential movement task without a collision. Outcome measures for *usability* were: the time taken to complete the course, and the joystick adherence to audio prompts (i.e. if the participant moved the joystick in the prompted direction within the first three joystick movements after the prompt was played). Measures were taken during each run.

RESULTS

Collision and time results were plotted with their mean and trend lines for visual analysis (Figures 2 to 5). Completion of movement tasks were summed per phase and converted to a total pass percentage (Table 2 - Movement Task Pass %). Adherence to IWS audio prompts were tabulated from the prompts played to each participant (Table 3).

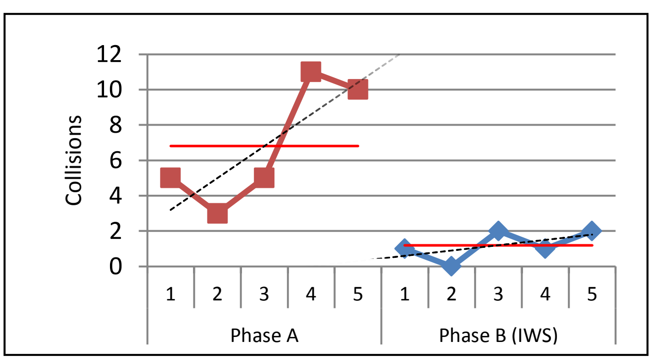

Figure 2: Front FOV collisions for Participant 1.

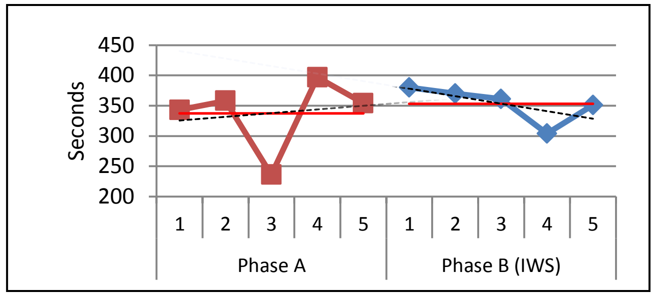

Figure 3: Time of Run for Participant 1.

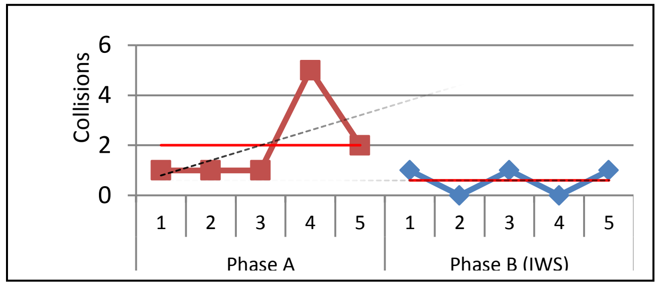

Figure 4: Front FOV collisions for Participant 2.

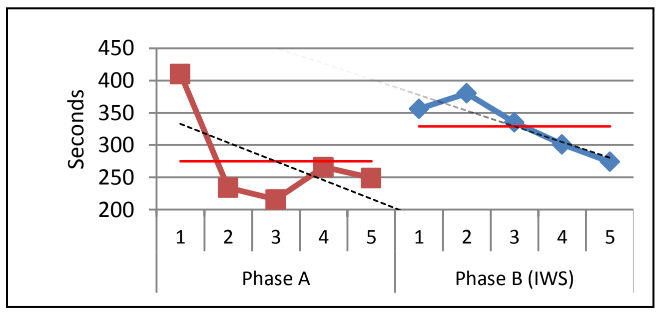

Figure 5: Time of Run for Participant 2.

Table 2: Movement Task Pass %

Movement Tasks	Participant 1		Participant 2	
	No IWS	***IWS***	***No IWS***	***IWS***
90º Left Turn	80%	70%	90%	100%
90º Right Turn	10%	100%	80%	80%
Straight Path	60%	80%	70%	100%
Stopping	80%	100%	100%	100%
Weaving	0%	0%	10%	10%
180º Turn	80%	80%	100%	100%

Table 3: Adherence to IWS Audio Prompts

Audio Prompt Response	Participant 1	Participant 2
Quick Adherence	76.5%	56.4%
No Adherence	23.5%	43.6%

DISCUSSION

Results from participant 1 support the idea that user safety in a powered wheelchair was increased due to the intervention of the IWS. This was shown by the large discontinuity in the collision data when the IWS was introduced, and the lower number of collisions that occurred in runs with the IWS. Pass rate of right turns also increased substantially from 10% to 100% between phases, which suggest that the IWS has the potential to promote safe maneuverability in powered wheelchairs. However not all movement pass rates were shown to increase. Time to complete the course appears not to have changed between phases (i.e. similar means, no discontinuity).

Results from participant 2 are less conclusive in supporting an increase in the user's safety. The large spike in phase A is likely due to a bad driving day, yet it appears that the IWS could limit the severity of these days by limiting the number of collisions that occur. Pass rate increased substantially from 70% to 100% for straight path movement. Time to complete the course was negatively affected with the introduction of the IWS, yet the user had a downward trend that suggests learning to use the system better.

It is difficult to generalize single-subject results to the entire population of cognitively impaired older adults. At best, these results give insight into how the IWS can affect individuals within the population. The IWS has the potential to increase safety, by lowering the number of collisions and increasing user's ability to complete essential movements without a collision. For usability, the time for course completion results were not able to show an increase in usability, and in one case showed a decrease, which may be due to a lack of familiarity with the IWS. Usability could also be linked to prompting adherence, since participant 2 had more usability issues and a lower prompting adherence than participant 1.

Although there are positive results, further work on the system needs to be done. The IWS needs to be improved to prevent all collisions due to the importance of safety, and usability could be improved with prompting methods that are tailored to the individual.

CONCLUSION

This study has shown that the IWS has the potential to increase the safety of powered wheelchair use for cognitively impaired older adults. It also gives insight into the design issues related to the older adult population. There is diversity in the population that must be accounted for. As well, care should be taken to design technology that does not increase the complexity of powered wheelchair use.

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REFERENCES

[1] S. Iwarsson, A. Stahle, A. Brandt, "Older people's use of powered wheelchairs for activity and participation," *J. Rehab. Med.*, no. 36, pp. 70-77, 2004.

[2] P Clarke, P. Chan, P.L. Santaguida, & A. Colantonio, "The use of mobility devices among institutionalized older adults," *J. Aging & Health*, vol. 21, no. 4, pp. 611-26, 2009.

[3] W.B. Mortenson et al., "Perceptions of power mobility use and safety within residential facilities," *Can. J. Occup. Ther.*, vol. 72, no. 3, pp. 142-52, 2005.

[4] T. Corfman et al., "A video-based analysis of tips and falls during electric powered wheelchair driving," *presented at RESNA*, Reno, NV, 2001.

[5] M.C. Nevitt, S.R. Cummings, S. Kidd, & D. Black, "Risk factors for recurrent nonsyncopal falls," *J. Am. Med. Assoc.*, vol. 261, no. 18, pp. 2663-8, May 1989.

[6] J.P. Odor, M. Watson, P. Nisbet, & I. Craig, "The CALL Centre smart wheelchair handbook 1.5," *CALL Centre*, 2000.

[7] R. Ceres, et al., "A robotic vehicle for disabled children," *IEEE Eng. Med. Biol.*, pp. 55-63, Nov/Dec 2005.

[8] L. Montesano, M. Diaz, S. Bhaskar, & J. Minguez, "Towards an intelligent wheelchair system for users with cerebral palsy," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 18, no. 2, pp. 193-202, 2010.

[9] R.H. Wang, S.M. Gorski, P. Holliday, & G.R. Fernie, "Evaluation of a contact sensor skirt for an anti-collision power wheelchair for older adult nursing home residents with dementia: Safety and mobility," *accepted to Assistive Technology*, 2010.

[10] A. Mihailidis, P. Elinas, J. Boger, & J. Hoey, "An intelligent powered wheelchair to enable mobility of cognitively impaired older adults," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 15, no. 1, pp. 136-43, 2007.

[11] P. Viswanathan, J. Boger, J. Hoey, & A. Mihailidis, "A comparison of stereovision and infrared as sensors for an anti-collision powered wheelchair for older adults with cognitive impairments," *Assist. Tech. Research. Series., IOS Press*, vol. 21, no. 16, pp. 165-172, 2008.

[12] K.J. Ottenbacher, "Evaluating clinical change: strategies for occupational and physical therapists," Los Angeles, Williams & Wilkins, 1986.

[13] D. Dawson, R. Chan, & E. Kaiserman, "Development of the Power-mobility Indoor Driving Assessment for residents of long-term care: A preliminary report," *Can. J. Occup. Ther.*, vol. 61, no. 5, pp. 269-76, 1994.

[14] *Wheelchair Skills Test (WST) manual*, Version 4.1, Dalhousie University, Halifax, Nova Scotia, Canada, 2008.