Enabling Power Wheelchair Mobility with Long-Term Care Home Residents with Cognitive Impairments

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
Graduate Department of Rehabilitation Science in collaboration with the Institute of Biomaterials and Biomedical Engineering
University of Toronto

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Abstract

For older adults, functional independent mobility is essential to well-being. Many care home residents have physical and cognitive impairments and use wheelchairs. Residents with difficulty self-propelling manual wheelchairs may benefit from power mobility; however, those with cognitive impairments may be precluded because of the potential for injury. My research goals were to apply novel power wheelchair technology to enable safe, independent mobility. Technology was developed to examine the value and implications of power mobility for residents with restricted mobility and mild or moderate cognitive impairments.

The first study tested a prototype anti-collision wheelchair with a contact sensor skirt. Six single subject studies were completed. Distances travelled in manual and anti-collision wheelchairs were compared. Observational and interview data were collected. Focus groups (37 staff) and interviews (18 staff, six other residents, one spouse) were performed. Three of six residents were able or had potential to operate the prototype. One resident chose to use it beyond the study, and his mobility and well-being improved. Case analyses showed factors limiting prototype acceptance. Residents were unsatisfied with the appearance and slow speed, and found the interface frustrating to operate because of inadequate feedback. Social isolation and reduced
autonomy restricted independence achievable with technology. Socialization and affective benefits of mobility were demonstrated in one case where prototype use was continually assisted. Residents and staff supported the anti-collision concept. On observation, the prototype compensated for absent or delayed responses of residents to obstacles below sensors and decreased injury risk. However, full sensor coverage of the environment was needed.

The second study addressed acceptance and interface usability issues. A simulated collision-avoidance wheelchair with a multimodal feedback interface was evaluated. The interface provided audio, visual and haptic feedback to guide navigation away from obstacles. Through observations, interviews and questionnaires, five residents evaluated the device. High device acceptance and usability were found. The device was easy to use and assisted with performance of indoor mobility goals. Further research is necessary before power wheelchairs with new features are available for users; however, these results could play a fundamental role in shaping technology development and mobility interventions for this neglected population.
Acknowledgments

I wish to thank the residents, their families and the staff of the long-term care homes that contributed to the studies discussed in this thesis. Without their participation and enthusiastic support for this research, progress in rehabilitation science, occupational therapy, and assistive technology development would not be possible.

Thank you to my thesis supervisor, Dr. Geoff Fernie (“Research Dad”). His leadership and vision for heightening the profile and broadening the possibilities of rehabilitation research are truly admirable. However, it is his sincere and enthusiastic desire to improve the lives of people with disabilities and their caregivers with solutions to the every day (and often mundane and messy) problems that is most inspiring. I am grateful for the guidance and encouragement over the years, as well as the oddly humorous stories.

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I thank the team members at Toronto Rehabilitation Institute iDAPT’s Technology R&D team. Thank you to Gerry Griggs and Adam Sobchak for developing the power wheelchair technology for the project, Pam Holliday (“Research Mom”) for guidance, support and overall assistance, Susan Gorski (“Safety Susan”), and many others for helping with data collection and analysis.

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I am grateful for the companies who donated the power wheelchairs for use in these studies. The Rocket™ power wheelchairs were donated by Nimble Inc. and the Nomad power wheelchair was donated by Dynamis Mobility.

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Preface

Thesis Format

This thesis is presented in a manuscript style format, and includes four manuscripts that have been published or submitted for publication in scientific journals. Chapter 1 includes a summary of the research problem, research goals and objectives, and a review of the literature. Chapter 2 contains information on the theoretical base that guides the research, methodology with descriptions and rationales for the selected approaches used in the two studies, and general information on the study settings, participants, and power wheelchair technologies used. Chapter 3 gives general information about the results and Chapters 4-7 contain the manuscripts originating from the studies. An overall discussion follows in Chapter 8 that integrates findings and knowledge, and outlines future avenues of research.

Summary of Original and Significant Contributions


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Chapter 1

1 Introduction

1.1 Summary of problem

For older adults, functional independent mobility is essential to health and well-being, and determines their capacity to participate in self-care, productivity and leisure activities. Many older adults living in long-term care homes have multiple and complex physical and cognitive limitations and use wheelchairs as a primary means of mobility. Residents who are physically unable to move a manual wheelchair may benefit from power mobility. However, residents who have cognitive impairments may not be able to safely operate a power wheelchair in the long-term care home environment because of the potential for injury to others. An ethical dilemma exists in the need to enable mobility for some residents while protecting the safety of others, especially frail ambulatory residents who are at high risk for falls. While many innovative technologies are in development, few are currently available for clinical use, and many have not been tested with end users. Options to enable safe and independent power mobility are extremely limited and residents remain dependent on caregivers to move them from place-to-place.

1.2 Research goals

The ultimate goal of this research is to improve the mobility independence and well-being of long-term care home residents with multiple and complex physical and cognitive impairments. In this thesis, novel technology-based interventions are developed and evaluated, and the value and implications of new power wheelchair technologies for users and others in the long-term care setting are explored. Through this research, design recommendations and considerations are provided for the implementation of future power wheelchairs for this often neglected population.

1.3 Literature review

1.3.1 Overview of long-term institutional care environment

Long-term institutional care facilities offer nursing care and assist residents who require help with their daily activities. Different terms are used to refer to long-term institutional care
facilities in different countries. In the US, there are nursing homes, which are privately paid, and skilled nursing facilities or units, which are paid for by Medicare if medically necessary (Medicare, 2009). Other terms used in the US may include convalescent homes or rest homes.

In Canada, long-term institutional care or long-term facilities-based care homes are provincially or territorially governed. The naming of homes, such as nursing home, personal care facility, and residential continuing care facility varies by governance. Across provinces and territories, there is also much variability in the services, level or type of care provided, cost coverage, and facility ownership. However, the minimum services offered in these facilities include 24-hour supervision, assistance with personal care, health professional care, meals, laundry and housekeeping (Health Canada, 2004).

The context of this research is the long-term institutional care setting in Ontario, Canada. The Ontario Ministry of Health and Long-Term Care governs and funds 24-hour nursing and personal care support in long-term care facilities or homes (Ontario Ministry of Health and Long-Term Care, 2009). Homes may be private, municipal-owned, or charitable homes, and offer shared or private rooms, shared dining and common rooms, lounge areas, gift shops, beauty salons, chapels and gardens. A range of services are provided: meals, housekeeping, pastoral care, social and recreational programs, medication management, assistance with personal care, and access to physicians and other health care professionals.

1.3.2 Health and function of residents

Older adults living in long-term care institutions have significant limitations to their functional mobility due to multiple chronic medical conditions. In Canada, the most common diagnoses in long-term care institutions include arthritis, diabetes, stroke, congestive heart failure and Alzheimer’s disease or other forms of dementia (Banerjee, 2009). The Canadian Study of Health and Aging reported that half of the Canadians with dementia lived in institutions (McDowell, Hill, & Lindsay, 2001). Owing to multiple physical and cognitive impairments, residents of long-term care institutions require considerable assistance in their daily activities. The 1995 National Population Health Survey found that 75% of residents needed assistance with personal care, moving around indoors, and transferring to and from a bed or chair (Tully & Mohl, 1995). In this survey, almost 40% of residents required assistance in all areas. Nearly 50% of older adults
living in long-term care institutions were found to use wheelchairs in the 1996/97 National Population Health Survey (Shields, 2004).

1.3.3  Mobility and residents

Independent mobility is being able to move around the environment by one’s own efforts. Independent mobility has been identified as a primary determinant of the quality of life of older adults living in institutions (Bourret, Bernick, Cott, & Kontos, 2002). Mobility is fundamental when determining the level of independence in daily activities (Hogue, 1984). Mobility includes different functional components such as transferring or moving from one surface to another such as from the bed to a wheelchair, or moving from one location to the next with or without an assistive aid such as a walker or a wheelchair. Functional mobility in long-term care home residents may not always consist of explicit goals. Wandering behaviour is common, owing to the large number of residents with cognitive impairments (Algase, Beel-Bates, & Beattie, 2003). Wandering or exploratory mobility may still be considered functional as it enables physical exercise and a change of environment that facilitates social and cognitive stimulation.

Understandably, restricted mobility and immobility can have a range of serious consequences. Decreased mobility significantly impacts an individual’s ability to participate in self-care, leisure, social, and other meaningful activities, and is related to decreased independence, quality of life, and higher risk for mortality in older adults (Yeom, Fleury, & Keller, 2008). Mobility limitations can lead to social isolation or decreased social opportunities (Mobily & Kelly, 1991). Psychological implications and behavioural changes include dependency, depression, agitation, aggression, withdrawal, apathy, confusion, or anxiety (Mobily & Kelly, 1991). Visual or auditory hallucinations due to sensory deprivation are also possible consequences (National Institute of Nursing Research, 2006). Chronic mobility impairment can lead to a range of physiological changes including bone demineralisation, muscular atrophy, joint contractures, cardiovascular and respiratory changes, pneumonia, pressure ulcers, constipation, and urinary retention (Mobily & Kelly, 1991; National Institute of Nursing Research, 2006).

1.3.4  Enabling mobility

Despite the significance of independent mobility, and that it is frequently named as a high priority goal by residents, independent wheelchair mobility is not often accommodated (Fuchs &
Wheelchairs are more commonly used for seating and positioning or as devices for staff to transport residents (Brechtelsbauer & Louie, 1999). The proportion of residents with independent wheelchair mobility ranges from 4-14% (Brechtelsbauer & Louie, 1999), up to 50% (Bourbonniere, Fawcett, Miller, Garden, & Mortenson, 2007). While many factors can contribute to the low levels of observed independent wheelchair mobility, it is evident that there is a considerable gap in knowledge regarding ways to improve the independence of long-term care residents.

Power wheelchairs may enable mobility with residents who are unable to physically propel a manual wheelchair. Power mobility use requires a certain degree of cognitive function, which may include decision making, memory, judgment, self-awareness (Brighton, 2003). Others have cited learning capacity and the ability to respond appropriately (Mortenson, et al., 2005) and environmental alertness (Massengale, Folden, McConnell, Stratton, & Whitehead, 2005) as important for power mobility device operation. Residents with cognitive and other limitations are not always considered for power mobility because of safety concerns (Hardy, 2004; Young, 2003). Of particular concern in a communal living environment is the risk to other residents who are highly vulnerable to falls (Neyens, et al., 2009; Oliver, et al., 2007). A bump or startle from a moving power wheelchair may increase the risk of falling. In nursing homes, 10% to 25% of falls lead to fractures, lacerations or the requirement for hospital care (American Geriatrics Society, British Geriatrics Society, & American Academy of Orthopedic Surgeons Panel on Falls Prevention, 2001). Fractures, particularly hip fractures, may result in significantly increased disability or death because of complications. Clinicians are presented with the ongoing challenge of balancing the need to facilitate mobility independence for residents while minimizing the risk of injury to drivers and other residents (Mortenson, et al., 2006).

The issue of power mobility driving safety in nursing homes is a significant and documented clinical concern (Dawson, Chan, & Kaiserman, 1994; Hall, Partnoy, Tenenbaum, & Dawson, 2005; Reed, Yochum, & Schloss, 1993). Despite the intensity of concerns, however, there exists limited statistical evidence of power wheelchair-related injuries specific to care homes and older adults with cognitive impairments. Existing reports of wheelchair-related accidents and injuries rely on specific databases that likely do not capture the full extent of the problems, are not recent and do not discern whether injuries occurred in an institution nor identify the ages of the people affected (Kirby & Ackroyd-Stolarz, 1995), and do not differentiate between manual or power...
wheelchairs (Xiang, Chany, & Smith, 2006). In the most recent report of accidents related to power mobility use, a survey of adult power wheelchair and scooter users, median age 77 years old and living in the community, indicated that about 20% of users reported accidents within the year (Edwards & McCluskey, 2010). Of these accidents, 11% required hospitalization because of fractures, lacerations and bruises and 33% damaged their mobility device. The authors state that power mobility safety is an issue of major concern for users, health care professionals and the public, and that additional research be conducted to improve safety and to better understand the role of cognition in power mobility device accidents.

Few studies, with the exception of a study by Mortenson, et al. (2005), have examined the perceptions of power mobility safety in long-term care home settings. Mortenson, et al. investigated perceptions of power mobility safety for the purpose of developing safety guidelines in three facilities, one of which served a younger population and the other two predominantly older adults. A diversity of participants was included: residents with progressive conditions such as Alzheimer’s disease and non-progressive conditions such as spinal cord injury, family members, and staff. Findings suggested that there were residents who are capable of driving safely despite dementia, poor motor function, and legal blindness. Thus when considering which residents might be considered for a power wheelchair trial, evidence suggested that evaluation should be based on function, and not diagnosis. Findings further suggested that while clinicians deemed power mobility inappropriate for those who could not stop their power wheelchairs (causing harm to themselves or others, and property damage) and for those who are unable to learn from their mistakes, excluding such individuals from driving overlooked the possibility that wheelchair modifications might make power mobility safe even for them.

There are various approaches to support power wheelchair use and minimize unsafe operation in institutional care settings. Personalized training is a typical method to improve driving safety that is routinely provided to new power wheelchair users and often to users who experience a change in their ability to drive. Only one study examined training in power mobility use in the long-term care setting (Hall, et al., 2005). This was a pilot study that compared two power mobility training protocols for older adults living in two long-term care facilities. The study found the two protocols to be comparable in content, but different in their training intensity (number of sessions and the overall timeframe over which training sessions were provided). Several factors including the facility, gender, type of power mobility device (either scooter or power wheelchair), and
training duration were suggested to impact the final driving performance of the residents studied. The Power-mobility Indoor Driving Assessment (PIDA) is an instrument developed specifically for residents of long-term care homes and is useful in assessing driving performance (abilities and safety), and guiding power mobility training or interventions (Dawson, et al., 1994). Risk assessment protocols (Mendoza, Pittenger, Savage, & Weinstein, 2003; Travis, Hendricks, McClanahan, Osmond, & Pruett, 2001) and driving safety guidelines (Mortenson, et al., 2006) have also been developed to help with clinical decision-making and to minimize the risk for unsafe power mobility use. There is a paucity of evidence that examines the effectiveness of these approaches for improving safety. Moreover, these interventions do not always address the residents’ need for self-mobility, especially in circumstances when driving abilities are marginal or deteriorate to such an extent that use of power wheelchairs is restricted or cannot be recommended.

1.3.5 Power wheelchair technology for users with cognitive impairment

Technology-based approaches are also being explored to enable people with multiple disabilities to use and benefit from power mobility. Forty-six power wheelchair projects using different contact and proximity sensors and modes of operation are described in a review by Simpson (2005). These devices are designed for people with decreased driving capability or safety due to combined changes in sensory/perceptual systems (low vision/blindness, visual field loss, neglect), cognition (attention, executive functioning (initiation, action planning, execution of plans, evaluation, judgment, reasoning, problem solving, decision making)), and physical abilities (decreased reaction time, fatigue, decreased range of movement or strength in head or neck restricting vision; ataxia, bradykinesia, dystonia, spasticity, tremor or weakness) (Simpson, LoPresti, & Cooper, 2008). The implications of these changes include decreased accuracy with using input devices or responding to obstacles. However, few systems have been clinically tested and even fewer are commercially available (Simpson, 2005). Primary reasons for the lack of testing with targeted users in real-life settings are that the systems are not sufficiently reliable in diverse environmental conditions or do not have adequate sensor coverage to protect users, others and property from harm (Sharma, 2009). Another reason cited is related to singular prototypes and the challenges to installing the user’s own customized wheelchair seating to the prototype, making the process time consuming and difficult when needing to test with multiple users (Tsui, Yanco, Feil-Seifer, & Mataric, 2008).
Only two other research groups have examined systems targeted for older adults with cognitive impairments living in institutions. Both of these groups are in collaboration with the investigators involved in the studies described in this thesis. The systems being developed are currently in development with minimal clinical evaluation to date. One of these groups developed a system that provides assisted navigation and prompting, and uses a stereovision video camera as the sensor (Viswanathan, Boger, Hoey, Elinas, & Mihailidis, 2007). Preliminary testing with long-term care home residents with cognitive impairments is pending.

Another system described by Mihailidis, Elinas, Boger, & Hoey (2007) uses a 3-D time of flight infrared laser range sensor and provides assisted navigation with audio prompting. Initial laboratory testing of the system in a controlled indoor lighting scenario demonstrated a 95% obstacle detection or hit rate. In a series of 100 trials to examine the detection of obstacles with different properties, five misses were identified with the cane that was tested. The low error tolerance for misses and the unsatisfactory performance of these sensors to detect obstacles in diverse environments led the group to focus on stereovision as the primary sensor. Pilot testing of their stereovision and audio prompting system has been completed with targeted users (Swartz & Mihailidis, 2009). The system was evaluated with five care home residents with dementia. Residents tested the power wheelchair without the system in place for one set of three trials of an obstacle course on one day, and repeated the same trial another day with the system in place. For most residents, there was no difference in the perception of safety or likeability of the power wheelchair with or without the anti-collision system. Residents identified that with the system in place, the wheelchair stopped prior to obstacle contact, but many also felt frustrated when driving with the anti-collision system in place. Results of this testing were used to improve the system and further trials with users are in progress.

1.4 Purpose and objectives

There are significant limitations to the clinical interventions to enable safe and independent mobility in residents with complex physical and cognitive impairments, and there is an absence of knowledge on the application of new power wheelchair technology for this population. Consequently, it was deemed reasonable and necessary to develop appropriately reliable prototypes and conduct early testing to better understand how residents might use new power wheelchair technology, how users and others respond to such devices, and what technology
features are useful and necessary for this environment. This research forms the foundation for further investigation and development in this field by offering novel knowledge grounded in the clinical testing of new technologies. Findings provide insight into power mobility users with cognitive impairments living in the long-term care home setting, their power wheelchair design needs, and the environmental factors that support or limit implementation of new technologies.

This research has five objectives:

1. To evaluate the safety and mobility implications of an anti-collision power wheelchair with a novel contact sensor skirt designed for residents with mild or moderate cognitive impairments living in long-term care homes,

2. To examine the experiences of long-term care home residents with mild cognitive impairment who used an anti-collision power wheelchair,

3. To explore the application of an anti-collision power wheelchair using an occupational therapy perspective for a long-term care home resident with moderate cognitive impairment,

4. To examine the usability of a multimodal feedback interface on a simulated collision-avoidance power wheelchair in residents with mild or moderate cognitive impairment in the long-term care home setting, and

5. To devise a framework to organize findings and future avenues of research and development.

The study objectives were investigated in two studies:

1. Enabling safe and independent power wheelchair mobility with long-term care home residents with cognitive impairment: Use of an anti-collision power wheelchair, and

2. Usability of a multimodal feedback user interface for a collision-avoidance power wheelchair
Chapter 2

2 Research approach

2.1 Theoretical influences

The guiding theoretical approach in this research is based on a person-environment-occupation model, and more specifically the Canadian Model of Occupational Performance–Engagement (CMOP–E; Townsend & Polatajko, 2007). The CMOP–E defines the dynamic interactions of the person, environment, and occupation. To enable performance and engagement in an occupation, the person, environment, or occupation may be altered. In this model, the person is comprised of physical, cognitive, and affective components. The environment consists of physical, social, cultural, and institutional elements. Occupation is a term used in the occupational therapy literature that encompasses “an activity or set of activities that is performed with some consistency and regularity, that brings structure, and is given value and meaning by individuals and a culture” (p.19, Townsend & Polatajko, 2007). Occupations may be organized into self-care, productivity or leisure pursuits. While priority occupations are as diverse as individuals, the performance of self-care such as eating, grooming or going to the toilet; visiting with friends and family; or leisure activities such as reading, watching television, or playing games are particularly relevant for residents in long-term care homes. Mobility is a fundamental constituent or action in the performance of many tasks and ultimately occupations. In the Taxonomic Code of Occupational Performance, mobility can be classified as an “action”, or “a set of voluntary movements or mental processes that form a recognizable and purposeful pattern”, (p.19, Townsend & Polatajko, 2007), and through increasing levels of complexity including tasks and activities leads to occupation.

Power wheelchair technologies are components of the physical environment. It follows that through the dynamic interaction of the person, environment, and occupation, that use of a power wheelchair to enable self-mobility (and performance and engagement in valued occupations) will influence elements of the person such as well-being, how occupations are performed (or whether some occupations are performed at all), and the environment including how others view the person or the amount of assistance offered. Moreover, technology design and acceptance of a
technological intervention are impacted by features of the user (person) and their activities and goals (occupations) and the environmental features that support or hinder use. This holistic approach was applied to understanding the residents in the long-term care setting, designing and evaluating the technological interventions, and examining the impact of interventions on the environment.

2.2 Methodology

Two exploratory studies, both using a concurrent mixed methods design (Creswell, 2008) are presented in this thesis. Both quantitative and qualitative approaches were applied whereby data were collected, analyzed and then integrated in the analysis to achieve a comprehensive understanding of the problem under investigation (Creswell, 2008). For research areas where there is currently little knowledge, a mix of methods allows a breadth of information to be gained from examining multiple facets of the research problem that are accessible by different methods. This approach also enables in-depth exploration of experiences and issues of study participants (Tashakkori & Teddlie, 2003). A single subject research study, case studies, and data collection methods that included participant observation, focus groups, interviews and standardized outcome questionnaires were used in this research. Components of the methodology that were applied are described below.

2.2.1 Single subject research design

The single subject research design is a highly appropriate method to study new interventions (Ottenbacher, 1986c), such as novel power wheelchair technology, and to gather primary data on effectiveness. In a single subject study, measures are collected repeatedly from one subject during different phases or conditions (Ottenbacher, 1986c). The repeated measures are then compared between the phases for each subject to determine if a change has occurred from one condition to the next. A group comparison design is not appropriate in this study to assess the efficacy of a novel intervention that requires customisation to the individual and not feasible owing to the small population from which subjects can be drawn (Ottenbacher, 1986c). In the first study multiple single subject studies, or repetition of the same protocol with different residents, were conducted. Further details about the single subject study, mobility measures and data analyses are presented in Chapters 3 and 4.
2.2.2 Case study design

Case studies are holistic and context-rich accounts of an incident or events (Patton, 2002; Yin, 2003). The term case study is both the process for collection, organization and analysis of data, and the results of analysis (Patton, 2002). Case study designs are ideal when looking to explain complex social phenomena such as individual and organizational processes (Yin, 2003). The strength of this methodology is that it investigates a phenomenon within its real-life context and addresses situations in which the boundaries between the phenomenon and its context are not distinct (Yin, 2003). Multiple or single-case studies are presented in Chapters 5, 6 and 7. Details regarding the data sources and analyses are included within these chapters.

2.2.3 Qualitative data collection methods and analysis

Multiple data collection and analysis methods and inclusion of diverse data sources function to improve the understanding of the problem being studied and support the validity and believability of the results. In qualitative research, this strategy is termed triangulation (Rothbauer, 2008). The first study used all three of the data collection methods described below, and data sources included resident users, staff and other residents. Triangulation in analysis methods in the first study involved the use of multiple researchers in the analysis of qualitative data. The second study used participant observation and interviews, involved resident users, and one researcher analyzing the data.

2.2.3.1 Participant observation

Participant observation is a means of data collection whereby observations are made in the real-life context and the observer is understood to participate to varying degrees in the situations being studied (McKechnie, 2008). This immersion in the naturalistic setting promotes a deep understanding of the environments, people interacting within the environments, and the meanings people attribute to their experiences (McKechnie, 2008). In this research, direct observation, participation in the daily lives of those being studied, and informal interviewing allows generation of vast quantities of data on personal behaviours and the physical, social, cultural and institutional elements of the environment. Observations were documented in structured observation forms and field notes. In addition to the breadth and depth of data collected this method was a vital component of this research as many of the residents were expected to have memory impairment or other cognitive limitations. It was felt that information
offered spontaneously at the time of using devices would be valuable and less accessible during summative interviews. The forms used to document observations in the two studies are included in Appendices 1-3 (Study 1: Structured (Time-sampled) Observation Form and Sample Observation Schedule; Study 1: Training Log; and Study 2: Training Log).

2.2.3.2 Focus groups

Focus groups were one of the strategies to collect data from long-term care home staff in the first study. Focus groups are useful to gather information on topics that have not been previously explored (Morgan, 2008). Thus, this approach is useful for analyzing the context and multi-faceted environment of the long-term care home setting and the influence of the environment on new interventions (Seale & Barnard, 1998). Focus groups can be used at different stages of a study, such as initially and after an intervention is implemented (Morgan, 2008). Group discussion is facilitated by a moderator, but there is variability in the degree of structure or involvement in directing the discussion (Morgan, 2008). This approach is convenient and has potential to capture the experiences of many participants at one time (Kitzinger, 1995). One of the primary features of focus groups is that concerns raised by individual participants are used to generate further discussion (Morgan, 2008). Naturally occurring groups, for example the staff of a nursing unit, can be recruited whereby participants are already known to each other and experiences with the residents, work routines and environments are similar. Discussion surrounding concerns and issues may be readily facilitated with participants who have some existing commonalities, and it may be possible to examine group culture and explore the ideas that participants support or do not support (Kitzinger, 1995). Sample topics and questions for the before and after study focus groups are available in Appendix 4 (Study 1: Staff Focus Group Sessions).

2.2.3.3 Interviews

Individual interviews were used to collect information from resident users, staff, family members and other residents. Interviews are suitable for gathering information on personal experiences and the contexts in which people participate. It is an opportunity to hear how they describe elements of their lives, their life situations and actions, and the meanings they attribute to experiences (Kvale, 1996). The interview approach used was flexible and open-ended, and used at various points in the studies to collect information, and at the end of the study as a summative
evaluation. Interviews with residents in the first study were general (for example, discussing topics such mobility or daily activities) and fluid depending on the issues identified during driving training sessions or other occasions, and experiences they had using the technology. In semi-structured interviews, a set of pre-set open-ended questions were asked of participants, and an interview guide is often developed prior to the interview (Ayres, 2008a). Interview guides were used in the first study with staff, family members and other residents, and in the second study with resident users. Sample interview guides are available in Appendices 5 and 6 (Study 1: Sample Interview Guides – Staff and Other Residents; and Study 2: Sample Interview Guide for Residents on Effectiveness and User Satisfaction).

2.2.3.4 Analysis

Data from participant observation and transcripts from audio recordings (of focus groups and interviews) were analyzed using thematic analysis techniques (Patton, 2002). In thematic analysis, data reduction and analysis occurs in a process where data are “segmented, categorized, summarized, and reconstructed in a way that captures the important concepts within the data set” (Ayres, 2008b). In this process, descriptive coding was initially conducted wherein sections of text were annotated with a code that reflected the meaning of the original statement. Categories were then formed using the codes. Using an inductive and iterative process, categories with similar content were examined for inter-relationships and further refined into fewer categories. To ensure the reliability of the analyses, an audit trail (Schwandt, 2001) was used to maintain records and encourage reflexivity about data collection and analysis procedures. The audit trail included the explanation of codes that were developed as part of the effort to make sense of the data, a description of the procedures used to analyze data, and reflections on data collection. Reflexivity is a term describing the process whereby investigators reflect on the role and impact they have on the project itself, and examine the choices made throughout the study (Dowling, 2008). The audit trail was reviewed by another researcher with experience in qualitative research to ensure that conclusions and assumptions in the analysis were supported by the data.

2.2.4 Assessments and outcome questionnaires

Assessments and outcome questionnaires were used in the second study. These were selected based on the documented psychometric properties of the tools. Properties such as demonstrated construct validity; previous testing with older adults, older adults with cognitive impairment or
older adults in the nursing home setting; and reliability were examined prior to selection and
application in the study. Further details about the assessments and outcome questionnaires, and
their features are included in Chapter 7 and Appendices 7-10 (Study 1 and 2: Power-mobility
Indoor Driving Assessment (PIDA); Study 2: NASA – Task Load Index; Study 2: Quebec User
Evaluation of Satisfaction with Assistive Technology (QUEST 2.0); and Study 2: Psychosocial
Impact of Assistive Devices Scale (PIADS)).

2.3 Study settings

The studies were completed in long-term care homes in Toronto, Ontario, Canada. The focus of
testing outside the laboratory was important to see how residents responded to devices in their
own environments, how other residents and staff responded to the devices, and to examine the
environmental requirements for use and implementation of such interventions. Consistent with
the high variability in set up, layout and other factors in care homes in Ontario, there was
variability in the three study locations and therefore between the two studies. All locations were
selected by convenience and their affiliation with the research institutes of the hospitals and the
University of Toronto. The first study was set in a veterans’ long-term care home and the
research ethics board of the care home approved the study. The second study was set in two
long-term care homes. The research ethics board of the hospital research institute approved the
second study for the two sites. Approved consent and information forms for the two studies are
available in Appendices 11 and 12 (Study 1: Consent and Information Forms for Resident Users,
Staff and Other Residents; and Study 2: Consent and Information Forms for Resident Users).

2.4 Study population

The focus of the research is on older adult residents of long-term care homes who have cognitive
impairments. It was determined not to test the technology with surrogate users that is, people
without mobility difficulties, non-wheelchair users, or people without cognitive impairments. It
was also expected that the testing period would be longer than that expected for surrogate users.
Residents may require longer periods of time for assessment, fitting of power mobility devices,
becoming familiar with the technology and training in use. There may also be longer waiting
periods for testing because of informed consent procedures for subject recruitment and residents
may be at higher risk for illness because of multiple and chronic health conditions. Nevertheless,
it was imperative to gain feedback from users for whom the technology is intended and to see how users interact and respond to the technology in the real world setting.

The residents recruited were of a population that is often neglected: residents with little self-mobility in manual wheelchairs, and with cognitive impairments that restrict their potential to use power wheelchairs. Residents with mild or moderate cognitive impairments (screened using the Mini Mental State Examination (MMSE, score between 21-26/30 – mild, 11-20/30 – moderate) (Folstein, Folstein, McHugh, & Fanjiang, 2001) of any diagnoses were included out of convenience and because the technology was intended for a resident population with multiple and complex impairments. The diagnostic specification of the cognitive impairment was not made as it is understood that cognitive impairment in this population is very heterogeneous and likely from mixed causes. It would also be challenging to recruit residents with only a certain diagnosis, for example Alzheimer’s disease. Residents with moderate cognitive impairment were included because from clinical experience, residents who score in this range in the MMSE may still occasionally be assessed for power mobility. While they can benefit from use of a power wheelchair, they are often assessed to be unable to operate them safely and independently.

The data collection forms for resident demographic and other information for the two studies are included in Appendices 13 and 14 (Study 1: Resident Data Collection Form; and Study 2: Resident Data Collection Form).

2.5 Power wheelchair technology

Two modified power wheelchairs were used to address the research objectives. The first study began with a prototype anti-collision power wheelchair with a contact sensor skirt that was designed to be safe and 100% reliable for use by residents in this setting. Six anti-collision power wheelchairs were fabricated for the first study. The second study was conceived after acquiring results from the first study and used a simulated collision-avoidance power wheelchair with a multimodal feedback user interface. One device was developed for testing. This study aimed to address specific aesthetic, size and usability factors found to be unfavourable and challenging for users in the first study. Risk analysis documentation for the technology used in both studies is available in Appendices 15-17 (Study 1: Risk Analysis for an Anti-collision Device for a Power Wheelchair; Study 1: Risk Analysis for a Wheelchair Distance Logging Device by Wheel Rotation; and Study 2: Risk Analysis for an Anti-collision Power Wheelchair Controller).
Technology inspection forms and incident logs for the studies are included in Appendices 18 and 19 (Study 1: Anti-collision Power Wheelchair Inspection Forms and Incident Log; and Study 2: Power Wheelchair Joystick Controller Safety Inspection Form).
3 Results

3.1 Studies and associated chapter numbers

The results are presented in the following chapters.

Study 1
Enabling safe and independent power wheelchair mobility with long-term care home residents with cognitive impairment: Use of an anti-collision power wheelchair

Study 2
Usability of a multimodal feedback user interface for a collision-avoidance power wheelchair

Each chapter, in manuscript format, is presented as close as possible to the style, language and format specified by the journal in which the manuscript is published or submitted. Preceding each manuscript is additional detail pertaining to the contributions of each of the authors listed, a general summary of the manuscript and its relevance to the scope and audience of the journal.

3.2 Study 1

3.2.1 Subjects

Table 1 shows the residents who participated in the study and the corresponding identification codes or pseudonyms used in the subsequent chapters related to Study 1.

<table>
<thead>
<tr>
<th>Chapter 4</th>
<th>Resident 1</th>
<th>Resident 2</th>
<th>Resident 3</th>
<th>Resident 4</th>
<th>Resident 5</th>
<th>Resident 6</th>
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<td>R1</td>
<td>R2</td>
<td>R3</td>
<td>R4</td>
<td>R5</td>
<td>R6</td>
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<tr>
<td>Chapter 5</td>
<td>Annie</td>
<td>Bart</td>
<td></td>
<td>Carl</td>
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<td>Chapter 6</td>
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<td></td>
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<td></td>
<td>Mr. Z.</td>
</tr>
</tbody>
</table>
3.2.2 Data collected and analyzed

3.2.2.1 Mobility data

Raw data collected from the distance loggers were processed using MATLAB Version 7.4.0. A sample of the data processing code and the results are shown in Appendix 20. Mobility data were determined for distances travelled by participants: 1) total distances traveled each day in the manual wheelchair, 2) independent distances traveled each day in the manual wheelchair, and 3) independent distances traveled each day in the power wheelchair. Additional details on analysis and final results are presented in Chapter 4.

3.2.2.2 Qualitative data

Tables summarising all the qualitative data collected for participants in Study 1 are available in Appendix 21.

3.3 Study 2

3.3.1 Subjects

Table 2 shows the residents who participated in the study and their corresponding pseudonyms.

<table>
<thead>
<tr>
<th>Resident 1</th>
<th>Resident 2</th>
<th>Resident 3</th>
<th>Resident 4</th>
<th>Resident 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>George</td>
<td>Mark</td>
<td>Jim</td>
<td>Lilian</td>
<td>Gerry</td>
</tr>
</tbody>
</table>

3.3.2 Data collected and analyzed

Tables summarizing the characteristics of the residents and their mobility are available in Appendices 22 and 23. A table summarising the qualitative data collected for participants in Study 2 is available in Appendix 24. A table showing results for the Power-mobility Indoor Driving Assessment (PIDA) for all participants is available in Appendix 25.
Chapter 4

4 Evaluation of a contact sensor skirt for an anti-collision power wheelchair for older adult nursing home residents with dementia: Safety and mobility


Contributions of the authors: RH Wang wrote the manuscript, developed the research design and protocol, and collected and analyzed the data. SM Gorski reviewed the manuscript, led the safety evaluation and risk management process for the technology, and helped to collect and analyze the data. PJ Holliday reviewed the manuscript, assisted with developing the research design and study protocol, helped to collect and analyze the data, and participated in the design of the power wheelchair technology. GR Fernie reviewed the manuscript, and led the design of the power wheelchair technology and the research project.

This chapter contains the main quantitative results of the first study, including the safety evaluation and the measured mobility impact of using the anti-collision power wheelchair. In addition, the qualitative results collected from the perspectives of the resident users, other residents and nursing home staff are included. This chapter describes the key findings about the safety of the device used in the nursing home setting, the resident and staff perceptions of safety, characteristics of the residents who were able to use the power wheelchair, whether mobility independence was impacted for resident users, and the perception of usefulness of the modified power wheelchair. The content is presented from the view of a technology developer and includes some of the technical elements of the technology development process, but focuses primarily on the clinical aspects of assistive device design and provision. The findings are of most significance to developers of assistive devices, and present the major directions for power wheelchair development and research for this population. The manuscript was accepted in Assistive Technology, a journal that is concerned about both the use and provision of assistive and rehabilitation technologies. The journal is broadly targeted toward researchers, assistive
device designers, clinicians, educators and consumers. The multidisciplinary nature of the journal and the audience encourages language that is not discipline specific and that is intended to be relevant and accessible to a wide range of readers.

4.1 Abstract

This study explored the ability of an anti-collision power wheelchair, fitted with a contact sensor skirt, to enable safe and independent mobility. The device was designed for nursing home residents with mild or moderate cognitive impairment related to dementia. Single subject studies, observations, interviews and focus groups were conducted. Observations on safety were tracked during resident driving sessions. Distances traveled by residents (six) in manual and anti-collision wheelchairs during single subject studies were compared. Data from interviews with resident drivers, staff and other residents, and staff focus groups were analyzed for themes related to perceived device safety and usefulness. The device was observed to compensate for absent or delayed responses of drivers to obstacles at the sensor skirt level and decrease the risk for injury. Two residents were able to use the device. One declined it as he thought it was too big and not helpful for him. The other’s mobility and well-being improved with the device. Another resident with potential to use the device withdrew because he did not like the device’s usability, speed and appearance. Two of the more cognitively impaired residents were unable to use the device because it did not compensate for decreased initiation, motor planning and awareness of obstacles above the sensor skirt. Another resident was withdrawn because of verbal aggression. Interview and focus group data showed the usefulness of the device, although perceptions of its safety were mixed. Further work is necessary to improve environmental coverage, sensor skirt reliability, and perception of safety; to match technology to the needs of a wider range of residents; and to enhance usability, functionality, and acceptance.

4.2 Background

For older adults living in long-term care institutions, independent mobility is important to perceived health and quality of life (Bourret, et al., 2002; Ramage-Morin, 2005). A significant proportion of nursing home residents use wheelchairs as a means of mobility. The 1996/97 Canadian National Population Health Survey found that 49% of residents in health care institutions used wheelchairs (Shields, 2004). Residents who are physically unable to move a manual wheelchair may use power wheelchairs; however, power wheelchair use may be
restricted because of safety concerns related to cognitive limitations. Indeed safety related to cognitive abilities is often cited by clinicians as a reason for not considering power mobility (Hardy, 2004). Power mobility-related safety incidences in the institutional setting are concerns frequently discussed in the literature (Mendoza, et al., 2003; Mortenson, et al., 2005). Some institutions even restrict power mobility use on nursing units with residents who have cognitive impairments. A particular safety concern relates to driving a power wheelchair in a communal living environment where other frail residents who are at high risk for falls are walking. A bump or startle from a moving power wheelchair may increase the risk of falling. In nursing homes, 10% to 25% of falls lead to fractures, lacerations or the requirement for hospital care (American Geriatrics Society, et al., 2001). Fractures, particularly hip fractures, may result in significantly increased disability or death because of complications. An ethical dilemma arises when a resident can significantly benefit from power mobility, yet is assessed to be unable to safely operate a power wheelchair. The benefits of power wheelchair use for the resident must be balanced with his or her potential to injure him- or herself and others. There are currently no commercially available mobility devices to enable residents with complex physical and cognitive limitations to move safely and independently. These residents continue to be dependent on caregivers to move them from place to place.

In light of this problem, we developed a prototype anti-collision power wheelchair with a novel contact sensor skirt to enable residents with limited wheelchair mobility and mild or moderate cognitive impairment related to dementia to independently mobilize without the risk of harm to self or others. The purpose of the study was to evaluate, in the nursing home setting, the ability of the device to enable safe and independent mobility. The specific objectives are to examine:

1. the device’s safety for use in the clinical setting, that is, whether it will eliminate the risk for injury to the resident and others;

2. the device’s perceived safety by resident drivers, staff and other residents;

3. whether the independent distance traveled by residents with mild or moderate cognitive impairment using the device will be greater than the independent distance traveled using their manual wheelchairs; and
4. the value of the device in enabling independent mobility as perceived by resident drivers, staff and other residents.

4.3 Literature review

4.3.1 Current interventions

The current interventions to promote safe power mobility are limited. Personalized driving training (Hall, et al., 2005), driving performance assessments (Dawson, et al., 1994), and the implementation of risk management strategies and institutional driving guidelines (Mendoza, et al., 2003; Mortenson, et al., 2006) are currently applied to minimize unsafe power wheelchair operation and maintain mobility independence in institutional settings. However, these interventions do not always address residents’ need for self-mobility, especially in circumstances when driving abilities are marginal or deteriorate and use of power wheelchairs is restricted.

4.3.2 Power wheelchair technology

Many innovative smart power wheelchair technologies are being developed to address some of these issues. Simpson (2005) published a comprehensive review of smart wheelchairs, covering 46 projects worldwide. The majority of these devices were far from being clinically and commercially available. None of these systems were designed specifically for nursing home residents with dementia. Rigorous performance criteria are needed because of the serious consequences that may result if a frail ambulatory resident was contacted by a moving power wheelchair. Sensors need to be highly reliable, and obstacle detection has to be robust to ambient lighting changes and detect obstacles of various properties.

Two commonly used proximity or non-contact sensors for smart wheelchairs were sonar and infrared (Simpson, 2005). At the time, our own laboratory evaluations of ultrasound (Dutta & Fernie, 2005) and infrared laser sensors (Huang & Fernie, 2005) for this application demonstrated that these sensors were not satisfactory. The range of detection for ultrasound sensors was appropriate. However, the sensitivity to obstacle properties (for example, cloth or other sound absorbing material), inability to detect table edges or walls at sharp angles, interference with other sounds or multiple ultrasound sensors led to the conclusion that use of ultrasound was not feasible. An infrared laser sensor was also not suitable because the sensors were sensitive to ambient lighting changes and flooring materials even though performance with
different object properties (objects smaller than 2 cm (0.8”), target surfaces, object orientations) was good. Laboratory testing of sonar and infrared sensors by other researchers found obstacle detection deficiencies also, leading to the recommendation for using multiple sensor types (Lopresti, Simpson, Miller, & Nourbakhsh, 2002). According to our evaluations and that of others, the non-contact sensors applied at the time were not satisfactory.

In Simpson’s (2005) review, about 40% of the projects (18/46) included bump or contact sensors as backup sensors should the proximity sensors fail. Contact sensors were not normally used as primary sensors since they typically cannot ensure full safety. Contact sensors would have to be very sensitive such that a small force is required to activate the sensors and cause the power wheelchair to come to a complete stop. There has to be no change in force from the time of first contact to the full stopping distance of the power wheelchair. Injury to a person may be induced by contact with a moving power wheelchair (even at slow speed) from the time of first contact to the time the power wheelchair stops. One clinically and commercially available system that includes bump sensors is the Communication Aids for Language and Learning (CALL) Centre Smart Wheelchair. This device was intended to enable children with severe disabilities to learn skills for mobility before progressing to a conventional power wheelchair, or as a more permanent means of mobility using the adaptive features (CALL Centre, 2000; Nisbet, Craig, Odor, & Aitken, 1996). The Smart Wheelchair bump sensors consisted of rubber tubes and pressure switches. When the tube was compressed, the change in pressure activated the switches. Unfortunately, the user manual specified that the bump sensors do not ensure full safety since the power wheelchair cannot be physically stopped before the tubes were compressed and contact was made with the metal bumpers (CALL Centre, 2000).

We explored a novel approach using contact sensors, as the detection capabilities of non-contact sensors were not yet suitable to the varied and complex obstacles and environments found in nursing homes. A prototype device would allow us to investigate the use of modified power wheelchairs in a nursing home population with restricted mobility and dementia, and examine critical issues such as device performance and the impact on users and others in this setting. One of the criticisms of many power wheelchair projects has been the lack of performance evaluation of technology by end users in real world environments (Simpson, 2005). This project aimed to address this deficiency, and develop technology to offer more mobility options for an often neglected population.
4.4 Methods

4.4.1 Description of prototype

The anti-collision power wheelchair, shown in Figure 1, was the Nimble Rocket\textsuperscript{TM} power wheelchair (Nimble Inc., Toronto, Canada) modified with a contact sensor skirt. The sensor skirt was 1.5 cm (0.6”) from the floor and 18 cm (7”) high. It was composed of nine panels (two front, two side front, two side middle, two side back, and one back) and four movable conical sections overlaying the corners. There were small gaps between the panels, 5 cm (2”) between the two front panels to 1.5 cm (0.6”) between the other panels. All conical sections and panels were covered by a continuous piece of fabric. The overall width and length of the modified power wheelchair (for a standard 46 cm or 18” seat width) were 79 cm (31”) and 140 cm (55”), respectively. The design ensured that small diameter objects (for example, a 2.5 cm (1”) diameter cane) and objects in contact with the floor (for example, people’s feet) were readily and consistently detected. When contact was made with an obstacle, the area of the skirt making contact collapsed, and sensors (microswitches) in that location triggered. Refer to Figure 2 for a cross sectional view of the sensor skirt. The mechanism of contact sensing was consistently light, with a barely noticeable touch. The contact force for a “head on” contact with a panel and a non-moving object was less than 1 N (0.22 lb\textsubscript{F}) from the time of first contact to the full 10 cm (4”) stopping distance of the power wheelchair. The power wheelchair was programmed to come to a complete stop when any sensor was triggered. Continued movement of the power wheelchair in the direction of the obstacle was prevented. Only movement away from the obstacle was permitted. The microswitches were designed to be “on” when no contact was made with an obstacle and “off” with contact, ensuring that failure within the sensor system would also result in the power wheelchair stopping. A set of indicator lights, mounted in front of the joystick controller displayed the directions where movement was allowed. It was postulated that a driver with cognitive impairment should maintain direct control of power wheelchair movement to minimize confusion and to achieve as much independence as possible. The maximum forward driving speed of the power wheelchair was set to 0.24 m/s (0.53 mph), approximately 20% of an average walking speed. The system had an override switch and an emergency stop button for caregivers to assist drivers if necessary. If any part of the technology failed, the power wheelchair stopped to ensure safety. Risk analysis for a contact sensor skirt for a power wheelchair (refer to Appendix 15 for details) was completed by our design team following
CAN/CSA-ISO 14971:01 (Canadian Standards Association, 2001). A total of six anti-collision power wheelchairs were constructed for the study. The seating system (back support and seat cushion) were fully customizable and included a built-in power tilt system to ensure comfort.

Figure 1: Anti-collision power wheelchair
Figure 2: Cross section of contact sensor skirt. The intricate living hinge system beneath the fabric skirt was designed to hold the microswitches in place until contact was made and the panel of the skirt collapsed.

4.4.2 Study setting

The study was conducted in a veterans’ care home in Ontario, Canada. Resident care areas were divided into physical and cognitive support units and each included three levels of personal care from minimal to total assistance. On admission, residents were assessed by an occupational and/or physical therapist for their mobility needs. Residents living in cognitive support units were not normally permitted to use power wheelchairs for safety reasons. Approval was received from the research ethics board of the facility where the study was conducted. Consent was sought from residents (or their substitute decision makers) and staff prior to participation in the study. Refer to Appendix 11 for consent and information forms.
4.4.3 Study design and data collection

A concurrent mixed methods design was used (Creswell, 2008). Both quantitative and qualitative data were collected and then integrated in the analysis to achieve a comprehensive understanding of the problem under investigation. Data were collected using multiple single subject studies (SSS), observations, interviews and focus groups.

4.4.3.1 Single subject studies (SSS)

4.4.3.1.1 Subjects

A convenience sample of seven residents was targeted to test the anti-collision power wheelchairs. Residents were recommended by staff and consecutively enrolled if they consented (or if their substitute decision makers provided consent) and met the inclusion and exclusion criteria. Residents were included if they had mild or moderate cognitive impairment (Mini Mental State Examination (MMSE) scores of between 11-26 out of 30, with lower scores representing worse cognitive function) (Folstein, et al., 2001) and had a manual wheelchair as a primary means of mobility but little observed self-mobility. The extent of self-mobility was based on the judgment of the staff members who knew the residents. Observations of residents’ behaviour and functional performance allowed screening of their level of attentiveness, motivation to participate, and ability to follow simple verbal or non-verbal directions. Residents were excluded if they were using a power mobility device or had a documented history of aggression leading to actual or risk of injury to self or others.

4.4.3.1.2 Procedures

The investigator (R.Wang) collected data for residents enrolled in the SSS from medical records, completed interviews with residents and the staff who worked with them, and assessed manual wheelchair mobility (refer to Appendix 13 for data collection form). Throughout the SSS, structured (time-sampled) observations of residents’ daily activities were conducted by R.Wang, a research associate (P. Holliday) (refer to Appendix 1 for details), and four trained research assistants. The Dementia Rating Scale-2 (DRS-2) (Jurica, Leitten, & Mattis, 2001) and Functional Independence Measure (FIM) (Uniform Data System for Medical Rehabilitation, 1997) were administered by P. Holliday.
The DRS-2 is a standardized assessment of cognitive ability for individuals with neurological impairment and differentiates levels of impairment severity (Jurica, et al., 2001). The DRS-2 includes five subscales and 36 items assessing attention (8 items), initiation/perseveration (11 items), construction (6 items), conceptualization (6 items), and memory (5 items). Subscale scores are added for a total score. Normative tables with different age groupings, comprised of data from healthy adults aged 56 to 105, are used to determine the Age-Corrected MOANS (Mayo Older Americans Normative Studies) Scaled Scores (AMSS score) and percentiles for the total score and subscale scores. Clinical interpretation of the scores is based on the expected percentage of participants attaining each AMSS score. Clinical interpretation of impairment severity includes: above average (intact), average (intact), below average (intact), mildly impaired, moderately impaired and severely impaired.

The FIM assesses function in six areas using 18 items (Uniform Data System for Medical Rehabilitation, 1997). These include self-care (eating, grooming, bathing, dressing – upper body or lower body, toileting), sphincter control (bladder and bowel management), transfers (bed/chair/wheelchair, toilet, tub/shower), locomotion (walk/wheelchair, stairs), communication (comprehension, expression) and social cognition (social interaction, problem solving, memory). Each item is scored on a 7-point scale based on performance and the amount of assistance required to perform the item. A total score ranging from 18-126 is summed from the scores, where lower scores represent a higher degree of assistance. Scores may be derived from observation, self report, or medical records, and usually from multiple sources.

The SSS were conducted in the format A B C or A (where A - baseline, B - power wheelchair driving training, and C - power wheelchair use). Each phase was a minimum of 12 days. The minimum of 12 observation days was selected to meet the requirements for statistical validity (van Belle, 2002) as there is currently no literature available that describes the variability of the mobility data expected. Residents used their own manual wheelchairs during the A phase. During the B phase, residents were trained to use the anti-collision power wheelchair by R. Wang. The Powered-mobility Indoor Driving Assessment (PIDA, refer to Appendix 7 for details) was used to guide driving training and assess driving performance (Dawson, Kaiserman-Goldenstein, Chan, & Gleason, 2006). Examples of driving skills included driving forward and backward, turning at intersections, navigating busy hallways, and driving into the bathroom to use the sink. Training was conducted in the residents’ usual environment which included their
rooms and the communal living areas of the facility. A minimum of 12 driving training sessions, lasting approximately 1 h each, were planned for each resident. Driving training for new power wheelchair users at the institution where the study was conducted typically consisted of six 1 h sessions. It was expected that residents with cognitive impairment would require more sessions. Use of the power wheelchair during this phase was supervised and limited to the duration of the training sessions. Observations made by R. Wang during the training sessions were documented in a log (refer to Appendix 2 for details). Noted were the duration of each session, skills practiced, types of prompts used and their outcomes, training environment, and comments from the resident or others. Residents continued to use their manual wheelchairs during the B phase. Residents who were willing and capable of using the power wheelchair after training, and with an acceptable level of support from caregivers were offered use of the power wheelchair (C phase). Residents who were not able or chose not to use the power wheelchair returned to the A phase.

The daily distances traveled by each resident during each of the SSS phases were tracked. Distances were measured continuously using custom-made electronic distance loggers mounted on the residents’ manual and power wheelchairs, as shown in Figure 3 (refer to Appendix 16 for details). The loggers used a rotation counter that tracked the number of revolutions of a small wheel. The number of revolutions was converted to a distance in meters. Seat switches were used to indicate times when the resident was sitting in either the manual or power wheelchairs. Switches on the manual wheelchair handgrips were used to indicate when mobility was assisted. Structured (time-sampled) observations made of residents’ daily activities validated the data from the loggers (refer to Appendix 1 for details).
4.4.3.1.3 Analysis

Case profiles were developed for each resident. Data from the distance loggers were processed using MATLAB Version 7.4.0 (refer to Appendix 20 for details). Mobility data were determined: 1. total distances traveled each day in the manual wheelchair, 2. independent distances traveled each day in the manual wheelchair, and 3. independent distances traveled each day in the power wheelchair. Mobility data were plotted using Microsoft Excel Version 2003. Visual inspection of the graphs was done initially to identify changes between study phases (for example, changes in trend, level or stability of data) and to assess for clinical significance (Ottenbacher, 1986a). If the resident continued to the C – power wheelchair use phase, the data series in all phases were examined for serial dependency according to the procedures outlined in (Ottenbacher, 1986b) using the autocorrelation coefficient (r) and Bartlett’s test. If r was not significant for any of the
data series, then the data for that case was considered not serially dependent. The two standard deviation (2SD) band method (Ottenbacher, 1986b) was then used to determine if statistically significant changes occurred between the A and C phases. If two consecutive data points in the C phase were outside the 2SD band, then a statistically significant change was concluded. The daily distances traveled by residents in their manual and power wheelchairs in each phase were averaged and tabulated.

4.4.3.2 Investigator observations on safety

4.4.3.2.1 Subjects and procedures

During the driving training sessions with residents in the SSS, R. Wang made observations related to safety. Recorded were descriptive accounts of major safety-related hits and misses reflecting the performance of the sensor skirt and potential risk for injury to the driver or others. A hit was defined as an incident when the sensor skirt detected an obstacle and responded by stopping movement of the power wheelchair. A miss was an incident when the sensor skirt did not detect a contacted obstacle and did not respond by stopping movement of the power wheelchair. Misses above the sensor skirt were included as they were relevant to the overall safety of the power wheelchair despite recognition that coverage was not planned for those areas (anticipated misses).

Additionally, performance of the sensor skirt was estimated quantitatively. One of the residents in the SSS was observed in more detail over six driving training sessions with the resident in the B phase. A research assistant followed the resident driver and R. Wang during these sessions and counted the total number of obstacle contacts and hits. Also recorded were: the number of obstacle contacts above or below the sensor skirt (and the circumstances of these events), the number of times the sensor skirt got caught, and the number of times the override button was used.

4.4.3.2.2 Analysis

Safety-related scenarios from all the driving training sessions and safety implications for drivers and others were summarized. For the detailed observation of one resident over six driving training sessions, the proportion of hits over the total number of obstacle contacts was calculated.
to estimate the reliability of the sensor skirt. Other results from observation of this resident were tabulated.

4.4.3.3 Interviews and focus groups

4.4.3.3.1 Subjects

Interviews were conducted with residents participating in the SSS. Staff members who worked closely with these residents were purposefully recruited for interviews. Residents who lived in the nursing units with the resident drivers and had seen the power wheelchair in operation were also purposefully recruited for interviews. A convenience sample of staff, including resident care managers, nurse specialists, occupational therapists, physical therapists, recreation therapists, nurses and resident support workers were recruited for focus groups. Staff members were eligible to participate in both the interviews and focus groups.

4.4.3.3.2 Procedures

R. Wang interviewed resident drivers and staff on resident mobility status and goals (if any) at the beginning of the SSS. At the end of the SSS, they were asked questions regarding their experiences with and responses to the device (refer to Appendix 5 for details). Focus groups with staff were facilitated by R. Wang and P. Holliday at the beginning and at the end of the whole study. During focus groups, staff received orientation to the device, tested it, and discussed their responses and observations of residents’ responses (refer to Appendix 4 for details). Audio recordings or field notes of interviews were made by R. Wang. Focus groups were audio recorded. Other relevant comments from residents or staff during driving training sessions or structured observations were recorded in field notes.

4.4.3.3.3 Analysis

Data from audio recorded interviews and focus groups were transcribed verbatim. All data, including transcripts and field notes were analyzed using the method of thematic analysis (Patton, 2002). Themes related to the perceptions of safety and usefulness of the device were coded. R. Wang and a trained research assistant independently coded the data, and themes and codes were compared and discussed until agreement.
4.5 Results

4.5.1 Single subject studies

Six residents participated in the SSS. A seventh resident was enrolled, but dropped out after consent primarily due to health reasons. He was not replaced as we felt that testing another resident with this prototype would not generate new information. Table 3 shows the descriptive information on the SSS participants. Table 4 gives the summary of resident participation. Four residents completed the full study protocol. One resident was withdrawn when he exhibited verbally aggressive behaviour. Another resident voluntarily discontinued participation. One of the four residents who completed the protocol used the device during the C phase of the study. The mobility data for this case was plotted and analyzed for clinical and statistical significance. The average daily distances traveled using manual or power wheelchairs for each resident are shown in Table 5. Profiles for each resident are presented.
Table 3: Descriptive information on single subject study participants

<table>
<thead>
<tr>
<th>Resident</th>
<th>Age at Time of Study (years)</th>
<th>Primary Diagnoses</th>
<th>MMSE (total score 30)</th>
<th>DRS-2 (AMSS)* (total score 126)</th>
<th>FIM (total score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>91</td>
<td>Dementia, chronic renal failure, aortic regurgitation</td>
<td>22 mild impairment</td>
<td>4 moderate impairment</td>
<td>48</td>
</tr>
<tr>
<td>R2</td>
<td>88</td>
<td>Dementia, multiple strokes, coronary artery disease, myocardial infarct, atrial fibrillation, hypertension, macular degeneration, left retinal hemorrhage, chronic obstructive pulmonary disease, depression, anxiety</td>
<td>22/27 mild impairment (questions requiring visual skills omitted)</td>
<td>2 severe impairment (questions requiring visual skills omitted)</td>
<td>48</td>
</tr>
<tr>
<td>R3</td>
<td>86</td>
<td>Dementia with Lewy bodies, multiple strokes, functional paraplegia, hypertension, Parkinsonism, polymyalgia rheumatica, depression</td>
<td>18 moderate impairment</td>
<td>2 severe impairment (questions requiring bilateral hand movements omitted)</td>
<td>40</td>
</tr>
<tr>
<td>R4</td>
<td>91</td>
<td>Dementia with Lewy bodies, stroke with carotid stenosis, right thalamic and basal ganglia infarcts, atrial fibrillation, coronary artery disease, myocardial infarct, hypertension, congestive heart failure, right hip fracture, vertebral compression fractures history of falls, right-sided blindness, glaucoma left eye, hearing impairment, query depression</td>
<td>23 mild impairment</td>
<td>3 severe impairment</td>
<td>41</td>
</tr>
<tr>
<td>R5</td>
<td>82</td>
<td>vascular dementia, cerebral hemorrhage, transient ischemic attacks, temporal arteritis, aphasia, dysarthria, paraplegia, obstructive sleep apnea, osteoarthritis in C-spine and right shoulder, blurred vision in right eye, mild cataracts, strabismus, depression</td>
<td>12 moderate impairment</td>
<td>2 severe impairment</td>
<td>26</td>
</tr>
<tr>
<td>R6</td>
<td>82</td>
<td>Alzheimer's disease, atrial fibrillation, hypertension, right hip fracture, history of falls</td>
<td>16 moderate impairment</td>
<td>2 severe impairment</td>
<td>53</td>
</tr>
</tbody>
</table>

MMSE – Mini Mental State Examination, DRS-2 – Dementia Rating Scale-2, FIM – Functional Independence Measure

*Age-corrected MOANS (Mayo Older Americans Normative Studies) Scaled Scores
Table 4: Summary of resident participation

<table>
<thead>
<tr>
<th>Resident</th>
<th>Progress in SSS*</th>
<th>Suitability for Anti-collision Power Wheelchair Use</th>
<th>Anti-collision Power Wheelchair Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>completed (A B A)</td>
<td>suitable</td>
<td>declined use</td>
</tr>
<tr>
<td>R2</td>
<td>completed (A B C)</td>
<td>suitable</td>
<td>used post study</td>
</tr>
<tr>
<td>R3</td>
<td>withdrew from study (A B)</td>
<td>not suitable because of verbally abusive behaviour</td>
<td>did not use</td>
</tr>
<tr>
<td>R4</td>
<td>withdrew from study (A B)</td>
<td>did not complete training phase but potentially suitable</td>
<td>did not use</td>
</tr>
<tr>
<td>R5</td>
<td>completed (A B A)</td>
<td>not suitable</td>
<td>did not use</td>
</tr>
<tr>
<td>R6</td>
<td>completed (A B A)</td>
<td>not suitable</td>
<td>did not use</td>
</tr>
</tbody>
</table>

*SSS – Single subject study
Table 5: Average daily distances traveled using manual and power wheelchairs in each phase for each resident*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>A</td>
<td>495 (12 days)</td>
<td>8 (12 days)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>328 (42 days)</td>
<td>9 (42 days)</td>
<td>395 (16 days)</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>292 (15 days)</td>
<td>6 (15 days)</td>
<td>-</td>
</tr>
<tr>
<td>R2</td>
<td>A</td>
<td>205 (12 days)</td>
<td>11 (12 days)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>204 (44 days)</td>
<td>6 (44 days)</td>
<td>370 (16 days)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>104 (23 days)</td>
<td>6 (23 days)</td>
<td>367 (12 days)</td>
</tr>
<tr>
<td>R3</td>
<td>A</td>
<td>371 (32 days)</td>
<td>0 (32 days)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>431 (5 days)</td>
<td>0 (5 days)</td>
<td>105 (1 day)</td>
</tr>
<tr>
<td>R4</td>
<td>A</td>
<td>441 (23 days)</td>
<td>75 (23 days)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>729 (20 days)</td>
<td>103 (20 days)</td>
<td>455 (4 days)</td>
</tr>
<tr>
<td>R5</td>
<td>A</td>
<td>242 (45 days)</td>
<td>4 (45 days)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>189 (20 days)</td>
<td>5 (20 days)</td>
<td>131 (12 days)</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>131 (21 days)</td>
<td>1 (21 days)</td>
<td>-</td>
</tr>
<tr>
<td>R6</td>
<td>A</td>
<td>1603 (58 days)</td>
<td>1169 (58 days)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2421 (29 days)</td>
<td>1675 (29 days)</td>
<td>202 (12 days)</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>1528 (15 days)</td>
<td>1084 (15 days)</td>
<td>-</td>
</tr>
</tbody>
</table>

* Averages calculated for days with mobility data (for example, days in bed not included), number of days included in brackets.

4.5.1.1 Resident 1

Resident 1 (R1) was a 91 year old man with dementia, chronic renal failure and aortic regurgitation. He scored 22/30 on the MMSE suggesting mild dementia, and required a lot of physical assistance with his care. He propelled with his arms for very short distances in his tilt-in-space manual wheelchair, at 0.06 m/s (0.13 mph). He was assisted by staff and volunteers for
his daily mobility. R1 completed the power wheelchair training (B phase) and was able to operate the power wheelchair around the nursing unit without direct supervision. He continued to require assistance getting on and off the elevators because of the height difference between the floor and floor of the elevator, which caused the power wheelchair movement to stop. This was a technical limitation of the sensor skirt and was consistent across subjects who used the elevator. Despite the potential for independent mobility, he declined use of the device and returned to using his manual wheelchair (A phase). He found the device to be too big and awkward, and he preferred to have others wheel him. In reviewing his manual wheelchair mobility throughout the study in Table 3, he travelled very little independently and averaged less than 10 m (33 ft) per day. Although his mobility using the device during the B phase was supervised and encouraged by R. Wang, it is notable that he self-mobilized on average for 395 m (1296 ft) per day which was similar in magnitude to the average total distance he traveled with assistance in his manual wheelchair.

4.5.1.2 Resident 2

Resident 2 (R2) was an 88 year old man with a history of multiple strokes, visual impairment due to macular degeneration and a retinal hemorrhage, and dementia. Cognitive assessment was complicated by his visual impairment. Omitting questions requiring vision, he scored 22/27 on the MMSE. Like R1, he required a lot of physical assistance for his daily activities. Although able to use his arms to propel very short distances in his tilt-in-space manual wheelchair, at a speed of 0.13 m/s (0.30 mph), he rarely did so. At the time of enrolment, he had only been using a manual wheelchair as a primary means of mobility for about six months. Because of a decline in his physical health, he was no longer able to ambulate with a walker. He preferred to stay in bed. He sat up for a maximum of 4 h on days when he was out of bed. R2 completed the training (B phase) and was able to drive the power wheelchair around the nursing unit without supervision. He required assistance to use the elevators. During the B phase, his caregivers and daughter noted that he was more inclined to get up out of bed. He reported that using the device gave him mobility and independence. He continued to use the device in the C phase, for four and a half months. He eventually stopped because he felt that driving the power wheelchair was too taxing for him and he still preferred to stay in bed.
The mobility data for R2 was plotted and shown in Figure 4. On visual inspection, his independent manual wheelchair mobility was extremely limited during the A phase (averaging 11 m (36 ft) per day as shown in Table 3) while his independent mobility in the C phase with use of the power wheelchair was notably greater (averaging 367 m (1204 ft) per day). Analysis using the 2SD band method (Ottenbacher, 1986b) confirmed the significance of this change. Figure 4 shows the independent manual distance mean and upper band for the calculated 2SD for the A phase (mean: 11 m (36 ft) per day, 2SD: 33 m (108 ft) per day, upper band: 44 m (144 ft) per day, lower band: -22 m (-72 ft) per day). All data points in the C phase for independent power mobility were consecutively outside of the upper SD band. A significant change was not found when comparing the total distance traveled per day in the manual wheelchair during the A phase (mean: 205 m (673 ft) per day, 2SD: 413 m (1355 ft) per day, upper band: 618 m (2028 ft) per day, lower band: -208 m (-682 ft) per day) with the distance traveled per day with the power wheelchair in the C phase. This suggests that R2 drove the power wheelchair for similar distances compared to the total distances he traveled with the assistance of an attendant.
Figure 4: Distances traveled each day by Resident 2 using manual and power wheelchairs. A – Baseline, B – Power Wheelchair Driving Training, C – Power Wheelchair Use; (——) A – Mean – (IndDisMan or DisMan) refers to the mean distances travelled each day during the A phase, ( - - - ) A – 2SD – (IndDisMan or DisMan) refers to the 2SD upper band for the mean distances travelled each day during the A phase.
4.5.1.3  Resident 3

Resident 3 (R3) was an 86 year old man with a history of dementia with Lewy bodies and multiple strokes. He scored 18/30 on the MMSE suggesting moderate dementia, and he required a lot of help with his functional activities. He had a low-to-the-ground manual wheelchair, but was unable to move his wheelchair any distance, as confirmed in Table 3, due to weakness in his extremities and his weight. He sat in his wheelchair for most of the day and a private companion assisted him to activities. R3 had one driving session in the B phase where he was able to use the joystick controller with verbal prompts from R. Wang to move the power wheelchair. He was verbally aggressive towards another resident and another resident’s family member while in the power wheelchair. After discussion with the nursing staff, it was agreed that he discontinue participation due to the potential for psychological harm to others. It was not possible to assess whether his mobility independence would change with use of the device.

4.5.1.4  Resident 4

Resident 4 (R4) was a 91 year old man who also had a diagnosis of dementia with Lewy bodies. He also had a history of a stroke. His score on the MMSE was 23/30 and he required a lot of physical support for his daily activities. He used a low-to-the-ground manual wheelchair and was able to propel his wheelchair for short distances in his room using his arms and legs. Indeed his average independent mobility in the manual wheelchair was 75 m (246 ft) per day as shown in Table 3. His speed was 0.30 m/s (0.66 mph). His mobility was limited by fatigue and shortness of breath and a private companion wheeled him to the garden. R4 participated in four driving sessions in the B phase, and voluntarily discontinued participation. He had potential to use the device independently but he felt the device was too slow, the joystick controller was frustrating to use, and the device was unattractive.

4.5.1.5  Resident 5

Resident 5 (R5) was an 82 year old man with a history of vascular dementia, and cerebral hemorrhage. He was dependent for personal care, and scored 12/30 on the MMSE. He used a tilt-in-space manual wheelchair and propelled with encouragement and physical guidance for very short distances using his arms. He did not initiate self-mobility very often, but was able to propel at 0.08 m/s (0.17 mph) when encouraged. As shown in Table 3, his average independent mobility during the baseline phase was minimal, at 4 m (13 ft) per day. He was dependent on staff to
move him. R5 completed the B phase, but was unable to operate the device without ongoing prompting. Due to the lack of improvement, it was determined that further driving training with this prototype would not make a difference in his performance and he returned to usual use of his manual wheelchair (A phase). The technology was not sufficient to enable him to use the power wheelchair.

### 4.5.1.6 Resident 6

Resident 6 (R6) was an 82 year old man with a diagnosis of Alzheimer’s disease. He scored 16/30 on the MMSE suggesting moderate dementia. He also required physical assistance with his daily activities. He used a low-to-the-ground manual wheelchair and foot and hand propelled. While he was able to move his manual wheelchair at a speed of 0.31 m/s (0.70 mph), he had difficulty coordinating movement of his extremities to propel his wheelchair without a lot of effort. It was reported by staff that his poor coordination and mobility posture was causing him harm. He often rocked back and forth in the manual wheelchair or pulled on the handrails along the hallways or on furniture to move himself. At other times he wheeled around bumping into furniture and getting stuck in different areas on the nursing unit. His average independent distance traveled in his manual wheelchair during the baseline phase was 1169 m (3835 ft) per day, as shown in Table 3. He completed the B phase, but was unable to operate the device without ongoing assistance. It was decided that additional sessions with this prototype would not improve his performance. He found the joystick controller confusing to use. The device did not compensate for his lack of awareness or understanding of obstacles above the height of the sensor skirt.

### 4.5.2 Investigator observations on safety

Observations related to safety were made over 59 driving training sessions (84 h in total duration) with the six residents in the SSS (refer to Appendix 21 for details). Observations revealed that the sensor skirt compensated for the absence of or delayed responses of drivers to obstacles and decreased the risk for serious physical injury or damage due to the inability of the driver to see objects or judge object distances at the level of the sensor skirt. Other residents who were contacted while they were asleep in their chairs in the hallways were not aware that contact occurred. One seated resident whose feet were contacted awoke with a startled response, but resumed sleeping immediately.
No injuries were sustained by the drivers or others and no property was damaged. However, incidents with minor and potentially significant implications were observed during use of the device. Gaps between the panels and the corner conics occasionally got caught with obstacles such as the anti-tippers or footplates of other wheelchairs. Swinging doors, push carts, tables with wheels, and wheelchairs without brakes applied were able to be moved by the force of the sensor skirt before the sensors were triggered. In these instances, contact with the sensor skirt panels was not head on and obstacles contacted the gaps between panels or on the corner conics, causing a slight delay in activation of the sensors and movement of obstacles with low resistance to moving. Bumps or slopes on the floor, or the height difference between the lobby floor and the floor of the elevator cab that were higher than 1.5 cm (0.6”) caused the sensors to be triggered and movement of the power wheelchair to stop. These scenarios prevented the driver from moving temporarily and/or required the driver to be assisted by another person and were considered false positives.

Obstacles above the sensor skirt had potential to cause physical injury to the driver or others, or damage to objects. Injury or damage in these cases did not occur as R. Wang was present to intervene. Obstacles that protruded out and above the sensor skirt such as table tops or the wheelchair headrest posts of other residents were potential sources of injury to the driver (for example, hands could be scraped or caught). There was one occasion when the armrest of the power wheelchair contacted the headrest post of another resident, which could have caused injury to the driver’s hand. Objects in the environment could also be damaged by any wheelchair components that protruded beyond the footprint of the sensor skirt (for example, footrests or headrests) or by equipment that was above the sensor skirt. There was one incident when the power wheelchair backed into an air pump for a circulating air mattress at the end of a resident’s bed.

The results from detailed observation of one resident (R5) during six driving training sessions in the B phase, totalling 6.5 h, are shown in Table 6. As with the other driving training sessions, these were in the resident’s usual environment around the nursing unit. An estimate of reliability, indicating performance of the sensor skirt, was calculated using the number of the hits (195) over the total number of observed obstacle contacts (205) and was found to be 95%. Contacts above or below the sensor skirt occurred 10 times, the sensor skirt got caught a total of six times, and the override button was used four times.
Table 6: Safety-related observations for Resident 5 driving over six training sessions, approximate driving time of 6.5 h

<table>
<thead>
<tr>
<th>Total hits and misses: all observed obstacle contacts with sensor skirt</th>
<th>205</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hits: observed obstacle contacts causing chair to stop</td>
<td>195</td>
</tr>
<tr>
<td>Misses: observed obstacle contacts not causing chair to stop</td>
<td>10</td>
</tr>
<tr>
<td>Anticipated misses: contacts above or below sensor skirt</td>
<td>10</td>
</tr>
<tr>
<td>Joystick controller contacts obstacle (with delayed detection by sensor skirt)</td>
<td>1</td>
</tr>
<tr>
<td>Driver's elbow contacts door frame</td>
<td>1</td>
</tr>
<tr>
<td>Driver's arm contacts handrail on wall</td>
<td>3</td>
</tr>
<tr>
<td>Drives over mop on floor and drags mop underneath chair</td>
<td>1</td>
</tr>
<tr>
<td>Driver's hand contacts wall, squeezed between joystick controller and wall</td>
<td>1</td>
</tr>
<tr>
<td>Driver's leg contacts another resident's raised footrest</td>
<td>1</td>
</tr>
<tr>
<td>Driver's hand contacts bed</td>
<td>1</td>
</tr>
<tr>
<td>Driver's foot contacts manual wheelchair footrest</td>
<td>1</td>
</tr>
<tr>
<td>Number of times sensor skirt got caught:</td>
<td>6</td>
</tr>
<tr>
<td>False positives: chair stops without obstacle</td>
<td></td>
</tr>
<tr>
<td>Bump on floor</td>
<td>3</td>
</tr>
<tr>
<td>Skirt panel sticking on Velcro (malfunction)</td>
<td>1</td>
</tr>
<tr>
<td>Misses: cabinet door stuck between 2 panels</td>
<td>2</td>
</tr>
<tr>
<td>Assistance required (override button used)</td>
<td>4</td>
</tr>
</tbody>
</table>

4.5.3 Interviews and focus groups

In addition to the six SSS residents, 20 staff members who worked directly with these residents were interviewed. Six other residents and the spouse of one of these residents who had exposure to the device were also interviewed. Focus groups ranged in size from three to 12 participants. A total of 37 staff members participated in focus groups, 25 in three pre-study groups and 12 in two post-study groups. The same participants were not recruited for the post-study focus groups owing to staffing changes and scheduling difficulties. Refer to Appendix 21 for a breakdown and summary of the interview and focus group data collected.
4.5.3.1 Perceptions of safety

Thematic analysis revealed two themes pertaining to safety: Power of Appearances and Safety while Driving.

4.5.3.1.1 Power of appearances

The external attributes of the power wheelchair contributed to whether it was perceived as safe by others. The appearance, especially the size, contributed to the “apprehensive” feeling that residents may have felt, as described by one resident in an interview. Staff agreed with one nurse’s comment in a focus group that residents “might be afraid of this wheelchair too, the size they might be afraid of.” Another resident in an interview described his impressions of the power wheelchair as “overpowering” and “making a lot of people nervous”. Another resident expressed his concerns when he saw the device going down the hallway, “you don’t know all the security they have for it”, and “you could roll him right over with that machine”. One nurse in a focus group reported a similar sentiment. She wondered if residents might be afraid that a driver would hit them, despite the slow driving speed, and that they would not be able to move out of the way. Some residents might be able to learn that the power wheelchair could not harm them, but this may not be the case for residents with confusion and memory impairment. The appearance of the sensor skirt as being solid raised some comments with residents as well. If the sensor skirt was solid or appeared solid, people might be more afraid of it and the damage that it might cause.

4.5.3.1.2 Safety while driving

The resident drivers reported feeling safe and secure when operating the power wheelchair. For example in an early driving session, R1 felt that driving was “scary”. As his familiarity with the device and his driving confidence increased this feeling was no longer a concern. R1 even concluded at the end of the training sessions that, “No, I can’t think of anything that you haven’t done…to make moving about safe.” R2 likened the power wheelchair to a tank, which suggested that he felt protected while using the device. The slow driving speed of the device contributed to R6’s experience of safety. In an interview at the end of the training sessions, he reported, “safe enough, yes…you know, it’s going slowly”.

4.5.3.2 Perceptions of usefulness

A few themes illustrating facets of the usefulness of the device emerged. These included: “It’s work worth doing”, Realities of Use, and Design Features Limiting Usefulness.

4.5.3.2.1 “It’s work worth doing”

The overall purpose of the power wheelchair to enable safe and independent mobility with residents who normally would not have access to power mobility was recognized and supported by residents and staff. When the concept of a wheelchair that stopped when obstacles were gently contacted was explained and demonstrated, residents and staff agreed that “it’s work worth doing” and that it was a “good idea”. The safety of residents and staff around power wheelchairs was very much a concern. R1 was often observed to explain the benefits of the safety features of the device to other residents and visitors, saying, “It has a bumper guard on it. When you hit it, the motor stops.” During a follow up focus group, one nurse felt that the device was good because she observed incidents previously when other residents and nurses were accidentally hit by power wheelchair users who were trying to drive inside the elevators. One nursing unit manager noted the safety benefits for some resident drivers whose visual-perceptual abilities have declined and the security she felt with the anti-collision adaptations, “…especially the ones who don’t judge distances very well anymore, I know it stops.” Another nursing unit manager in a focus group spoke of the challenges in ensuring the safety of others while promoting resident independence, particularly with power mobility users whose driving abilities were deteriorating.

Residents who drove the power wheelchair or who observed the device in action recognized the benefits for mobility independence. R1 said of driving the power wheelchair, “you can put it wherever you want” and “you wouldn’t have to wait for a pusher, that would be a big plus…” R2 echoed the advantages of driving himself to places and not needing the help of others to push him. One of the resident observers interviewed noted the benefits to independent mobility for residents whom he believed to have cognitive limitations, “I think the objective of the thing is good…it shows him that he could have the power to sit in the chair and walk around the floor despite the fact maybe one light is off or something.”
Staff also clearly expressed their expectations for mobility independence and improved well-being with power wheelchair use. Even for some residents, such as R5, who might not travel very far with a power wheelchair, his nurse said, “that could be good for him too because he can’t mobilize much but at least if he’s mobile he can at least go and reach for anything he wants.” One staff member in a focus group also identified that there was great potential for residents to experience more mobility control and thereby increase the motivation to participate: “…some of these fellows, if they see that they can drive this thing around, then they might be more motivated…to want to be up longer and then to go off the floor and see things.”

4.5.3.2.2 Realities of use

The outcomes of power wheelchair use on residents’ mobility independence, well-being and quality of life were vastly different. Outcomes ranged from a negative impact, indifference, to a complete shift in life outlook for the better. One nurse believed that R4 had a negative experience with the device as she felt it increased his agitation. R6 became somewhat indifferent to using the power wheelchair saying, “I don’t care. I will leave it up to you.” R5 was observed to enjoy the driving experience. He often drove up to staff members and made jokes. One nurse commented that she has never seen him so happy. The largest shift was observed in R2 who appeared to change his outlook on life with the experience of driving. He said about the power wheelchair, “Well, that means that I can take the thing (power wheelchair) out for a walk around the block. That sounds like independence.” Others reported a change in his outlook as well. One nursing unit manager succinctly stated about use of the power wheelchair, “the difference with (R2) really brought home that this is really valuable and it can make a difference….”

4.5.3.2.3 Design features limiting usefulness

Specific features of the device were identified to be important to usefulness. The slow driving speed received mixed feedback. When asked during focus groups, nurses felt that the slow driving speed was positive for safety. Slow speed, however, may not be effective and may be frustrating for drivers. One nurse in a focus group identified, “from a resident, they may be like my nurse can push me faster…” R1, R2 and R4 recognized that the driving speed was slow and indeed R2 and R4 expressed frustration during driving.
Another feature that impacted usefulness was the joystick controller. Some residents found the controller difficult and again, frustrating to operate. Residents had particular difficulty navigating away from obstacles once contact with an obstacle was made and movement of the power wheelchair stopped. The allowed movements of the joystick did not correspond to the allowed movements of the power wheelchair, so the user interface did not provide meaningful feedback to guide residents to the correct actions. R2 learned a strategy to consistently move the joystick in a circle to find the positions of allowed movement, but not all residents had such capacity to learn. R4 found the interface unresponsive, frustrating and “very dissatisfying” to use. R6 was confused about how the controller worked. After movement of the power wheelchair stopped with an obstacle, he would move the joystick in random directions and say, “it doesn’t want to go”. While the lit arrows were supposed to indicate the directions of allowed movement, residents like R2 had difficulty seeing them, and some residents did not understand how they worked, including R6 who tried to move the power wheelchair by pressing the arrows that were lit.

The large size and “awkward” form contributed to the perception that its usefulness might be limited in some way. R1, in an interview following the training sessions, reported that the power wheelchair worked very well, but that the size was the “stumbling block”. Resident and staff observers expected that the large size and space limitations would restrict access in the facility. Comments ranged from anticipated difficulties getting through doorways, going through crowds, or turning inside elevators. Nurses also identified that the size of the power wheelchair may cause space problems with additional traffic in the hallways or storage problems with fire and health and safety implications.

This power wheelchair prototype was designed for use indoors where the ground surface was flat. Residents like R4 and R5 voiced the desire to go outdoors, particularly to the surrounding gardens of the facility. Others like R1 enjoyed bus outings, so he would have to transfer to and from his manual wheelchair in order to go outdoors. He felt that this would require too much preparation and effort to be useful for him.

4.6 Discussion

This was the first device, to the authors’ knowledge, to be tested for an extended period of time in the clinical setting that aimed to address the power mobility needs of nursing home residents
with physical and cognitive impairments. Technology targeted for this population has so far involved only controlled laboratory testing of prototypes with surrogate users (adults without disabilities), although preliminary results are promising (Mihailidis, Elinas, Boger, & Hoey, 2007; Viswanathan, et al., 2007). Reasons for the lack of testing are that many of these systems are not sufficiently reliable in diverse environmental conditions or do not have adequate sensor coverage to protect users, others and property from harm (Sharma, 2009). Before expending valuable resources to develop a sophisticated prototype with proximity and contact sensors, we believed it was reasonable and necessary to better understand how residents might use new power wheelchair technology, how people would respond to such devices, and what residents and staff wanted in technology. We expected that a failsafe contact system would ultimately serve as a back up for a complete system that included proximity sensors.

4.6.1 Safety evaluation

As previously mentioned, ensuring the safety of others around the power wheelchair user is of great importance in a communal living environment such as a nursing home. Enabling the mobility of one resident should not put others at an increased risk for harm. The reliability of detecting walking residents was given the highest priority when designing this prototype with a targeted 100% sensor reliability, minimal contact force for the full stopping distance of the power wheelchair, and fail-safe operation. Given the very stringent criteria for safety, the prototype contact sensor skirt system did not meet the requirements.

Our first objective was to examine whether the power wheelchair would be safe for use in the clinical setting, that is, eliminate the risk for injury to the driver and others. The safety evaluation showed that the sensor skirt was able to detect a majority of obstacles encountered in the nursing home, and that the stopping function worked as intended. There were some occasions when the sensor skirt as a whole did not perform as required. These were considered minor design or construction faults that could be readily corrected (such as minimizing the gaps between skirt panels). However, the primary safety concern was that additional sensors were required for complete environmental coverage and to further minimize the risk of injury related to obstacles and power wheelchair components above the sensor skirt. Since it was concluded that proximity sensors at the time were not sufficiently reliable to detect canes, walkers and the legs of other people in all circumstances, it was necessary to surround the power wheelchair with a simple,
soft, contact sensor skirt that would be certain to activate when an obstacle was contacted. The sensor skirt had to be capable of collapsing during the distance taken to gently stop the power wheelchair without increasing the forces applied to the obstacle. This inevitably resulted in a large bumper-like appearance. It was not possible to extend this concept to detect objects at all heights above the floor. The inclusion of proximity sensors using computer vision technology such as that currently being applied to some modified power wheelchairs (Bailey, et al., 2007; Satoh & Sakaue, 2007; Simpson, 2005; Viswanathan, Boger, Hoey, & Mihailidis, 2008) may improve coverage and overcome some of the issues with previously discussed proximity sensors. A future version of the anti-collision power wheelchair will likely combine an even more reliable sensor skirt with computer vision technology. With a new prototype, further study is recommended to assess whether a sensor skirt that surrounds the entire base of the power wheelchair will be necessary or if certain sections (such as middle sides) may be removed.

The second objective was to examine the perceived safety of the power wheelchair. The resident drivers perceived the device and driving experience to be safe, but responses from some staff and other residents suggested opposing views. The perceptions of safety by users and others who live and work in the nursing home are important considerations. While the device may prevent injury to others or damage to property, it may still be perceived to be frightening or unsafe. This is of particular concern for residents with cognitive impairment who may not understand the purpose of the device, or why it appears different. In the design of future prototypes, further attention needs to be paid to size, form and construction and the interaction of exterior features with how the device is perceived. It is well known that the visual appearance of a product impacts how it is perceived, for example, inducing strong psychological responses such as pleasure or fear (Norman, 2004). The appearance creates impressions of device characteristics as well, as in the case of a truck, the appearance may communicate strength and power (Bloch, 1995). Further development is warranted to create forms and features that render the device less conspicuous and increase the confidence of users and others regarding device safety. For example the form may appear smaller in size with softer lines or color or textural contrasts. A softer appearance and color options might create a visual image that is friendlier.
4.6.2 Mobility evaluation

The residents in this study had very restricted independent manual wheelchair mobility. They were not considered candidates for conventional power wheelchairs as they did not meet the criteria for provision. To use a power wheelchair, residents need to be able to use the power wheelchair independently in their every day lives (Assistive Devices Program Ontario Ministry of Health and Long-Term Care, 2009; Veterans Affairs Canada, 2009). Safe and independent use requires residents to have a high level of cognitive functioning with goal-directed behaviour, safety awareness, judgment, problem solving skills, capacity to learn, good attention and a sufficiently fast response to unexpected obstacles. The sensor skirt and stopping feature of the device were useful to prevent injuries and property damage when residents contacted obstacles because of their delayed or absent response. Residents who were able to operate this power wheelchair such as R1, R2 and possibly R4, tended to be attentive, but missed some obstacles in the environment and had a delayed response time to static and dynamic obstacles. These residents also had some goal-directed behaviour, intact procedural memory for use of a joystick to control movement of a vehicle, the ability to follow simple directions, initiation to use the joystick to start movement, and some capacity to learn with repetition. For these residents, the device had potential to help them to mobilize safely and independently in the nursing home.

Two of the residents, R5 and R6, who were more cognitively impaired, could not operate this prototype without ongoing assistance. The lack of initiation and motor planning with R5, and the lack of awareness and understanding of the implications of obstacles above the sensor skirt with R6, were the main limiting factors. This suggests that the technology was not sufficient to accommodate these limitations and allow the residents to effectively mobilize. Further development such as an advanced control system and coverage for obstacles above the sensor skirt, as previously discussed, is necessary to enable more residents to benefit from power mobility. An advanced control system might include mixed initiative or semi-autonomous driving modes, such as those being explored with other modified power wheelchairs (Mihailidis, et al., 2007; Parikh, Grassi Jr., Kumar, & Okamoto Jr., 2007; Simpson, 2005). Other features might include automated verbal prompting strategies to encourage mobility that is either exploratory or based on a resident’s routine, or multimodal warnings to indicate nearby obstacles. Further exploration of these shared control functions and complex multimodal warning
and prompting systems for mobility devices is required as the impact on confusion or frustration is unknown for older adult users with cognitive changes.

Increased independent distance traveled was demonstrated by one of the residents in this study, and clinically and statistically significant changes were noted for this resident. Because only R2 used the device during the C phase of the SSS and beyond, investigation of the longer term effects on mobility for the others could not be determined. For R2, improvement in his subjective well-being was also demonstrated. This finding supports the assertion that independent mobility is an important element of well-being and quality of life for older adults living in institutions (Bourret, et al., 2002; Mortenson, et al., 2005). R2 was more inclined to use the device as a means of mobility and independence, possibly because at the time of the study he only transitioned from using a walker to a manual wheelchair within the previous six months. As he had difficulty manually pushing his wheelchair, the recent loss of his mobility independence may have encouraged him to seek other strategies to self-mobilize. This is an important point as it suggests that residents may be more motivated to accept interventions to improve mobility at points of loss or transition, rather than at stages when mobility restrictions have become chronic. While further investigation is warranted, it is also possible that power mobility users with declining driving capabilities may be more inclined to use devices to extend their independence.

Despite the potential for improved mobility independence, for R1 and R4, various circumstances lead to their disinclination to use the device. Their decisions may suggest that for some residents, independent mobility to get from one place to another is not as high a priority as other factors in the context of their lives, or that influences in the environment restrict them from using a power wheelchair for mobility. The perceived benefits of use may not outweigh the features of the prototype that were unsatisfactory. These results were surprising and contradictory to the literature on the significance of mobility independence. It was believed that residents would want to have some degree of independent mobility even if the means were not perfect. Careful examination of the psychosocial factors related to assistive device use or the implications of institutional living may further explain these findings and guide intervention development and implementation.

The value of the anti-collision power wheelchair in enabling mobility was generally recognized by resident drivers, staff and other residents. The safety function that the prototype device
provided was recognized to be useful. There were pervasive beliefs, supported in the literature, that power wheelchairs can improve mobility, independence and well-being of users (Brandt, Iwarsson, & Stahle, 2004; Davies, DeSouza, & Frank, 2003; Evans, 2000). However, an improved device with greater reliability, usability, functionality, and acceptability is required to further examine the impact and longer term outcomes of a modified power wheelchair for nursing home residents with complex physical and cognitive impairments, and to better understand the range of residents who might benefit from this type of intervention. Once such a device is available, the effect on independent mobility, affect or mood, activity participation, well-being and quality of life may be further investigated.

4.6.3 Study limitations

The evaluation of sensor skirt reliability was conducted with only one resident, rather than with multiple residents using power wheelchairs of the same design in different driving environments. However, for this stage of the design and testing process, an estimate of reliability of the sensor skirt was sufficient. Observation and tracking of the major safety-related scenarios or incidents was more pertinent for improving design.

The limited sample size and replication of the SSS in the same testing site with the same investigator acting as the trainer may limit the generalizability of the results. Nevertheless, a SSS design was the most appropriate method to study a new intervention particularly to gather primary data on effectiveness (Ottenbacher, 1986c). Other study designs such as a group comparison design were not appropriate to assess the efficacy of individualized interventions and not feasible due to the small population from which participants could be drawn (Ottenbacher, 1986c). Nursing home residents with dementia are a heterogeneous group often with multiple diagnoses that affect cognitive functioning. Each resident case was unique and pointed to different reasons why each resident could or could not use the device, or opted not to use it. Capturing the variability in responses to the prototype allows better examination of requirements for this population and gives a broader perspective on resident needs.

It was not possible to make definitive conclusions about the impact of anti-collision power wheelchair use on independent mobility for a majority of residents, as only one resident used the prototype in the C phase of the SSS. Most of the power mobility data were collected during the B phase when use was structured and supervised. Ongoing encouragement to drive the device was
provided during these sessions. It was not possible to assess whether residents would voluntarily drive or have the capability of driving the device outside of the training situation.

4.7 Conclusions

This study using a concurrent mixed methods design with multiple SSS and observational, interview and focus group data generated a breadth of information about a new power wheelchair intervention for a population that has been largely neglected. The three key findings are summarized:

1. the need for this device was supported by residents and staff;

2. the device improved independent mobility and well-being in one resident; and

3. further research and development is necessary to improve environmental coverage and reliability of sensors to ensure safety and to increase the perception of safety; to match technology features to the needs of a wider range of residents with cognitive impairments; and to enhance usability, functionality, and acceptance.

This study provides encouragement to engineers, designers and clinicians to devote the time and effort required to produce a more refined prototype that is capable of reliably detecting obstacles from the floor to head height of the driver. These findings suggest that such a power wheelchair could improve the mobility and well-being of some nursing home residents with complex physical and cognitive impairments. The extent of the improvement and the proportion of residents who might benefit will require further study when such a product or prototype becomes available.
Chapter 5

5 The experiences of using an anti-collision power wheelchair for three long-term institutional care residents with mild cognitive impairment


Contributions of the authors: RH Wang wrote the manuscript, developed the research design and protocol, and collected and analyzed the data. PC Kontos assisted with writing the manuscript and with the data analysis. PJ Holliday reviewed the manuscript, assisted with developing the research design, helped to collect the data, and contributed to the design of the power wheelchair technology. GR Fernie reviewed the manuscript, and led the design of the power wheelchair technology and the research project.

Additional data from the first study were analyzed qualitatively to explore in greater depth the factors underlying the residents’ inclination and disinclination to use the anti-collision power wheelchair as a primary means of mobility. Data from three residents were included in this analysis. Findings are pertinent for clinicians and policy makers/administrators involved in the provision of new mobility technologies, and device developers who require a broader understanding of user needs and the contexts in which technology is used. This manuscript is published in the journal *Disability and Rehabilitation: Assistive Technology*. This multi-disciplinary journal focuses on understanding disability and advances the study and practice of rehabilitation. This journal includes topics in areas such as gerontology, psychosocial adjustment, social policy, and assistive technology. Owing to the multi-disciplinary readership, discipline-specific language and concepts are avoided to ensure accessibility to rehabilitation therapists, medical practitioners, psychologists, social scientists, engineers, and policy makers.
5.1 Abstract

5.1.1 Purpose

Presented are three case analyses of long-term care home residents with cognitive impairment who tested an anti-collision power wheelchair. We discuss technology design and research implications for this population.

5.1.2 Method

Case studies involved 371 h of participant observation and 7 h of open-ended interview with residents (n=3), family members (n=3) and clinical staff (n=11). Thematic analysis generated themes related to technological, psychological, and social aspects of residents’ inclination and disinclination towards power mobility use.

5.1.3 Results

Themes examined the discordance between others’ and residents’ reports of anti-collision power wheelchair use, a facet of response bias, unanticipated implications for independence and dependence, and implications of device design for self-presentation.

5.1.4 Conclusions

Technology alone is insufficient to help residents to fully benefit from the autonomy that a wheelchair intervention can provide: close attention is required to the social and organizational factors of institutional life. For technology to be acceptable, the design must meet the functional and aesthetic needs of users. Considerations in the design of future power wheelchairs for residents with cognitive impairment include capabilities to drive on uneven surfaces, effort-reducing driving modes, improved user interface usability, and acceptable driving speed, size and appearance.

5.2 Introduction

Older adults living in long-term care institutions often have significant limitations to their functional mobility because of multiple chronic medical conditions. In Canada, the most common diagnoses in long-term care institutions include arthritis, diabetes, stroke, congestive heart failure and Alzheimer’s disease or other forms of dementia (Banerjee, 2009).
Consequently, residents of long-term care institutions require considerable assistance in their daily care activities. The 1995 National Population Health Survey found that 75% of residents needed assistance with personal care, indoor mobility, and transferring from bed or chair, and over one-third needed assistance in all areas (Tully & Mohl, 1995).

Restricted mobility and immobility can have a range of serious consequences. Decreased mobility significantly impacts an individual’s ability to participate in self-care, leisure, social, and other meaningful activities, and is related to decreased independence and social interactions, poorer quality of life, and higher risk for mortality in older adults (Mobily & Kelly, 1991; Yeom, et al., 2008). Psychological implications and behavioural changes include dependency, depression, agitation, aggression, withdrawal, apathy, confusion, or anxiety (Mobily & Kelly, 1991). Visual or auditory hallucinations due to sensory deprivation are also possible (National Institute of Nursing Research, 2006). Chronic mobility impairment can lead to a range of physiological changes including bone demineralisation, muscular atrophy, joint contractures, cardiovascular and respiratory changes, pneumonia, pressure ulcers, constipation, and urinary retention (Mobily & Kelly, 1991; National Institute of Nursing Research, 2006).

Independent mobility has been identified as a primary determinant of the quality of life of older adults living in institutions (Bourret, et al., 2002) and a high priority goal for many wheelchair users living in institutions (Fuchs & Gromak, 2003). Nevertheless, independent mobility is rarely accommodated. Wheelchairs are more commonly used for seating and positioning or as devices for staff to transport residents than as means of self-mobility (Brechtelsbauer & Louie, 1999). For example, Brechtelsbauer and Louie (1999) observed self-propelled mobility in only 4-14% of residents. Moreover, power wheelchairs are often not considered a viable option for people with cognitive impairment (Hardy, 2004; Young, 2003) since safe and appropriate power mobility use is believed to be contingent on cognitive functions that include decision making, memory, judgment, self-awareness (Brighton, 2003); learning capacity, the ability to respond appropriately (Mortenson, et al., 2005); and environmental alertness (Massengale, et al., 2005).

Clinicians often cite safety concerns related to cognitive abilities as a reason for not considering power mobility (Hardy, 2004). In the long-term care home setting, these concerns relate to the potential for driver injury, as well as the risk of harm to other residents who are already frail and highly vulnerable to falls (Neyens, et al., 2009; Oliver, et al., 2007). Despite the intensity of
concerns, however, there exists limited evidence of power wheelchair-related injuries specific to long-term care homes and older adults. Existing reports of wheelchair-related accidents and injuries rely on databases that likely do not capture the full extent of the problems, are not recent and do not discern whether injuries occurred in an institution nor identify the ages of the people affected (Kirby & Ackroyd-Stolarz, 1995), and do not differentiate between manual or power wheelchairs (Xiang, et al., 2006). Nevertheless, power mobility-related safety incidences are priority issues often discussed by clinicians and researchers (Mendoza, et al., 2003; Mortenson, et al., 2005). Clinicians continue to be challenged to balance the need to facilitate mobility independence for residents and minimize the risk of injury to the wheelchair drivers and other residents (Mortenson, et al., 2006). Consequently, personalized driving training (Hall, et al., 2005), driving safety assessments (Dawson, et al., 1994), risk assessment protocols (Mendoza, et al., 2003; Travis, et al., 2001) and driving safety guidelines (Mortenson, et al., 2006) have been instituted to facilitate power wheelchair use and minimize unsafe operation in residential care settings.

To date, there has been little exploration of the perceptions of safety in long-term care institutional settings. A notable exception is Mortenson, et al. (2005) who qualitatively investigated perceptions of power mobility safety for the purpose of developing safety guidelines in three facilities, one of which served a younger population and the other two predominantly older adults. Participants included residents with progressive conditions such as Alzheimer’s disease and non-progressive conditions such as spinal cord injury, family members, and staff. Findings suggested that there were residents who are capable of driving safely despite dementia, poor motor function, and legal blindness. Therefore when considering which residents might be considered for a trial of power mobility, evidence suggested that evaluation should be based on function, and not diagnosis. Findings further suggested that while clinicians deemed power mobility inappropriate for those who could not stop their power wheelchairs (causing harm to themselves or others, and property damage) and for those unable to learn from their mistakes, excluding such individuals from driving overlooked the possibility that wheelchair modifications might make power mobility safe.

Technological approaches are being explored to address safety and independent power mobility with cognitively impaired residents in long-term care facilities. At present, for this user population, three power wheelchairs modified with collision avoidance systems are in
development (Mihailidis, et al., 2007; Viswanathan, et al., 2007; Wang, Gorski, Holliday, & Fernie, in press). The system described by Mihailidis, et al. (2007) uses a 3-D time of flight infrared laser range sensor and provides assisted navigation and prompting. Viswanathan, et al. (2007) described a system that also provides assisted navigation and prompting, but uses a stereovision video camera as the sensor. Finally, the anti-collision power wheelchair described by Wang, et al. uses a contact sensor skirt embedded with microswitches. In this system, a set of indicator lights beside the joystick controller specified the directions of allowed movement in order to assist the user to navigate away from obstacles. Of these three projects, only Wang, et al. have tested the device with the targeted population and have utilized qualitative methods to examine user experience.

5.2.1 Purpose

Our purpose here is to present findings from our qualitative evaluation of the anti-collision power wheelchair described by Wang, et al. Data presented relate to user experience and are intended to inform device design and future research with this user population.

5.3 Method

Ethical approval was granted by the research ethics board of the long-term care facility that participated in the study (refer to Appendix 11 for consent and information forms). The study was conducted in a veterans’ care home in Ontario, Canada. Resident care areas are divided into physical and cognitive support units. Power wheelchair use by residents in the cognitive support units was not previously allowed. The units are comprised of three levels of care ranging from minimal to maximum personal support. The average age of the residents is 88 years and 94% are male. The level of cognitive impairment amongst the population ranged from no impairment to severe impairment as measured by the Mini Mental State Examination (MMSE) (Folstein, et al., 2001). Accommodations varied from private to four-bed rooms. The facility offered multiple daily entertainment and activity programs in addition to physio, occupational, recreational and music therapy services. Programs were offered off the nursing unit in the entertainment hall, activity rooms or the garden. On-unit programs were also offered in the dining room, lounge areas, activity rooms or in resident rooms for one-to-one activities. Volunteers were available to assist with transporting residents to and from programs.
Full details of the main study, including descriptions of the prototype anti-collision power wheelchair and the driving training sessions, are reviewed elsewhere (Wang, et al., in press). Briefly, the device consisted of a Nimble Rocket™ power wheelchair (Nimble Inc., Ontario, Canada) modified with a contact sensor skirt that caused movement of the power wheelchair to stop upon contact with an obstacle. Refer to figure 5 for a picture of the device. Movement was controlled by the driver using a joystick controller. The maximum forward driving speed was 0.24 m/s or approximately 20% of an average walking speed.

![Prototype anti-collision power wheelchair](image)

**Figure 5: Prototype anti-collision power wheelchair**

A purposeful sampling strategy (Creswell, 2007) was used to select the participants for the main study, and involved the following criteria for participant eligibility: 1) at the time of the study used a manual wheelchair as the primary means of mobility, 2) had little observed self-mobility as reported by primary caregivers, and 3) had cognitive impairment that was mild-to-moderate (MMSE scores between 11 and 26 out of 30) (Folstein, et al., 2001). Resident care managers, nursing staff and physio and occupational therapists of the nursing units identified participants whom they assessed as meeting all three eligibility criteria. Those participants deemed eligible
and who agreed to be contacted by the investigators were contacted in person or by telephone, informed of the purpose of the study and were asked whether they were willing to participate. Informed consent or proxy consent was obtained from seven participants according to the procedures approved by the facility ethics review board. All participants were male, owing to the predominantly male population at the veterans care home.

All seven participants were considered for inclusion in the qualitative case examination, intended to explore experiences associated with the use of the anti-collision power wheelchair. However, four of the seven were deemed ineligible owing to: withdrawal from the study due to verbally aggressive behaviour (n=1), inability to use the prototype power wheelchair after driving training (n=2), and dropped out prior to the start of driving training (n=1). See Wang, et al. for additional details regarding residents in the main study. Profiles of the case study participants, Arnie, Bart and Carl\(^1\) are presented in the next section.

A case study design was selected for this analysis (Yin, 2003). Case study designs are ideal when looking to explain complex social phenomena such as individual and organizational processes. The strength of this methodology is that it investigates a phenomenon within its real-life context and addresses situations in which there are indistinct boundaries between the phenomenon and its context. Given the exploratory, in-depth and labour-intensive nature of the case study method, it is acceptable that the case study units be few (Meyer, 2001).

This study reports the findings from participant observation (Crabtree & Miller, 1999) and open-ended interviews related to the three cases. Refer to Appendices 1 and 2 for observation documentation forms and Appendix 5 for interview details. Participant observation time totalled 371 h, and each note is indicated as Obs(participant number).(note number) or Obs(participant number).DT(note number), where DT indicates a driving training session. Participant observations were made by RHW (primary investigator), PJH (third author), or trained research assistants (RAs) and included unstructured daily activities (leisure, personal care, meal times) or structured activities (driving training). A total of 4343 observations, for a total of 318 h of observations, were made at 5 min intervals in 2 h sessions. In these observations, several 2 h

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\(^1\) In the interests of maintaining anonymity of the study participants, all names of participants referred to here are pseudonyms.
sessions were randomly selected each week. Two of the residents were observed weekly for four sessions, between 8:30am and 4:30pm. One resident was observed weekly for five sessions, between 8:00am and 6:00pm because he was out of bed for a longer period. In addition, a total of 34 driving sessions were observed by RHW totalling an additional 52 h 44 min of participant observation. A summary of the observational data collected and analyzed is shown in Table 7. Interview data totalled 7 h 11 min and are indicated as Int(participant number).(note number). RHW interviewed residents (n=3), family members (n=3) and staff (n=11).

### Table 7: Summary of observational case study data

<table>
<thead>
<tr>
<th>Resident</th>
<th>Arnie</th>
<th>Bart</th>
<th>Carl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity observation time (h)</td>
<td>78</td>
<td>178</td>
<td>62</td>
</tr>
<tr>
<td>Driving training observation time (h:min)</td>
<td>17:43</td>
<td>27:15</td>
<td>7:46</td>
</tr>
</tbody>
</table>

All data were analyzed by RHW and a RA using thematic analysis techniques (Patton, 2002). Descriptive coding was first conducted wherein sections of text were assigned a code that reflected the original statement. Categories were thus formed using the codes. Using an inductive and iterative process, categories with similar content were examined for inter-relationships and further refined into fewer categories. RHW and the RA developed the initial coding scheme for all qualitative data. Each independently open-coded by hand 2-3 transcripts and 4-5 observation notes, after which they met to compare and contrast codes emerging from the data, and to ensure consistency in the definitions and interpretations of codes. Where there was inconsistency, coding schemes were discussed and further refined until agreement was achieved. Once a satisfactory level of inter-coder reliability was established, the data were divided equally between RHW and the RA for coding. To ensure the reliability of the analyses, an audit trail (Schwandt, 2001) was used to maintain records and encourage reflexivity about data collection and analysis procedures. The audit trail included explanation of codes that were developed as part of the effort to interpret the data, a description of the procedures used to generate and to analyze data, and reflections on data collection. The audit trail was reviewed by PCK (second author) to ensure that conclusions and assumptions in the analysis were supported by the data. In addition, triangulation (Rothbauer, 2008) via interview transcripts and qualitative field notes from observations was used to ensure internal and external validity.
5.4 Profiles of the participants

Three resident cases were explored using qualitative analysis. Profiles for these residents, Arnie, Bart and Carl are presented below. Further detail and a summary of resident characteristics are presented in Table 8.

**Table 8: Case study participants - Detailed characteristics and main study findings**

<table>
<thead>
<tr>
<th>Resident</th>
<th>Arnie</th>
<th>Bart</th>
<th>Carl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical characteristics of residents</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at time of study</td>
<td>91 years</td>
<td>88 years</td>
<td>91 years</td>
</tr>
</tbody>
</table>
| Primary diagnoses | • dementia  
• chronic renal failure  
• aortic regurgitation | • dementia  
• multiple cerebral vascular accidents, coronary artery disease, myocardial infarct, atrial fibrillation, hypertension  
• left retinal hemorrhage, macular degeneration  
• advanced chronic obstructive pulmonary disease  
• depression and anxiety | • dementia with Lewy bodies  
• cerebral vascular accident with carotid stenosis, right thalamic and basal ganglia infarcts  
• atrial fibrillation, coronary artery disease, myocardial infarct, hypertension, congestive heart failure  
• right hip fracture, vertebral compression fractures, history of falls  
• right sided blindness, glaucoma of left eye  
• hearing impairment  
• possible depression |
| Cognition | • MMSE score: 22 (mild impairment)  
• DRS-2 (AMSS): 4 (moderate impairment) | • MMSE score: 22/27 (mild impairment, base score reduced due to visual limitations)  
• DRS-2 (AMSS): 2 (severe impairment; questions requiring visual skills omitted) | • MMSE score: 23 (mild impairment)  
• DRS-2 (AMSS): 3 (severe impairment) |
<p>| Function | • FIM Score: 48 (requires a lot of assistance for daily care) | • FIM score: 48 (requires a lot of assistance for daily care) | • FIM score: 41 (requires a lot of assistance for daily care) |
| Manual | • did not self propel | • did not self propel | • self propelled short |</p>
<table>
<thead>
<tr>
<th>wheelchair mobility</th>
<th>often</th>
<th>often</th>
<th>distances inside room</th>
</tr>
</thead>
<tbody>
<tr>
<td>• wheeled by staff and volunteers to activity programs</td>
<td>• wheeled by caregivers (staff and daughter) &amp; changed from using wheeled walker to manual wheelchair only 6 months before study</td>
<td>• wheeled by caregivers (private caregiver, staff and daughters)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity participation</th>
<th>• up in manual wheelchair daily</th>
<th>• preferred to stay in bed, up in manual wheelchair sporadically and for short periods &amp; did not participate in group activity programs</th>
<th>• up in manual wheelchair daily &amp; did not participate in group activity programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• participated in group activity programs almost daily</td>
<td>• did not participate in group activity programs</td>
<td>• private caregiver wheeled him to garden or entertainment hall</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social engagement</th>
<th>• friendly and sociable</th>
<th>• reclusive, spent most of time alone in his room &amp; visited almost daily by private caregiver</th>
<th>• reclusive, spent most of his time in his room &amp; family visited frequently</th>
</tr>
</thead>
<tbody>
<tr>
<td>• visited by staff and volunteers on one-to-one basis</td>
<td>• visited by daughter weekly</td>
<td>• visited by chaplain on one-to-one basis</td>
<td></td>
</tr>
<tr>
<td>• enjoyed socializing with staff and volunteers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study findings on experiences of using anti-collision power wheelchair *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-collision power wheelchair study status</td>
</tr>
<tr>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>• used power wheelchair for 18 weeks beyond training phase</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Theme 1</th>
<th>Discordance between reports of others and residents' reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>• staff, family visitors and others positive and encouraging about use of power wheelchair</td>
<td>• family enthusiastic and staff positive and encouraging about use of power wheelchair &amp; resident and family initially enthusiastic about use of power wheelchair</td>
</tr>
<tr>
<td>• resident apprehensive, would miss social interaction of those who pushed him in his wheelchair</td>
<td>• resident ambivalent about use - independently mobile but mentally and physically demanding to use, preferred to save energy for daughter's visits &amp; resident and family subsequently disinterested after several driving sessions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Theme 2</th>
<th>Beyond response bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>• resident uncomfortable with offering negative feedback to investigator</td>
<td>• resident felt unease with telling investigator that he wanted to stop using power</td>
</tr>
<tr>
<td></td>
<td>• resident felt unease with telling investigator that he wanted to stop using power wheelchair</td>
</tr>
</tbody>
</table>
investigator about power wheelchair
• resident felt guilty and did not want to disappoint investigators by saying he did not want to use power wheelchair
wheelchair - communicated decision through daughter
- communicated decision through daughter
• apprehensive and vague about reporting his critique of power wheelchair

Theme 3
Not quite independent: unanticipated dependence
• resident able to independently mobilize with power wheelchair
• resident able to independently mobilize with power wheelchair
• resident had potential to independently mobilize with power wheelchair
• resident dependent on nurses for transfers - concerned about burden to nurses, he perceived additional work for nurses to transfer him on and off power wheelchair because of limitations of power wheelchair
• resident dependent on nurses - concerned about unpredictability of getting staff help, power wheelchair sometimes got stuck and override button needed to be pushed by someone else, dependent on staff and their schedules to transfer him back to bed when he was up in power or manual wheelchair

Theme 4
Design and its implications for self-image
• resident noted power wheelchair speed too slow - self-conscious about others noticing as well
• resident dissatisfied with slow speed of power wheelchair – because not able to keep up with people walking
• resident had major concern with slow speed of power wheelchair – felt embarrassed about being associated with it
• resident felt power wheelchair was too big - self-conscious about space he would take up in social situations
• appreciated size and form of power wheelchair – reminded him of tank which was meaningful and familiar to him as former tank operator
• resident felt appearance of power wheelchair was "hideous", offended his dignity

MMSE – Mini Mental State Examination (total score 30, unless otherwise specified)
DRS-2 – Dementia Rating Scale-2, AMSS - Age-corrected MOANS (Mayo Older Americans Normative Studies) Scaled Scores
FIM – Functional Independence Measure (scores range from 18 - 126, where 18 means complete dependence/total assistance and 126 means complete independence)
* Refer to text for explanation of themes and detailed narrative
5.4.1 Arnie

Arnie was a 91 year old man who was formerly an air force pilot and then a salesman. He had diagnoses of dementia, chronic renal failure and aortic regurgitation. He had a MMSE score of 22/30 suggesting mild dementia. He required a lot of physical help with his day to day care. He used a tilt-in-space manual wheelchair and only occasionally self-propelled using his arms, as he was very slow and tired easily. Nursing staff reports and field work observations evidenced a friendly, social man who attended many activity programs and enjoyed very good rapport with staff and volunteers. He was observed being taken by volunteers to group activity programs on an almost daily basis. Outside of the periods in social programs, he was most often observed outside his room beside the nursing station in his manual wheelchair socializing with staff or volunteers. Most of the non-scheduled activities he engaged in would take place in public areas and in his manual wheelchair, including reading or sleeping in his wheelchair. Arnie indicated at the start of the study that he was content with getting assistance to move from place to place, but was happy to participate in the study to test the power wheelchair.

5.4.2 Bart

Bart was an 88 year old man who was a tank operator in the army and subsequently a cartographer. He had a history of multiple strokes, visual impairment due to macular degeneration and a retinal haemorrhage, and dementia. His cognitive assessment was complicated by his visual impairment. He scored 22/27 on the MMSE with the questions requiring vision omitted. Using a manual tilt-in-space wheelchair, he was capable of wheeling short distances slowly with his arms, but he rarely did so. His nurses reported that within the last 6 months prior to his participation in the study, his physical health declined such that he was no longer able to use a wheeled walker to ambulate, but was required to use a manual wheelchair. He also required a lot of physical assistance for daily activities. He was reported by the nursing staff to be very reclusive, independently minded and often even stubborn. He was observed spending most of his time in his room, with a preference for staying in bed most days owing to self-reported physical aches. His daughter and the nursing staff said that he got up out of bed only with much encouragement. As he did not enjoy scheduled group activities, he declined to participate in most activities such as bingo, arts or music groups. He was visited at least weekly by the chaplain on a one-to-one basis. Bart did not express any mobility goals but was very keen
to test the power wheelchair as something that might give him more to do during the day and to improve his independence.

5.4.3 Carl

Carl was a 91 year old man, a former air force pilot, and later an artist, designer and photographer. His primary diagnoses included dementia with Lewy bodies and stroke. He scored 23/30 on the MMSE. Carl used a low-to-the-ground manual wheelchair and was able to propel for short distances in his room with his arms and legs. He fatigued easily and had shortness of breath. He required a lot of physical support for his daily activities. His daughter and the staff physiotherapist reported that he tended to stay in his room to watch television and did not join in group activity programs. His family hired a private caregiver to stay with him for 8 h each day, 5 days a week, to assist him with meals, encourage him to do more outside of his room, and wheel him to the garden or to the entertainment hall if he agreed to go. Even when accompanied by his caregiver he spent a lot of time sitting with his eyes closed and not talking to others. In a discussion with him prior to the start of the study, he was enthusiastic about the possibility of using a power wheelchair and thought that a power wheelchair would enable him to be more independent.

5.5 Results

Only Arnie and Bart completed the full training protocol (minimum 12 driving training sessions). Both were able to independently and without supervision drive the power wheelchair around their nursing units, and required elevator assistance only to venture off the unit. Both declined continued use of the power wheelchair: Arnie at the end of the training phase and Bart 18 weeks past the end of the training phase. Carl participated in four driving training sessions before declining use of the power wheelchair and discontinuing participation in the study.

Analysis of the data revealed that the residents’ experiences of power mobility use and their decision-making regarding their return to exclusive manual wheelchair use are reflective of social and inter-relational, and psychological and technological considerations. These findings are organized under four themes:

1. Discordance between reports of others and residents’ reports,
2. Beyond response bias,

3. Not quite independent: unanticipated dependence, and


An overview of the main study findings is presented in Table 8 along with detailed resident characteristics.

5.5.1 Discordance between reports of others and residents’ reports

The first theme identifies a critical disconnect between the perceptions of others and those of the resident drivers. Observations and reports from staff, family members and others demonstrated encouragement and even extreme enthusiasm for residents using the power wheelchair. In contrast, residents presented as ambivalent about the power wheelchair.

Observations during the training phase indicated that Arnie received a lot of positive and encouraging comments from staff members, other residents and visitors about his use of the power wheelchair. When a nurse saw Arnie driving the power wheelchair she excitedly asked him, ‘How does it feel to have all that independence?’ (Obs1.DT5). She commented that while she used to see him sitting in the hallway outside his room all the time, she anticipated that with the freedom that the power wheelchair afforded him, she would instead be seeing him constantly on the move. However, Arnie did not affirm this, but instead acknowledged with some trepidation that, ‘It’s a little different right now’ (Obs1.DT5). The difference, as he explained in an observation during the training phase, was that he would “miss the companionship” (Obs1.11).

Arnie had a lot of social interaction with those he termed his ‘pushers’, those staff and volunteers who wheeled him in his manual wheelchair. Observations made throughout the study phases indicated that each morning he was wheeled to his usual spot beside his bedroom by the nursing station, and staff and volunteers would come by regularly to chat with him and to inform him of the daily activity programs. If the program interested him, they would wheel him to the appropriate destination. The independent mobility that the power wheelchair afforded was perceived to be at the cost of highly valued social interaction with those who assisted him in his
manual wheelchair since the assumption was that he would travel independently, and directly, without cause for socializing with the ‘pushers’.

Family and staff shared similar enthusiasm for Bart’s use of the power wheelchair. For example, at the start of the study, Bart’s daughter shared with him her excitement and hopes for all of the things the power wheelchair would allow him to do such as going downstairs to the pub or entertainment hall, and moving on his own so that he would feel like he has more control. Staff also readily reported on the benefits to mobility and independence that the power wheelchair offered. At the end of the training period, one of Bart’s primary nurses remarked: ‘The power wheelchair motivated him. It gives him independence. Self-empowerment’ (Obs2.116). His physiotherapist commented in an interview following the training phase that she perceived a change in Bart’s level of participation in activities:

…for him to go down [to the pub in the basement] and get his beer on his own, I don’t know how you measure that, but I think it’s fairly significant….Never saw him look unhappy when he was on the vehicle….I don’t know where those good moments could come if it hadn’t been for that (Int2.8).

Bart’s daughter commented that her father was more willing to get up out of bed, and that ‘he had something to live for’ (Int2.3). His daughter was so passionate about his use of the power wheelchair that she suggested to RHW strategies to raise money to support the study and to promote awareness and ongoing development of these power wheelchairs (Int2.5). Staff also reported observable change in Bart’s disposition. One nurse indicated during one training session, ‘You can see his whole face light up’ (Obs2.DT6).The chaplain expressed similar observations after the training period when Bart was using the power wheelchair:

[The power wheelchair] brought a lot of brightness to his life, his tone of voice changed, I noticed, his facial expression changed…I found him to be brighter in his facial expression…there was laughter. There was a smile…I would assess that this chair has been a tremendous source of meaning to him (Int2.9).

In contrast to the consensus of how his daughter and staff perceived the power wheelchair, Bart conveyed ambivalent feelings throughout the training and use phases. During a training session a nurse asked Bart ‘What a nice chair. Do you like it?’”, and his reply was, ‘I don’t know yet’
(Obs2.DT6). This was markedly different to his positive remarks about the benefits of the power wheelchair during a later training session: “It’s a great thing. It’s ideal…you don’t have to have someone pushing you’ (Obs2.DT12). In an interview during the period when he was using the power wheelchair he again commented that he found the power wheelchair to be useful: ‘I can take the thing out for a walk, walk around the block. That sounds like independence’ (Int2.7).

Also evident was Bart’s deliberation on the advantages and disadvantages of using the power wheelchair, and the competing priorities in his day to day life activities. Bart found driving the power wheelchair to be a mentally and physically demanding activity. The concentration that driving required caused him fatigue and he often had to take breaks during driving sessions and even terminated sessions due to his fatigue such as when he requested of the investigator: ‘Drive me back to my room’ (Obs2.DT6). In this case RHW would take over operation of the joystick controller and drive while he sat on the power wheelchair. In this regard, it could be considered that RHW was operating as a ‘pusher’. He believed that the effort required during use of the power wheelchair detracted from his participation and enjoyment of valued social activities. A telling example occurred when he declined to drive on a day he thought his daughter was visiting; he explained that it was more important for him to save his energy for her visit (Obs2.87).

It is noted that Carl’s case did not fit into the theme of discordance as defined here. The basis for this theme lies in the conflicted feelings that residents had toward use of the device in contrast to the perceptions of others. Carl’s initial enthusiasm and subsequent disinterest in the device were consistent with the feelings of his family.

5.5.2 Beyond response bias

Residents often showed hesitation about disclosing their true feelings about their use of the power wheelchair, and apprehension in telling RHW that they no longer wished to use the device and participate in the study. This theme expands the notion of social desirability response bias to include the residents’ distinctive concerns about disrupting social relationships with others, in this case with the investigator.

In an interview following the training phase Arnie indicated that he did not wish to continue using the power wheelchair (Int1.4). He said he did not think that it would help him in his day to
day activities, citing concerns about its size (Int1.6). His criticism was interlaced with his validation of the work of RHW and the technology developers, suggesting discomfort with offering negative feedback: ‘…it’s just too big…all together…other than the size, which is the stumbling block really, you know, the thing works exactly as you planned it…and it runs very well…’ (Int1.6). Arnie’s discomfort with sharing with RHW his critique of the device was further evidenced in an interview with one of his nurses at the end of the study in which she indicated that he had confided in her that ‘he felt guilty about saying that he doesn’t want it [power wheelchair]. Or that he would disappoint them [research team]’ because RHW had spent a lot of time with him (Int1.5).

While Bart and Carl were more overt about their feelings about the power wheelchair, both residents showed uneasiness in directly indicating to RHW their final decision to stop using the power wheelchair and to discontinue their participation in the study. Both residents corresponded their decision via their daughters. In Bart’s case, a brief note written by his daughter, said, ‘He has decided to not be involved in the program [study] anymore. It is too taxing on him and he feels he no longer can keep it up’ (Obs2.115). Bart was able to elaborate on his decision after RHW read the note, but referred to the note which indicated succinctly why he no longer wished to participate. Carl similarly had difficulty saying that he no longer wished to use the power wheelchair. After the fourth driving session when RHW asked if he would like to go driving that day, he declined. When asked if there was a particular reason why, he said that it was too difficult to explain. This incident was followed up by a phone call to RHW from Carl’s daughter conveying Carl’s decision to stop using the power wheelchair altogether. Noted of the conversation:

She said that she was talking to her father on the weekend and they discussed the power wheelchair and his participation in the study. He wants to stop his participation….She said that he wasn’t sure how to say he didn’t want to participate any longer without sounding offensive (Int4.8).

During an interview with Carl and his daughter to probe in further depth Carl’s reasons for discontinuing use of the power wheelchair, RHW encouraged him to be as honest as possible regarding his experience. His apprehension in reporting his reactions to, and critique of the power wheelchair was evident in his behaviour and vague responses. He indicated, ‘Now there’s
all sorts of things wrong with it but….yeah [long pause], uh….I don’t know how, that’s it, and the….taking a good wheelchair and turning it into a disaster and pardon my saying so [nervous laugh]’ (Int4.9). He did not elaborate in this interview on specifics regarding the design or how the power wheelchair operated. He stated more generally, ‘Well, it’s hard to describe it, it just that it’s not that, using that, was a, was very difficult to use’ (Int4.9). When asked about the appearance of the device, he said, ‘the appearance?...[pause] couldn’t say I noticed, and when you’re sitting in it, don’t know, can’t tell what it looks like you know’ (Int4.9).

5.5.3 Not quite independent: Unanticipated dependence

Interestingly, both the increased and decreased need for assistance from others associated with use of the power wheelchair proved problematic for the residents. This theme examined the residents’ experiences of depending on others, their perceived changes in dependence with use of the power wheelchair and the consequences of institutional care routines.

Toward the end of the training phase, Arnie was capable of moving around the nursing unit freely with the power wheelchair without supervision, yet Arnie expressed concern that his use of the power wheelchair might burden the nurses. The prototype was designed only to be used on flat indoor surfaces as the sensor skirt was low to the ground intentionally to detect low lying obstacles such as people’s feet or canes. Because Arnie participated in outdoor activities, it was necessary for him to transfer back and forth between the manual and power wheelchairs. Indeed one of the issues he identified about using the power wheelchair was the need for assistance with the additional transfers. In an interview after the training phase he said, ‘It boils down to the fact that you need someone to help you get on and off. Regardless of whether you put another engine in there’ (Int1.6). Upon completion of the training sessions with Arnie in an interview with one of his nurses it was suggested by RHW that the power wheelchair could be left for him to use but his nurse noted that Arnie would not ask staff to retrieve it or assist with its use (Int1.5).

Although he was able to drive the power wheelchair on the nursing unit on his own, for Bart a similar limitation of the power wheelchair created unpredictability in terms of required assistance. The power wheelchair would occasionally get stuck at the entrance of the elevator because the low to the ground sensor skirt was activated by the 1.5 cm step between the floor of the elevator and the floor. Following such an occurrence Bart indicated it was unpredictable when he would need someone to press the system override button on the power wheelchair and
hold the elevator doors until he was safely on or off the elevator (Obs2.115). This created distrust in the device, but also anxiety because he could not rely on the immediate availability of staff to respond.

This apprehension was heightened as Bart already found it challenging to get help when he needed. Bart was totally dependent on nursing staff and their schedules to transfer him back to bed after he was sitting up in a wheelchair. The following observation note recorded comments made by Bart that link his disinclination for continued use with active distrust regarding staff assistance:

[Bart] does not want to drive anymore. [He said] he still has to wait for too long for the nurses to get him back to bed after he has gone out for a drive. He feels that he never knows when the nurses will be back to put him back to bed once he is sitting up (Obs2.115).

The researchers observed similar patterns of interaction with staff regardless of manual or power wheelchair use. When in his manual wheelchair he was observed to call for nursing staff to put him to bed and when left to wait he would become agitated. On one occasion during the phase when he was using the power wheelchair he was observed to wait almost 2 h to be transferred from the power wheelchair to bed, despite indicating to the staff that he felt unwell (Obs2.84). It appeared that he often opted to remain in bed as a means of exercising personal control over his daily routine. During the same period, a nurse reported that Bart had said to her, ‘It’s not up to you if I get up, it’s up to me’ (Obs2.103). The nurses often expressed concern about Bart’s preference to stay in bed all day because they felt that prolonged bed rest was detrimental to his health.

Even in the short duration of his use of the power wheelchair, Carl’s experience of increased mobility dependency was evident. During the driving sessions with RHW, Carl experienced frustration with the delay in response of the wheelchair movement to the joystick controller, often resulting in the need for assistance from RHW. For example, when Carl drove through the doorways of the nursing unit, contacts were often made with the door frame causing power wheelchair movement to stop. This required him to redirect movement of the power wheelchair multiple times in order to pass through a door. However the delay in response of the power wheelchair to his direction led to angry outbursts - ‘I’d like to kill the people who designed this
thing’ – and the need for RHW to physically assist him to redirect the power wheelchair (Obs4.DT3). In the follow up interview after he indicated that he no longer wished to use the power wheelchair, he said, ‘…it’s very….dissatisfying or frustrating trying to manoeuvre it….through the doors and so on’ (Int4.9). As with Arnie and Bart, Carl required assistance from another person to effectively use the power wheelchair, which introduced an element of dissatisfaction and uncertainty as to whether he might need help or get help in the future with using the power wheelchair.

5.5.4 Design and its implications for self-image

When using the power wheelchair, residents attracted much attention from other residents, staff, and visitors in the long-term care home. This final theme suggests that features of the device design, especially the slow driving speed and aesthetics, were issues that influenced the residents’ self-image and how they believed they were perceived by others.

The maximum speed of the power wheelchair was 20% of an average walking pace, which was notably slow. Arnie’s acknowledgment of the slow speed was revealed through joking comments in response to remarks directed at him. During the driving training phase when a nurse asked Arnie how it was going, he replied “slowly” in a light-hearted manner (Obs1.DT3). In another training session, a resident asked in a friendly and teasing tone, ‘Is that in high gear now?’ (Obs1.DT1). Another resident observing Arnie said ‘You’re in no hurry’, and Arnie responded with a smile, ‘I’d better not be in a hurry’ (Obs1.DT4). Acknowledging comments in a good-humoured way may have been his way to avoid self-consciousness or to indicate that he agreed with the comments.

The issue of speed was also raised by Bart who was more direct about his dissatisfaction. Bart commented in an interview after the training sessions were completed, ‘One of the frustrations is that [the power wheelchair] just goes too damned slow. I’m going at one third walking pace’ (Int2.6). Bart noted that other people were passing him, walking faster than the power wheelchair was able move. Not being able to keep up with others seemed to be a source of frustration and discontentment for him.

The slow speed was a major concern for Carl. Carl’s response to the power wheelchair and his comments strongly suggested that he felt embarrassed about being associated with the power
wheelchair, and that he had definitive opinions about users of this type of device. In an interview following his decision to discontinue participation in the study, he said of the power wheelchair, ‘…I see the other guys on the proper scooters, chairs, zooming by, you know? And I’m creeping along’ (Int4.9). His comment about others zooming around in their ‘proper’ wheelchairs suggests that a premium is put on the speed of the other mobility devices that renders them ‘proper’.

When his daughter informed RHW that he no longer wished to participate in the study, she said that he complained that the power wheelchair was slow, and that he said ‘only a moron would want to use it’ (Int4.8). Using the power wheelchair contributed to his already negative perception of being around others that he did not identify with, particularly the residents with cognitive impairment. He did not wish to be perceived as having a greater degree of disability than he identified with. Carl’s use of the word 'moron' to describe users of this device, suggests that perceptions about intelligence or disability and the speed of mobility devices are interrelated.

The study participants had distinct emotional responses to the aesthetic design of the power wheelchair, specifically to the size and form. These responses were aligned with their personal life experiences and beliefs. Arnie said in an interview after the driving training phase that one of the main problems with the device was the size: ‘it’s too big…too big. It would take up the space of three others’ (Int1.6). The sensor skirt extended 10 cm out from the entire base of the power wheelchair, making it 20 cm wider and longer than a conventional power wheelchair. This was a concern because he was a very social person and participated in many group activities. He was aware of the space that he would take up using a power wheelchair of that size. Arnie’s self-consciousness was accentuated by comments made by staff and visitors to him about the power wheelchair’s conspicuously large appearance - likening it to a ‘Cadillac’, ‘hovercraft’, ‘spaceship from Star Wars’, and even ‘the ruddy Queen Mary’ ocean liner (Obs1.DT1, 4). Carl as a former artist, designer and photographer found the appearance of the power wheelchair to be ‘hideous’ according to his daughter (Int4.8). His daughter noted that Carl likely felt it offended his dignity to use it. She said that he is very aware that the people on the floor have cognitive deficits, and that he felt he does not relate with them (Int4.1). She further reported he said ‘the power wheelchair was designed by an idiot to be used by a moron’ (Int4.8). Reiterating his previous comment associated with speed, he felt that users of such a device had to be ‘morons’. Carl’s response suggests that degrees of disability correspond to different types of mobility devices and that the device itself signals to others one’s degree of disability. Bart, in contrast, appreciated the
size and form of the power wheelchair, describing it as a ‘tank’ which held meaning for him as a war veteran and former tank operator. In his discussions with his daughter and the chaplain, he conveyed that using the power wheelchair had a sense of familiarity for him both in its operation and experience using it. This was emphasized by the chaplain who said:

…it gave [Bart] more freedom….More independence… many times he referred to it as a tank, and being a veteran, that to him was like being in that tank again, that sense of freedom, that sense of almost a accomplishment (Int2.9).

5.6 Discussion

Independent mobility is often cited as an essential element in the quality of life of older adults living in institutions (Bourret, et al., 2002). Though power mobility devices have been found to facilitate independence and improve well-being and quality of life of users (Brandt, et al., 2004; Evans, 2000; Mortenson, et al., 2005), power mobility is often denied to residents with cognitive impairments due to safety concerns in institutional care settings. Yet in our exploration of residents’ use of a prototype anti-collision power wheelchair, we found that some residents were able to, or had the capacity to operate the wheelchair, and at no time was their safety or the safety of others compromised. Our findings further challenge the assumption that the power wheelchair alone will afford independence for all users (Brandt, et al., 2004; Evans, 2000; Mortenson, et al., 2005); independence was mitigated by social and organizational factors of institutional life, and by functional and aesthetic dimensions of the power wheelchair that negatively impacted the self-image of the participants. These findings will be discussed in terms of two inter-related implication areas important to promoting independence and improving the quality of life of long-term care residents – technology design, and research and clinical practice.

5.6.1 Implications for technology design

The design of the anti-collision sensor skirt intended to ensure safety by detecting low to the ground obstacles consequently caused difficulties related to the need for assistance. The sensors were activated by uneven ground that is common outdoors and by the small height difference between the floor of the elevator and the floor of the corridor. An increased number of transfers between the manual and power wheelchairs was necessary for residents like Arnie who participated in a lot of outdoor activities. Drawbacks related to increasing the number of daily
transfers might include increased physical stress for residents who stand to transfer or increased workload or perceived workload for care staff who assist residents with transfers. The step between the floor of the elevator and the floor of the corridor is a common environmental barrier in this and likely other older facilities, that needs to be addressed as it makes it challenging for other residents with mobility devices and is a tripping hazard. Because of the unintended stopping of the power wheelchair as a result of the elevator’s floor height, there was a perceived lack of dependability with the device. This was a source of additional stress, for example, with Bart. Getting accustomed to a new technology may already be stressful, and the process may be more stressful or even frightening if users do not trust it. Stress, fear and lack of trust may cause users to abandon technology. Technology that is designed to be easy to understand and is reliable (Phillips & Zhao, 1993), and that is provided with training that is catered to individual needs (Riemer-Reiss & Wacker, 2000) may relieve concerns and promote use. Additionally, devices that require ongoing assistance from others to use may be perceived as counter productive to the goals of improving independence. A new version of the modified power wheelchair would ideally be designed to accommodate small and predictable changes in ground elevation and include indoor and outdoor driving capabilities equivalent to commercially available products. It will certainly be challenging, however, to detect and avoid low lying and low profile objects such as people’s feet and distinguish them reliably from similar variations in the height of ground surfaces.

Power wheelchairs are often recommended for individuals who have low tolerance or endurance for physically wheeling a manual wheelchair. However, operating (or learning to operate) a power wheelchair required additional effort in alertness by the driver, which had a consequence of increased fatigue due to the cognitive load. With the tendency to tire easily, Bart, in particular, was forced to make decisions on how to best use his energy for valued activities such as visits with his daughter. Low activity tolerance for driving the power wheelchair can be understood given the poor general health and functional status of many long-term care residents. Effort-reducing driving features that may need to be considered in future power wheelchairs, may include autonomous and semi-autonomous driving modes (Parikh, et al., 2007; Simpson, 2005) or mixed initiative control where artificial intelligence strategies are used to anticipate user behaviours or needs (Mihailidis, et al., 2007). These modes may decrease the physical and mental demands for driving such that users (or caregivers who know the routines of the
residents) may indicate the desired destinations, and the power wheelchair will move to the location safely on its own or with variable input from the driver. Further investigation into this area, especially the user’s response, is required since we initially felt that having direct control over movement of the power wheelchair enabled the most independence with the least degree of confusion for residents with cognitive impairment.

Operational limitations of the joystick controller resulted in frustration, feelings of decreased control during use, and dependency on others. Sources of irritation, particularly for Carl, were the slow response and lack of feedback for driver movements with the joystick. The slow response was related to the power decreasing as the driving speed was decreased. Contributing to the slow response was the dead space inherent in the joystick such that movement of the joystick did not cause movement of the power wheelchair until the joystick was moved closer to its end range. The lack of feedback for his joystick movements contributed to user dissatisfaction, as it did not adequately indicate to Carl whether his actions were doing something effective to move the power wheelchair. As such, the user interface, due to the absence of valuable feedback, did not work as expected or desired and was a major source of frustration and a failure to achieve the goals of the device (Fisk, Rogers, Charness, Czaja, & Sharit, 2004). Carl’s dissatisfaction with using the device was compounded by a feeling of increased dependency as he constantly needed assistance to renegotiate away from obstacles. Assistance from long-term care staff to move residents in manual wheelchairs out of tight corners or other locations currently occurs, so it was expected that a certain degree of assistance might be required if residents were stuck. It was unexpected, however, that this would be a cause for discontinuing use. Nevertheless, limitations of the joystick controller are features that could be readily addressed. For example, haptic feedback could be added so that resistance provided when trying to move toward an obstacle with which the power wheelchair has contacted can be ‘felt’ through the joystick by the driver.

Another concern expressed was the notably slow speed. The speed was set deliberately to a slower speed for the long-term care environment, and also to account for the stopping distance required for the time of obstacle detection to full and gentle stopping of the power wheelchair. While future modified power wheelchairs using different sensors and/or sensor arrangements and high computer processing speeds may allow somewhat higher driving speeds, it is highly unlikely that the allowable operating speeds would be comparable to those of conventional power wheelchairs.
The three residents also perceived varying degrees of social stigma related to using the power wheelchair. The slow driving speed and the size and form of the device invoked feelings of being different from everybody else. The differences between the prototype device and others typically seen in the long-term care home were obvious to the resident drivers and these differences were very much reinforced by remarks from others. Perceptions of social stigma are often found to be associated with assistive device use (Larsson Lund & Nygard, 2003; Resnik, Allen, Isenstadt, Wasserman, & Iezzoni, 2009). Stigma may be associated with concerns about growing older and becoming more physically disabled, or being viewed as disabled (Resnik, et al., 2009).

The study by Resnik, et al. (2009) supports the notion that the type and features of mobility devices imply a certain degree of disability with users, with some devices perceived more positively or negatively. Mobility aids such as canes were much more acceptable compared to wheelchairs as they represented a much less severe degree of disability. However, power wheelchairs were viewed more positively compared to manual ones, and in some instances even to walkers. The perception of a power mobility device is that it is easier to get around in, goes faster and contributes to feeling younger. This perception may explain why Bart, using a ‘powered device’ was frustrated because it did not meet his expectations for performance and in fact, he was moving slower than other residents using walkers. Likewise, the expectation for faster speed and improved mobility performance coupled with the obvious design features aimed to improve safety gave Carl the impression that the prototype device was intended for someone with more significant disability than he had.

Assistive devices contribute to the construction of the user’s self-image (Larsson Lund & Nygard, 2003). Acceptance or rejection of an assistive device is rooted in the capacity of the device to improve performance in daily activities, and is dependent on whether the device is congruous with the image that the user wishes to portray to others. For Arnie and Carl in particular, the speed and the size and form of the device were inconsistent with their perceived images of self. Larsson Lund & Nygard (2003) also suggest that self-image is changeable according to the person’s adaptation to disability. In Carl’s case, his daughter identified that he denied having declining cognitive abilities, and he discontinued use of a device that did not fit his self-image.
In this study, the appearance of the prototype appeared to have an influence on its perceived acceptability. These findings were not consistent with results found by Pippin & Fernie (1997), who studied older adult mobility aid users. Pippen & Fernie (1997) found that users of walkers were less concerned about the appearance of their walkers and instead focused on the personal autonomy that the devices offered them. It may be reasoned that the device in this study was novel in its appearance as it is a prototype compared to other power wheelchairs, whereas there is a more general acceptance of walkers and rollators or even other wheelchairs based on their prevalence. Also, appearance and the associated perceived stigma were likely only two of multiple factors that impeded adoption of the prototype power wheelchair.

Nevertheless, users also have preferences for the appearance of mobility devices if presented with choices (Pippin & Fernie, 1997). Standard or “medical-appearing devices” were perceived much more negatively (Resnik, et al., 2009). In studies of older adults’ perceptions on the appearances of devices, colourful and sporty appearances were preferred (Pippin & Fernie, 1997; Resnik, et al., 2009). Unfortunately, being a prototype or device still under investigation, many choices in features were not available to residents in the study.

As the appearance of the power wheelchair, even as a prototype, was demonstrated to have an impact on acceptability, future designs will have to consider the most desirable forms and features for the user population. As suggested by previous research, colourful and sporty appearances were preferred by older adults (Pippin & Fernie, 1997). Additionally offering choices for specific features or some degree of customization in the appearance might induce users to be more willing to use devices. The challenge will be to design a device that users will ultimately be proud to use or be associated with, thereby minimizing the perception of stigma.

5.6.2 Research and clinical practice implications

Our findings illustrated a marked discrepancy between the perceptions of others and those of the resident drivers. These data suggested that there was a pervasive belief that independent mobility was essential, fundamentally desired by everyone, and anyone who was not independently mobile would want to strive for it. The beliefs permeated all social interactions between staff, family members, and even the research staff with the residents and presented as encouragement and enthusiasm for residents using the power wheelchair, and expectations for residents to desire to achieve mobility independence. This situation created a positive and supportive environment
for residents to use the power wheelchair. However, residents in the study had very mixed feelings about using it, at least partially because of other priorities, such as maximising socialization and minimizing fatigue which trumped increased independence.

Consequently, a potential detriment might be that presupposed beliefs restrict the capacity to understand the complex needs of residents. This discordance stresses the importance of applying an approach in both research and clinical practice that recognizes the range of possibilities of resident needs. Sensitivity to the content and manner of communication of residents may help to understand differences and needs. Some studies have found that many older adults with cognitive impairment (scoring 9 or 10 out of 30 on the MMSE) and living in institutional settings are able to respond meaningfully to interview questions related to their experiences, preferences, and quality of life (Mozley, et al., 1999). Despite changes in cognition, it is imperative to include the opinions of residents themselves rather than of proxy respondents in research.

The messages that residents received on the usefulness of the power wheelchair and the significance of independent mobility created a milieu where residents felt uneasy about stating their dissatisfaction or lack of acceptance of the power wheelchair, and even pressure to bias their responses in a direction that they felt would be agreeable to the investigators or others who were so encouraging about their use of the device. This phenomenon of social desirability response bias is a concern in self-report based data collection approaches such as interviews (Furnham, 1986). Future intervention research with this population might involve different researchers participating in implementing the intervention and those completing the feedback evaluations or interviews.

The findings also extend the view of social desirability response bias beyond its usual conceptualisation as the wish to please the investigators or protect them from being disappointed. This expanded view highlights the residents’ need to maintain positive social ties with those who work and spend time with them. Studies involving multiple interactions or longer term involvement of researchers in the daily lives of residents have the consequence of increased familiarity and the development of new social connections. It may be perceived that disagreeing with, or speaking negatively about something being offered to them might cause them to lose the prospects for social interaction. The theme of ‘beyond response bias’ emphasizes the residents’ desire for social relationships in long-term care home settings and the vulnerability of the
resident population with respect to their need to develop and maintain social contacts. The fact that residents sought out a mediator to convey that participation in the study was no longer desired, and were concerned about the disruption in social relations with the investigator (possibly offending her, or feeling guilty about the time she spent with them) underscores the need to be cognizant of the social and psychological vulnerability of residents when doing research with this population.

The importance of social relationships in the institutional care environment was also dramatically revealed in the cases of Arnie and Bart, and underscores how the institutional environment can have implications for a residents’ non-use of an assistive device that is aimed to improve independence. The significance of social contact and relationships are well supported in the literature and believed to be important to the well being, quality of life and even lifespan of institutional care residents (Kiely & Flacker, 2003). For Arnie, it was acceptable, and even preferable for him to receive assistance moving from place to place as it ensured social contact from those who helped him. His concern was that if he were more independent he would lose the social contact from those assisting him without the promise of other sources of social interactions. Indeed dependence for personal care activities has been found to be associated with lower levels of loneliness in nursing home residents, as the process of receiving care increased social opportunities (Drageset, 2004).

Arnie also highly valued the interactions that he had with the staff and volunteers. It is stressed increasingly that relationships between staff and residents are of great importance to both parties (Brown Wilson, 2009; McGilton, 2002; McGilton & Boscart, 2007). Residents also preferentially seek interactions with staff rather than with other residents (Hauge & Heggen, 2007). However, one study found that while nurses reported that social interactions with residents were important and beneficial, the time required to complete their care tasks highly restricted their availability for socializing or addressing specific resident requests (Bowers, Lauring, & Jacobson, 2001). Social time with residents was deferred or minimized due to the prioritisation of care tasks. Severe limitations on social contact with staff lead residents to more highly value the limited time that they have with them.

Arnie’s case powerfully illustrates concerns about social isolation. Loneliness in institutional settings may lead to increased dependency in self care, cognitive decline, and increased feelings
of hopelessness (Hicks, 2000). For many residents, the move to a long-term care home may have a large impact on social networks and access to family or friends (McGilton, 2002), as it eliminates ties to communities, and restricts residents to the confines of the care home where social interactions may be infrequent. Resident reports of depressed feelings and social isolation during the transition period are common (Choi, Ransom, & Wyllie, 2008). Social isolation may also be related to challenges in making new friends in the institutional care setting. Limited physical mobility, and changes in cognition, vision, hearing and communication abilities present challenges to building and supporting new relationships in care homes (Brown Wilson, 2009; Resnick, Fries, & Verbrugge, 1997).

Bart’s case also clearly illustrates the prioritisation of social relationships in long-term care homes. His choice to forego some degree of mobility independence to conserve his energy to socialize with his daughter indicates the strong prioritising of social aspects of daily living and maintaining important social relationships. The choice of social interaction over mobility independence challenges the notion that mobility is of primary importance to the well-being and quality of life of long-term care home residents, and underscores the importance of research on social interaction in long-term care homes.

Findings from the cases of Arnie and Bart suggest that routines or care practices in the institutional setting constrain the ability to be fully autonomous, because residents are highly dependent on staff for transferring at wake and bed times. Thus even with a power wheelchair that facilitated increased physical independence to move within the nursing unit, their independence was militated by institutional schedules for care practices that afforded no flexibility around morning and evening patterns of care. Institutional schedules and practices structure daily activities and significantly diminish residents’ sense of control and independence (Choi, et al., 2008; Lidz, Fischer, & Arnold, 1992).

Residents are acutely aware of these institutional restraints to their routines and shortages in staff. This might lead them to lower their expectations for more personalized care or to refrain from asking for help even when necessary (Choi, et al., 2008; Sacco-Peterson & Borell, 2004). This concern for burdening staff with additional requests was identified by Arnie in his reluctance to consider adopting the power wheelchair in his daily life. Additionally, residents may be reluctant to burden staff with particular requests due to fears of being perceived
negatively or even mistreated or ignored, which are consequences of great significance given their dependence on staff for daily care. In all cases, residents were uncertain when they might be able to get help. The anticipation of needing help and the reality of care structures in institutional settings may lead residents to give up on devices that offer incomplete independence as these devices may increase independence for part of the time, rather than all of time. Lowering expectations and not asking for help are sometimes adopted as coping strategies as residents adjust to living in an institutional setting, at the expense of autonomy and independence.

In Bart's case, however, autonomy was so significant that he opted to stay in bed, and this was his strategy to exercise the most control over his day to day life. He felt that once he was up in his manual or power wheelchair, he was not able to control when he could go back to bed. The addition of a device to improve his mobility independence while sitting up actually increased his need for assistance and ultimately was perceived by him to have little consequence. This finding was similar to another study that reported that residents sometimes opted to stay in bed for entire days as a means of controlling their own rest times (Fox, Sidani, & Brooks, 2009).

Especially in the case of Carl, the acceptance of physical or cognitive decline is a very personal experience and some choose not to use assistive devices because of the stigma and negative association with disability. Ultimately the choice to use or not use a mobility aid is the resident’s. Clinicians may support residents by continuing to offer choices such as with different types, designs and features for mobility devices, and focus on the benefits that devices may offer, such as mobility independence or increased participation in valued activities. Highlighting benefits of mobility device use in specific scenarios may also help users to gradually accept a device.

5.6.3 Methodological considerations

The findings of this study have limitations in generalizability due to the small sample size, the qualitative nature of the results, and the nature of the institutional environment and the services provided. Qualitative research findings may not be representative of the broader population. However, qualitative findings can be theoretically generalizable (Maxwell & Mittapalli, 2008) in that they can generate theoretical perspectives or explanatory frameworks that have applicability beyond the immediate context of the reported study. In analyzing the experiences of residents who trialled an anti-collision power wheelchair, we moved beyond basic outcome measures of use or non-use to better understand the technological, psychological, and social contexts in
which decisions regarding device use are made. Given the prevalence of social isolation amongst residents in long-term care homes, these findings may have further importance in terms of challenging the assumption that mobility independence is the greatest priority. By exploring the experiences of the residents in the context of their living environment it was identified that institutional constraints regarding residents’ autonomy militate against their fully benefiting from the independence that a mobility device can offer them. These findings expand our understanding of residents’ experiences with technology for independence and the environments that enable or constrain intervention implementation.

5.7 Conclusions

The experiences of using an anti-collision power wheelchair were explored through the case studies of three long-term care home residents with cognitive impairment. For technology to be acceptable, the design must be such that it meets the functional and aesthetic requirements of users. This exploration uncovered design considerations that will be important for the continued research and development of future modified power wheelchairs for this population. Considerations include the capability to drive on uneven surfaces such as outdoors, the potential need for effort-reducing driving modes, enhanced user interface usability, options for faster driving speed, and a more acceptable appearance. However, technology alone is not sufficient to help residents to fully benefit from the autonomy that technological interventions can provide; more social interaction and greater flexibility in routines and practices must be incorporated into the care of residents in the long-term care home setting. Without these elements in place, the full benefits of technology cannot be realized.
Chapter 6

6 Power mobility for a nursing home resident with dementia


Contributions of the authors: RH Wang wrote the manuscript, developed the research design and protocol, and collected and analyzed the data. PJ Holliday reviewed the manuscript, assisted with developing the research design, helped to collect the data, and contributed to the design of the power wheelchair technology. GR Fernie reviewed the manuscript, and led the design of the power wheelchair technology and the research project.

This chapter is a case examination of additional data from the first study. The resident presented in this case was selected for more in-depth analysis as he represented a nursing home resident who is typically not perceived to benefit from power mobility use because of his cognitive and functional status. While the anti-collision power wheelchair required further development for him to use it, the benefits of using such a device on his capacity for socialization was demonstrated. The case is published in the *American Journal of Occupational Therapy* and is framed using an occupational therapy conceptual model of practice. The theoretical framework applied in this case analysis and the findings are most relevant to occupational therapy researchers and practitioners who are typically involved in the provision of power mobility devices. This case presents a novel mobility device that may offer opportunities for innovation in practice and helps to stimulate the thinking of therapists toward a broader view of mobility and the benefits of power mobility use for nursing home residents with dementia.

6.1 Abstract

6.1.1 Objective

This case study describes an occupational therapy intervention to increase the self-mobility and social participation of a nursing home resident with dementia using a power wheelchair equipped with a collision-prevention system.
6.1.2 Method

We used an exploratory case study design. Data sources included the medical record, standardized assessments, interviews, observations of daily activities and a driving log.

6.1.3 Results

During driving sessions, changes in affect such as smiling and attempts to socialize were noted. The resident required ongoing prompting to operate the modified power wheelchair.

6.1.4 Conclusion

The resident was unable to achieve self-mobility with an intervention involving a modified power wheelchair. However, this study demonstrates that even supervised mobility can have a positive impact on affect and social participation. Observations from this study are being applied to the design and testing of the next generation of power wheelchairs intended for use by nursing home residents with dementia.

6.2 Introduction

Many older adults have chronic health conditions that limit their mobility. For those who live in institutions, independent mobility is essential to quality of life (Bourret, et al., 2002) and a fundamental action that enables engagement in self-care, leisure and social participation. Occupational therapists often promote mobility by providing wheelchairs, and for residents who do not have the physical capacity to move a manual wheelchair, therapists may recommend power wheelchairs. Various reports have described the benefits of power wheelchairs for older adults (Brandt, et al., 2004), the assessment (Dawson, et al., 1994) and training (Hall, et al., 2005) of nursing home residents for power wheelchair use, and safety concerns related to use of these devices in nursing homes (Mortenson, et al., 2005). Despite the research and practice knowledge available, residents who are physically unable to move a manual wheelchair, yet have dementia or other conditions that limit them from safely operating a power wheelchair because of inadequate attention, learning capability, safety awareness and judgment, still present a challenge to therapists. To date, no effective interventions have been developed to assist these residents, and they remain dependent on others to move them from place to place.
Advances in technology offer the possibility of power mobility for people not normally considered capable of driving power wheelchairs by compensating for physical and cognitive deficits. A review by Simpson (2005) described 46 “smart” power wheelchair projects at various stages of development, but to date, only a few have focused on the needs of those living in nursing homes. Wang, Gorski, Holliday & Fernie (2007) reported that a power wheelchair adapted with a contact sensor skirt helped residents with cognitive impairment to compensate for delayed reaction times and prevent injury and property damage. Mihailidis, Elinas, Boger & Hoey (2007) suggested that intelligent collision avoidance and navigation assistance for power wheelchairs have the promise to enable mobility and decrease caregiver dependence for residents with cognitive impairment.

This new technology means that therapists will be involved in evaluating novel interventions to enhance occupational performance and engagement. In examining how a new power wheelchair intervention can improve mobility and enable goal achievement, a conceptual model of practice such as the Canadian Model of Occupational Performance-Engagement (CMOP-E) (Townsend & Polatajko, 2007) may be used to frame interventions. The CMOP-E defines the dynamic interactions of the person, environment, and occupation. Therapists assess physical, cognitive, and affective performance components of the person and analyze physical, social, cultural and institutional environmental factors. Using this framework, therapists may modify the person, the environment or the occupation to enable performance or engagement. A power wheelchair may be viewed as an environmental modification that alters how an occupation is performed.

Because power wheelchairs have not previously been available to people with dementia, little research evidence is available to guide therapists on how to best facilitate power wheelchair use. A good starting point is assumed to involve a cognitive rehabilitative approach using some fundamental guiding principles, as described by Boccardi & Frisoni (2006). To facilitate performance with individuals with dementia, Boccardi and Frisoni identified the need to ensure that the person has the motivation to participate and suggested stimulating intact cognitive skills, breaking tasks down into subtasks, and grading activity requirements. Stimulation of intact cognitive skills, particularly procedural memory, may work to help power wheelchair operation. Power wheelchair use can be facilitated by offering the person supported opportunities to drive and by grading the complexity of driving skills to match the person’s abilities. Procedural memory, part of the implicit memory system that pertains to learned skills, is fairly well
preserved in people with dementia, and stimulation of these preserved memories is believed to be a viable method to promote skill performance (DeVreese, Neri, Fioravanti, Belloi, & Zanetti, 2001). Residents’ memory for the cause-and-effect relationship of using a joystick to move and the process of navigating through the environment may be intact because they may have operated joystick-controlled vehicles in the past (Hall, et al., 2005). To support correct driving performance, another cognitive rehabilitative strategy such as the system of least prompts may be used (Doyle, Wolery, Ault, & Gast, 1988). Some studies have described the application of the system of least prompts with older adults with dementia to facilitate daily skills performance with some effect (Labelle & Mihailidis, 2006). This strategy involves a progression of minimally intrusive verbal prompting to more involved demonstrations of targeted behaviours to assist performance.

6.2.1 Objective

The objective of this exploratory case study was to evaluate the outcome of an anti-collision power wheelchair intervention to enable self-mobility for Mr. Z., a nursing home resident with dementia, thus facilitating his social participation. This case was part of a larger study that examined the effect of anti-collision power wheelchair use on nursing home residents with cognitive impairment.

6.3 Methods

We used an exploratory case study approach as defined by Yin (2003) and used the CMOP-E to frame the intervention. Data sources included the medical record, results from standardized assessments, interviews (refer to Appendix 5 for details), structured observations (refer to Appendix 1 for details), and driving logs (refer to Appendix 2 for details). Mr. Z.’s medical and social histories and previous driving experiences were collected from the medical record. Pamela Holliday administered the Mini-Mental State Examination (MMSE) (Folstein, et al., 2001), Dementia Rating Scale-2 (Jurica, et al., 2001), and Functional Independence Measure (FIM ®) (Uniform Data System for Medical Rehabilitation, 1997). Rosalie Wang interviewed the resident and his caregivers (two nurses, a music therapist, and two recreation therapy staff) to formulate a suitable occupational performance goal. Holliday, Wang, or one of two trained research assistants made structured observations of Mr. Z.’s daily activities at 5-min intervals during five randomly selected 2-hr blocks each week for the duration of the study. Wang conducted the
driving training sessions and completed a log that included summaries of the skills instructed; training strategies used; and Mr. Z.’s driving behaviour and performance, affect, and social interactions. Wang also documented comments made by others on his driving and the impact of driving during and after completion of the sessions. Observations from others helped to corroborate the findings and minimize investigator bias. We reviewed all data sources and summarized common ideas relevant to the intervention’s outcomes. The study was approved by the research ethics board of the hospital where it was conducted (refer to Appendix 11 for consent and information forms). Informed consent was granted by Mr. Z.’s substitute decision maker and assent was granted by Mr. Z.

6.3.1 Participant

Mr. Z. was an 83-year-old man with a diagnosis of mixed Alzheimer’s and vascular dementia. Mr. Z. was selected purposefully from among participants in the larger study. He had complex physical and cognitive limitations, with dementia at the lower limit of the inclusion criteria for the larger study. His score on the FIM was 26 out of 126, indicating maximum to total assistance for daily activities. Mr. Z. had been living in the nursing home for almost 4 years. He was previously an air force pilot and had experience with using a joystick. Mr. Z.’s physical, cognitive, and affective performance components are summarized in Table 9.
### Table 9. Mr. Z.'s Physical, Cognitive, and Affective Performance Components

<table>
<thead>
<tr>
<th>Physical</th>
<th>Cognitive</th>
<th>Affective</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Blurred vision in right eye, cataracts, strabismus in left eye</td>
<td>• 12/30 on Mini-Mental State Exam (moderate dementia)</td>
<td>• Positive when socializing with others</td>
</tr>
<tr>
<td>• Dysarthria</td>
<td>• 72/144 on Dementia Rating Scale-2 (severe cognitive impairment)</td>
<td>• Smiled often</td>
</tr>
<tr>
<td>• Paraplegia</td>
<td>• Mild to moderate receptive and expressive aphasia</td>
<td>• Slept in wheelchair when not interacting with others</td>
</tr>
<tr>
<td>• Transfer: mechanical lift, assistance of one person</td>
<td>• Fluctuating level of alertness, sleepy after meals</td>
<td>• Displayed discontent by turning his head away or grimacing (for example, occasionally during personal care)</td>
</tr>
<tr>
<td>• Seating: tilt-in-space manual wheelchair</td>
<td>• Alert and responsive during social interactions</td>
<td></td>
</tr>
<tr>
<td>• Wheelchair mobility: did not often initiate mobility, hand propelled short distances at 0.08 m/s (from bed to bedroom door) with verbal prompting and manual guidance, tended to veer to right side and bumped into walls and furniture</td>
<td>• Followed one-step directions with gestures and references to environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Difficulty maintaining attention and retaining information, disoriented to place, staff noted that he was aware of his surroundings</td>
<td></td>
</tr>
</tbody>
</table>

### Environment

The study was conducted in a nursing home in Toronto, Ontario, on a nursing unit that provided maximum personal care support for residents with severe physical and cognitive impairments. He lived in a four-bed room with three others. Mr. Z. spent the majority of his time in the lounge in front of the television. There were no power wheelchairs used on this nursing unit before this study.

### Occupation

Mr. Z. enjoyed social contact with others, and while sitting in the lounge he often sought contact by looking at people, reaching out with his arm, or initiating conversation. One staff member stated, “He likes to be with other people. He very much likes to be a part of the group. And he will be as involved as he can be . . . because he has a sense of humour, too.” His access to other people with whom to interact was often limited because he was unable to physically move to
others’ locations. His interactions appeared dependent on other people approaching him. On many occasions, he would reach out his hand and speak, but people did not notice him.

We formulated the goal of enabling self-mobility to increase social participation after observing Mr. Z.’s behaviours and speaking with him and the five primary staff who worked with him. Because of his dysarthria, aphasia, and cognitive impairment, he was unable to name a specific goal, but it was apparent that he was motivated by social participation. The nursing, music and recreational therapy, and research staff agreed that participation in the study and the potential to be mobile may increase his social opportunities.

6.3.4 Intervention

We proposed an environmental intervention to compensate for Mr. Z.’s personal limitations and modify elements influencing his social participation performance. Specifically, we proposed that facilitated use of an anti-collision power wheelchair that compensated for decreased awareness of, or response time to, environmental obstacles and prevented collisions would allow Mr. Z. to safely and more independently access people with whom to socialize. Mr. Z. would ideally be able to move around safely and freely in his room and the communal areas, although use of the power wheelchair would be restricted to the indoor nursing home setting where staff were available for periodic assistance.

The anti-collision power wheelchair used in this study was described previously in Wang et al. (2007). A Nimble Rocket™ power wheelchair (Nimble Inc., Toronto) was modified, as in Figure 6, so that a very low force (an estimated 1-N) contact with the sensor skirt surrounding the base of the wheelchair caused movement to stop. The skirt was designed to collapse without applying additional force during the distance required to bring the wheelchair to a gentle full stop. Only movement away from the obstacle was then permitted. Mounted beside the joystick controller were indicator lights that displayed the directions in which movement was allowed, as shown in Figure 7. The maximum forward speed of the power wheelchair was set at 0.24 m/s (approximately 20 % of an average walking speed).
Figure 6: Anti-collision power wheelchair.
The basic and complex driving skills required to operate the modified power wheelchair in the indoor nursing home setting are shown in Table 10. The performance components or abilities necessary to participate in the driving sessions are listed in Table 11. In a preliminary evaluation of Mr. Z.’s abilities and the driving requirements, we found that Mr. Z. had sufficient capacity to participate in the driving sessions using the modified power wheelchair. Mr. Z.’s strong social tendencies and motivation to be around other people were also important factors in determining his suitability for the proposed intervention.
Table 10. Basic and Complex Driving Skills for Use of Modified Power Wheelchair

<table>
<thead>
<tr>
<th>Basic</th>
<th>Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Turn power on and off</td>
<td>• Drive in congested areas (for example, entertainment hall)</td>
</tr>
<tr>
<td>• Drive forward</td>
<td>• Drive in small spaces (for example, bathroom)</td>
</tr>
<tr>
<td>• Driving backward</td>
<td>• Parking (for example, beside bed or under dining table)</td>
</tr>
<tr>
<td>• Turn right, left, 180°</td>
<td>• Back-in parking or backing out of small space</td>
</tr>
<tr>
<td>• Navigate around obstacles</td>
<td>• Get on and off elevators</td>
</tr>
<tr>
<td>• Navigate away from obstacle when contacted</td>
<td></td>
</tr>
</tbody>
</table>

Table 11. Performance Components Necessary to Use Modified Power Wheelchair

<table>
<thead>
<tr>
<th>Physical</th>
<th>Cognitive</th>
<th>Affective</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sitting tolerance to drive for approximately 1 h</td>
<td>• Alertness and awareness of surroundings</td>
<td>• Motivation to participate and to be mobile</td>
</tr>
<tr>
<td>• Upper-extremity coordination, strength, range of motion, and hand dexterity sufficient to operate power button and joystick</td>
<td>• Follow one-step directions (verbal or nonverbal) to participate in driving sessions</td>
<td></td>
</tr>
<tr>
<td>• Vision to see indicator lights on wheelchair controller (not absolute requirement)</td>
<td>• Verbal or nonverbal ability to communicate needs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Attention to immediate task</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Track movement of objects in environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Conceptual understanding of power button, joystick directions (and indicator lights, but not absolute requirement)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Procedural memory for use of power button and joystick</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Initiation to use joystick to start driving</td>
<td></td>
</tr>
</tbody>
</table>

Driving training sessions were conducted on Mr. Z.’s nursing unit. The approach to facilitate driving performance was dynamic, interactive, and based on procedural memory stimulation and the system of least prompts. According to the system of least prompts, a simple verbal prompt (for example, drive forward) was delivered first. If this prompt did not achieve the correct
performance, then pointing combined with the same verbal prompt was tested. If this prompt was also unsuccessful, gestures were tried. Maximally assistive hand-over-hand guidance was used if gestures were unsuccessful. In this case, the trainer (Wang) physically guided Mr. Z.’s hand through the appropriate movement sequence. Reinforcements or corrections were provided after correct or incorrect behaviours were observed. Care was taken to limit distractions and monitor fatigue or sensory overload. Progress was evaluated after 12 sessions to determine whether continued training was beneficial.

6.4 Results

The intervention as implemented encouraged, but did not sustain social participation because Mr. Z. was unable to operate the power wheelchair on his own. He drove for 12 sessions, each approximately 1 h in duration, over 4 weeks. Although use of the power wheelchair appeared to be a positive experience for him, he required ongoing support to use it.

From his agreement to drive the power wheelchair, and heightened level of alertness, frequency of smiling, and attempts to make social contact with others while driving, the research staff and his caregivers inferred that the intervention positively impacted his affect and social participation. During the sessions, he tended to drive up to staff, initiate greetings, watch what they were doing, listen to them talking, and make jokes. On one occasion he drove up to the unit clerk and said clearly, “How do I get out of here?” and smiled. On another occasion, he spontaneously waved his left arm in the air and said, “Where is my lasso?” in a joking fashion. The staff also encouraged his driving and offered many positive comments when he drove up to them. Several of the staff commented that they were surprised that he could move the power wheelchair as they rarely observed him moving his manual wheelchair.

Mr. Z. was able to use the power button, drive forward continuously, and turn right, left, and 180° with one step concrete verbal prompts and gestures. He was able to navigate away from some obstacles when driving, but when an obstacle was contacted, he required verbal prompts and hand-over-hand assistance to navigate away. Complex skills were not attempted. Mr. Z. only occasionally initiated movement of the joystick, and prompting was required for most of his driving. He was easily distracted by sounds or other people around him. He demonstrated poor short-term recall for instructions. Although Mr. Z. always wanted to continue driving when asked, for sessions longer than approximately 1.25 hr, he appeared fatigued and slower to
respond to prompts or obstacles. Hence, the anti-collision power wheelchair, although designed to prevent collisions, was unable to compensate for his decreased initiation, motor planning, and new learning. Including preparation and take-down time, approximately 2 hr of trainer time were required for each driving session. The degree of support required for Mr. Z.’s continued use of the power wheelchair was high.

6.5 Discussion

This study is the only one of which we are aware of that examines the outcome of a power mobility intervention for a nursing home resident with limited mobility and dementia, primarily because the technology has not been previously available for clinical use. When this study was undertaken we were uncertain how residents with severe cognitive impairment would respond and whether this type of intervention would be worthwhile to pursue with these residents. This study’s outcomes were intended to guide future work to develop more effective interventions, identify suitable candidates for testing, and develop more rigorous study protocols.

The CMOP-E was a useful framework in which to position this intervention in an occupational therapy context. Because the focus of this case was on examining Mr. Z.’s response to the power wheelchair intervention and determining whether there might be some benefit, we did not explore other avenues to address the goal of increasing social participation.

Mr. Z.’s affective behaviour was positive, and his social participation was enhanced while driving. Because he was not able to move himself in the power wheelchair without prompting, observed benefits could not be sustained, and we could not assess the intervention’s longer-term impact. This case illustrates, however, that a resident with complex physical and cognitive limitations can continue to experience positive affect through participation. This result is encouraging and suggests that this intervention may be worthwhile to pursue. However, further study of intervention effects using more rigorous techniques to document behaviours and social participation is recommended.

As anticipated, this study also revealed how the anti-collision power wheelchair requires further development to ensure usability for residents with severe cognitive impairment. The ability of the power wheelchair control system to prevent collisions by stopping automatically protected the safety of residents and property but was not sufficient to enable Mr. Z. to drive the power
wheelchair on his own. To use a power wheelchair, he required prompting from staff or a more sophisticated wheelchair control system able to provide automated prompting and guidance. The anti-collision power wheelchair tested in this study may be of more benefit to residents with greater initiation and motor planning abilities.

The foundations for facilitating power wheelchair use for Mr. Z. were based on a cognitive rehabilitative approach using procedural memory stimulation and the system of least prompts. We presumed that when presented with a joystick that controlled the movement of a vehicle, a resident with previous experience using joysticks such as in piloting a plane would tap into previously learned skills and use the joystick to move the power wheelchair. We expected the system of least prompts to promote correct performance. For the most part, this case supported these approaches.

6.5.1 Future Research

As a result of this exploratory case study, we have several recommendations to improve the design of future studies and the power wheelchair intervention for nursing home residents with dementia. We did not examine the preservation of procedural memory for joystick use and driving and the extent of transfer of these skills, but they warrant further exploration. Future studies should also address the limitations in the study’s design because we did not collect quantitative data for prompts, reinforcements, and corrections applied during the driving sessions. Subsequent studies should include video recordings of the driving sessions; coding of the prompts, reinforcements and corrections delivered; and analysis of the performance outcomes.

Suggestions to improve the design of the power wheelchair for a clinical group with decreased driving initiation and motor planning include an automated prompting system, enhanced feedback to assist the driver with navigating around the environment or away from obstacles, and possibly a semiautonomous driving control system.

6.6 Conclusion

This case demonstrates that an intervention involving use of a modified power wheelchair was unable to facilitate sustained social participation for a nursing home resident with dementia and severe cognitive impairment because self-mobility was not achieved. However, this resident
showed that even supervised mobility can have a positive effect on affective experience and social participation. We have gained valuable information that is being applied to the design and testing of the next generation of power wheelchairs intended for use by nursing home residents with dementia.
Chapter 7

7 Usability testing of a multimodal feedback interface on a simulated collision-avoidance power wheelchair for long-term care home residents with cognitive impairments


Contributions of the authors: RH Wang wrote the manuscript, developed the research design and protocol, collected and analyzed the data, and assisted with the conception of the user interface. A Mihailidis reviewed the manuscript and assisted with the research design; T Dutta reviewed the manuscript, assisted with conception of the power wheelchair technology, and assisted with data collection. GR Fernie reviewed the manuscript, and led the design of the power wheelchair technology and the research project.

This chapter presents the results of a second study that examined the usability of a system consisting of a novel user interface with multimodal feedback and a simulated collision-avoidance power wheelchair. Findings from this study are most relevant to technology developers and clinicians interested enabling power mobility use and expanding the possibility of power mobility for people who are currently excluded from use. The manuscript has been submitted to the Journal of Rehabilitation Research and Development. This journal specializes in multidisciplinary research in disability and rehabilitation. One of the goals of this journal is to disseminate biomedical and engineering research developments, and publications include both technical reports and clinical evaluations of interventions.

7.1 Abstract

Many older adults in long-term care homes have complex physical and cognitive impairments and have difficulty propelling manual wheelchairs. Power wheelchair use is restricted owing to
safety concerns. Power wheelchairs with collision-avoidance features are being developed to enable safe and independent mobility, but there is a paucity of information on interface features to help users to navigate away from obstacles. We developed a system with an interface with auditory, visual and haptic feedback and a simulated collision-avoidance power wheelchair. This device allowed the investigator to stop movement of the power wheelchair when the user approached obstacles and to deliver feedback to assist navigation. Device usability, which included effectiveness, efficiency and user satisfaction, was evaluated by five care home residents with mild or moderate cognitive impairments. Each resident used the device for six - 1 h sessions. Observations, feedback interviews and outcome questionnaires were completed during and after the sessions. It was found that the device was effective in enabling residents to achieve basic driving tasks and self-identified indoor mobility goals. Furthermore, workload was perceived to be low, and residents were satisfied with the device. Finally, residents felt that the feedback was useful to help them to navigate away from obstacles.

7.2 Introduction

Independent mobility is an essential factor in the quality of life of older adults living in institutions (Bourret, et al., 2002). Mobility can be restricted owing to multiple chronic conditions such as arthritis, diabetes, stroke, congestive heart failure and Alzheimer’s disease or other forms of dementia (Banerjee, 2009). Approximately 50% of older adults in Canadian institutions use wheelchairs as a means of mobility (Shields, 2004); however, residents are often unable to use their wheelchairs to move independently. Sources cite a wide range of residents who are able to self-mobilize in their wheelchairs, from as low as 4 -14% (Brechtelsbauer & Louie, 1999) to 50% (Bourbonniere, et al., 2007). Hence, mobility independence is reduced or not achieved for a large number of residents.

Power wheelchairs can improve the independence and quality of life of people with physical mobility problems (Brandt, et al., 2004; May & Rugg, 2010; Mortenson, et al., 2005). Individuals who have significantly restricted mobility, and impaired vision, perception, and cognition do not always have access to power mobility (Hardy, 2004). In the institutional setting, access to power mobility may be denied because of driving safety concerns and the possibility of striking older adult residents who are already at high risk of falling (Neyens, et al., 2009; Oliver, et al., 2007). For many, currently-available power wheelchairs are unable to accommodate their
abilities and enable independent mobility (Fehr, Langbein, & Skaar, 2000; Simpson, et al., 2008).

Modified or ‘smart’ power wheelchairs with collision-avoidance and navigation assistance features are being developed to enable safe and independent mobility in users with complex physical, sensory and cognitive limitations. A comprehensive review of smart wheelchair projects is provided by Simpson (2005). With a few exceptions (Swartz & Mihailidis, 2009; Wang, et al., in press), the majority of advanced power wheelchairs have not been designed for long-term institutional care residents with cognitive impairments. Moreover, only two systems have been tested with this targeted population. The system presented by Swartz & Mihailidis (2009) was evaluated in a pilot study with care home residents with dementia. This system used a stereovision camera as a sensor and audio prompts to direct users away from nearby obstacles. Residents tested the power wheelchair without the system in place for one set of three trials of an obstacle course on one day, and repeated the same trial another day with the system in place. For most residents, there was no difference in the perception of safety or likeability of the power wheelchair with or without the anti-collision system. Residents identified that with the system in place, the wheelchair stopped prior to obstacle contact, but many also felt frustrated when driving with the anti-collision system in place. The system described by Wang, et al. (in press) included a contact sensor skirt and indicator lights to assist with navigation when contact with an obstacle caused movement of the power wheelchair to stop. This device was tested with residents with dementia in the institutional care setting for up to several months, depending on the resident. Findings indicated that while the concept of a collision-avoidance power wheelchair was supported, use of the device as a primary means of mobility was low as some users found it frustrating and difficult to use and some users were unable to use it. In reality, power mobility without some type of collision-avoidance system is not possible for this population.

Most of these new technologies are in development. There is a paucity of information on interface designs and specifications to help users, especially those with cognitive impairments, to drive power wheelchairs with collision-avoidance features. General principles for the design of technology usable by people with dementia have been outlined (Maki & Topo, 2009). The authors indicate that technology needs to be designed to support user choices and varying abilities, be simple and intuitive to use, provide prompting for the correct sequence of user actions, provide appropriate feedback for actions (particularly positive feedback), have
information presented multimodally (audio, verbal, tactile) to add redundancy in communicating needed information, require minimal or no new learning to limit confusion, minimize errors when using the device, and require low physical effort.

Joysticks are the most common input interface for power wheelchairs (Fehr, et al., 2000). It is suggested that use of a joystick to operate a moving device has low cognitive requirements because of the overt cause and effect link (Nilsson & Nyberg, 1999). Interface adaptations have been made to compensate for physical limitations including decreased upper extremity strength or range of motion, spasticity, or tremor (Dicianno, Spaeth, Cooper, Fitzgerald, & Boninger, 2006; Pellegrini, et al., 2004). Haptic or force feedback joysticks have been used in collision-avoidance systems to assist with navigating away from obstacles (Bourhis & Sahnoun, 2007; Fattouh, Sahnoun, & Bourhis, 2004; Protho, LoPresti, & Brienza, 2000). Haptic interfaces interact with a user’s touch and kinesthetic systems through force or other mechanical stimuli (Hayward, Astley, Cruz-Hernandez, Grant, & Robles-De-La-Torre, 2004) and passively or actively guide the user away from obstacles. These technologies have been tested in laboratory settings with computer simulation or virtual systems and subjects without physical or cognitive disabilities (Bourhis & Sahnoun, 2007; Fattouh, et al., 2004), or a virtual reality environment with adults with cerebral palsy or post polio syndrome (Protho, et al., 2000).

The application of multimodal interfaces to provide feedback and guide users to specific actions is relevant to assisting operation of new power wheelchairs. These interfaces include different sensory outputs mostly audio and visual, and some tactile, to support the use of various devices or applications (Sarter, 2006). User performance may be improved by incorporating multiple sensory channel outputs offering redundant information (to compensate for information that may be missed), creating synergistic effects (that augment or heighten the impact of individual modalities), or widening the window for information to be received and used (Sarter, 2006). This multisensory approach may be particularly useful for older adults as sensory processing with single channels like hearing and vision declines with age, and there is evidence that multisensory input potentially compensates for declines in single sensory channels with aging (Laurienti, Burdette, Maldjian, & Wallace, 2006). Combined audio and visual feedback have been tested with some success in other applications, including the COACH, aimed to assist long-term care home residents with dementia to complete hand washing or other activities (Mihailidis, Boger,
Craig, & Hoey, 2008). Multimodal interfaces also have significant potential to assist users with safe automobile driving (Gray, 2008; Spence & Ho, 2008).

Specifications for suitable interface designs and feedback systems will be increasingly important as testing of new collision-avoidance power wheelchairs progresses to clinical populations. We sought to develop a joystick interface with multimodal feedback for use with future collision-avoidance power wheelchairs, and to evaluate the usability of the interface with a simulated collision-avoidance power wheelchair with long-term care home residents with mild and moderate cognitive impairments. Usability according to the International Standards Organization (ISO 9241-11: Guidance on Usability (1998)) is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” (Tullis & Albert, 2008), where effectiveness is “being able to complete a task”, efficiency is “the amount of effort required to complete the task”, and user satisfaction is “the degree to which the user was happy with his or her experience while performing the task” (Tullis & Albert, 2008). The objectives of this study were to evaluate the device according to the three usability domains:

1. **Effectiveness** – Residents will be observed to be able to perform self-identified mobility goals and satisfactorily perform driving tasks from the Power-mobility Indoor Driving Assessment (Dawson, et al., 2006).

2. **Efficiency** – Residents will be able to operate the power wheelchair with the user interface within six-1 h driving sessions as assessed using the Power-mobility Indoor Driving Assessment, and residents will report a low level of workload on the NASA Task Load Index (Hart & Staveland, 1988).

3. **User Satisfaction** – Residents will report satisfaction with the user interface, and satisfaction and positive well-being on the Quebec User Evaluation of Satisfaction with Assistive Technology and the Psychosocial Impact of Assistive Devices Scale (Day & Jutai, 2003; Demers, Weiss-Lambrou, & Ska, 2002) associated with the use of the device.
7.3 Methods

The following methodology was approved by the academic hospital research ethics board prior to the start of participant recruitment and testing. A concurrent mixed methods design, integrating quantitative and qualitative approaches, was used (Creswell, 2008). Data sources included quantitative assessments and questionnaires, field notes made of observations and resident comments during driving sessions, and interviews.

7.3.1 Setting

Residents were recruited from two residences in Toronto, Canada. These residences offered 24-hour nursing care and personal care assistance. One site was a non-profit retirement residence (107 residents) and long-term care centre (120 residents). Accommodations in the long-term care side were private (own bathroom), semi-private (2 beds per room, shared bathroom) or basic (4 beds per room, shared bathroom). The second site was a long-term care centre with 128 residents. The centre was affiliated with a large academic hospital and managed by a contracted long-term care service provider. Eighty rooms were private (own bathroom) and 48 rooms were standard (own room, bathroom shared between two residents).

7.3.2 Device set-up for testing

A commercially-available, mid-wheel drive, Nomad power wheelchair from Dynamis Mobility (Barrie, Canada) was equipped with a modified joystick interface connected via a wire (3 m in length) to a laptop computer (running Windows 98 and MS-DOS) (iDAPT, Toronto Rehabilitation Institute, Canada). Figures 8 and 9 show the set-up of the device for testing. The system was a simulated collision-avoidance power wheelchair, whereby the investigator stopped movement of the power wheelchair if the user approached an obstacle, and delivered feedback to the user on how to best navigate away from obstacles. Because there were different combinations of possible movement directions to navigate away from an obstacle located around the periphery of the power wheelchair, the directions of joystick and power wheelchair movement were divided into eight zones (see Figure 8). The safest preferred combination of navigation directions for an obstacle located in the eight zones were programmed into the logic of the interface software. The preferred combinations were determined by the investigators during pilot testing whereby different obstacle locations were evaluated to identify the movement directions to best
navigate away. When a user approached an obstacle and contact was imminent, the investigator pressed a marked key on the computer keyboard that corresponded to the location of the obstacle near the power wheelchair. Pressing one of the marked keys stopped movement of the power wheelchair and delivered three modes of feedback (audio, visual and haptic) that indicated the preferred directions of movement away from the obstacle. When the user correctly navigated away from the obstacle, the investigator pressed the “all clear” key to indicate that all movement directions were available.
Figure 8: Set-up and operation of simulated collision-avoidance power wheelchair with multimodal feedback. Eight obstacle zones are marked by dashed lines. “AC” denotes key for “All clear” command. 1. Obstacle at front left side, 2. Investigator presses key on computer that corresponds to location of obstacle, 3. Power wheelchair movement stops, 4. Audio, visual and haptic feedback delivery.
The user interface was simple in appearance consisting of a power on/off button and a proportional control joystick (see Figure 10). The three feedback modes delivered together were aimed to provide consistent, immediate and readily identifiable feedback for driving. Pre-recorded audio prompts gave four simple driving directions: “go forward”, “turn right”, “turn left” and “go back”, and an “all clear” prompt. Audio prompts were recorded with a woman’s voice and delivered via a small speaker mounted at the upper back of the power wheelchair. Visual feedback was provided by eight large green LEDs surrounding the joystick as shown in Figure 10. Haptic feedback was implemented such that the user’s joystick movements were restricted in the directions of obstacles and only movement away from obstacles was allowed. Haptic feedback was generated using eight radio-controlled servo motors mounted around the
base of the joystick. Refer to Figure 11 for details. The servo motor mechanisms segregated the
directions of movement into eight zones. When activated, a servo motor rotated a small plate
which in turn moved a bar towards the joystick. The joystick was attached to a plate which
interfaced with the bars. When a combination of bars was activated, the user could not move the
joystick in those directions, preventing the movement of the wheelchair in the same direction.

Figure 10: Top view of user interface. Visual feedback was provided by 8 large green LEDs surrounding
the joystick, indicating the directions of allowed movement.
Figure 11: Inside joystick interface showing haptic feedback mechanisms. When movement of the power wheelchair stopped, the directions of joystick movement (and movement of the power wheelchair) toward the location of the obstacle was blocked. a. 8 radio-controlled servo motors mounted around the base of the joystick produced haptic feedback. b. When activated, a servo motor rotated a small plate which in turn moved a bar towards the joystick. The joystick was attached to a plate which interfaced with the bars. When a bar moved toward the joystick, the user cannot move the joystick in that direction, preventing the movement of the wheelchair in the same direction.
The distance from obstacles at which the investigator stopped movement of the power wheelchair depended on the stopping distance of the power wheelchair (which depended on the speed at which it was moving), and the response time of the investigator. The forward driving speed was set to a maximum of 1.8 km/h (1.1 mph) which was almost half of an average walking speed. At this maximum speed the stopping distance of the power wheelchair was tested to be 40 cm (15.75”). The driving speed was typically much slower while driving in tight spaces such as inside the bedroom or around the dining room, so shorter stopping distances were tolerable.

The device had several other features, primarily to ensure safety. The system had a fail safe mode such that any failure of the device caused the power wheelchair to stop and become inoperable. Movement of the power wheelchair could also be stopped by one of two emergency stop buttons located on the power wheelchair and underneath the computer. An additional all stop control was enabled through the computer software. To better simulate the appearance of a future anti-collision power wheelchair, casings and mounts for the location of camera-based sensors were included on the power wheelchair.

All modifications to the power wheelchair were made by a research technologist. Risk analysis was completed according to CAN/CSA-ISO 14971:01 Medical devices - Application of risk management to medical devices (Canadian Standards Association, 2001). Risk management was led by a clinical engineer (refer to Appendix 17 for details).

7.3.3 Subjects

Residents were included in the study according to the following criteria: (1) had mild or moderate cognitive impairment screened using the Mini Mental State Examination (MMSE, score between 21-26/30 – mild, 11-20/30 – moderate) (Folstein, et al., 2001)), (2) able to speak and understand English and respond to the interview questions and questionnaires, (3) consent or assent to participate in the study (with a substitute decision maker giving consent as necessary), and (4) have a sitting tolerance of over 2 h at a time as confirmed by staff. Residents were excluded if they had a history of aggressive behaviour leading to actual or risk of harm to others. Refer to Appendix 12 for consent and information forms.
7.3.4 Recruitment

Residents were recruited based on staff recommendations. Residents and their substitute decision makers were asked by staff if they were willing to speak with the investigator about the study. If they agreed, the investigator met with the resident and/or the substitute decision maker or spoke to the substitute decision maker on the phone to review the study, consent procedures and information and consent forms. For residents with substitute decision makers, assent was also sought from residents. The investigator explained the study to the resident using a simplified information and assent form. If willing, the resident signed the form. Willingness to participate was also confirmed on each study day. Residents were screened and those who fit the inclusion and exclusion criteria were enrolled. Five residents in total were targeted for testing, with the number selected based on the recommendation that testing with five users can identify 80% of the usability issues (Nielsen & Landauer, 1993). It follows that resolving issues identified from testing with five users allow product developers to quickly move to a new iteration of the design for subsequent testing.

7.3.5 Study procedures

Prior to testing the device, residents were assessed to achieve a better understanding of their abilities. Refer to Appendix 14 for data collection form. The selection of assessments was based in part on the North Shore Health Power Mobility Assessment (Brighton, 2003). Assessments included standard tests for near acuity, distance vision, visual fields and scanning, and peripheral vision; visual perception using the Motor-Free Visual Perceptual Test (MVPT – 3) (Colarusso & Hammill, 2003); and cognition using the MMSE (screening tool), Trail Making Tests A and B, and the Clock Drawing Test. Behaviours such as distractibility, inattention, mental slowness, and the ability to follow directions were noted. A physical screen looking at sitting posture, upper extremity function, seating and joystick controller requirements, transfers, and wheelchair mobility was also completed. Seating and positioning of the joystick controller were adjusted for comfort and function.

Study procedures and the operation of the device were explained to the resident. The resident was informed that the investigator was able to stop movement of the power wheelchair and deliver feedback using the computer attached to the wheelchair. The investigator was present at all times during driving sessions to give instructions to the resident and to stop movement of the
power wheelchair and to deliver feedback if contact with an obstacle was imminent. Each session was approximately 1 h in duration and video-recorded. Residents used the power wheelchair for six sessions over six days. The first session was reserved for general orientation to the device, allowing residents to drive freely to become familiar with how the device operated and to assess whether changes in driving parameters (for example, speed, turning speed, acceleration) or seating were needed. Subsequent sessions were dynamic and loosely structured with “warm up” and “content” periods. During the “warm up” residents were able to drive wherever they wished and explore. The investigator then provided more instruction and suggested skills to practice. The content was based on residents’ self-identified mobility goals (primarily self-care and leisure activities that they wished to perform as part of their day) and the driving skills and tasks from the Power-mobility Indoor Driving Assessment (PIDA, additional information below and in Appendix 7). The pace of the training sessions and driving activities were graded according to the resident’s tolerance and performance. Scoring on the PIDA was based on their last performance of each task. Observations and resident comments made during driving sessions related to: self-identified mobility goals, efficiency and satisfaction with the device were documented in field notes (refer to Appendix 3 for details).

Interviews and questionnaires were completed after all six of the driving sessions were completed. Residents were asked questions about what they thought about the power wheelchair and user interface and how the device worked for them, whether they were able to understand how it works (what helped or hindered their understanding), the feedback that was provided when obstacles were nearby, the usefulness of the device, and suggestions they might have to improve the device (refer to Appendix 6 for details). Information related to the questionnaires is provided below. Interviews and questionnaire responses were audio-recorded.

7.3.5.1 Power-mobility Indoor Driving Assessment (PIDA)

The PIDA was developed to be a valid and reliable instrument to assess the power wheelchair or scooter mobility of long-term care home residents (Dawson, et al., 1994; Dawson, et al., 2006). The PIDA was also intended to evaluate change over time after a mobility intervention. Items to be performed related to skilled driving (turning right/left/180 degrees, driving backward, manipulating in congested areas, manoeuvring, and responding to unexpected obstacles) and mobility around the bedroom, bathroom, doors, elevators, parking, and ramps. Only items
relevant to the resident’s environment or daily requirements were scored. Items were scored on a performance scale from one to four, one being unable to complete the task and four being completely independent. A total percentage score was calculated by summing all the scored items and dividing by four times the number of items scored. The PIDA has been used clinically and has been described in a study that looked at two driving training protocols for older adults living in institutions (Hall, et al., 2005). Refer to Appendix 7 for further details.

7.3.5.2 NASA Task Load Index (NASA-TLX)

The NASA-TLX is a widely used measure that evaluated workload in six subscales - mental demand, physical demand, temporal demand, performance, effort and frustration (Hart & Staveland, 1988). Ratings for the subscales were made from one to 20, and converted to a rating out of 100, with lower scores meaning “low” (for example, for mental demand) or “good” (for performance). Weights were assigned by the resident based on 15 pair-wise comparisons of the relevance of the task on workload subscales. An overall workload score from zero to 100 was calculated based on the subjective weights given. The NASA-TLX has been used in many studies looking at the perceived workload of automobile drivers, including older adult drivers, under various driving conditions (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Matthews, Legg, & Charlton, 2003; Sullivan, Bargman, Adachi, & Schoettle, 2007) and used in a study evaluating shared user and autonomous driving control of an intelligent wheelchair with users without disabilities (Parikh, et al., 2007). Refer to Appendix 8 for further details.

7.3.5.3 Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0)

The QUEST was used to assess user satisfaction with devices and services using 12 items on a five-point scale (Demers, et al., 2002). The overall QUEST score was calculated by averaging the results for all items scored. Details of the psychometric properties are found in the QUEST manual (Demers, Weiss-Lambrou, & Ska, 2000). The Danish version of the QUEST has been used in a study looking at power wheelchair use by older adults (Brandt & Iwarsson, 2001). The QUEST has also been used in studies looking at seating and positioning device interventions in older adults in nursing homes (Trefler, Fitzgerald, Dobson, Bursick, & Joseph, 2004) and community-based users of mobility devices (Brandt & Iwarsson, 2001). Refer to Appendix 9 for further details.
7.3.5.4 Psychosocial Impact of Assistive Devices Scale (PIADS)

The PIADS was a questionnaire consisting of 26 items that measured impact in three subscales: competence, adaptability and self-esteem (Day & Jutai, 2003). The scale was comprised of items that were elemental to quality of life. The user rated the items on a seven-point scale, ranging from -3 (maximum negative impact) to 3 (maximum positive impact). The PIADS was designed to be used either before the device was provided to assess the user’s expectation of the impact of the device or after the device was provided (Day & Jutai, 2003). The instrument has been used with older adult wheelchair users (Devitt, Chau, & Jutai, 2003) and power wheelchair users (Buning, Angelo, & Schmeler, 2001). Refer to Appendix 10 for further details.

7.3.6 Data analysis

The number of self-identified mobility goals achieved and results from the pre-driving assessments, PIDA, NASA-TLX, QUEST 2.0 and PIADS were tabulated. Field notes made during the study were supplemented by notes made during review of the video data for each driving session. For each resident, data were labelled according to the driving session number (for example, DS.1 for driving session 1) or labelled as Interview. All interviews were transcribed verbatim with identifying information removed. Transcriptions were made primarily by the main investigator with the remaining 25% of transcriptions completed by three trained research assistants. The 25% was checked by the main investigator. Data from all sources were summarized and organized under the domains of effectiveness, efficiency and user satisfaction. Thematic analysis techniques were used with the qualitative data pertaining to user satisfaction.

7.4 Results

7.4.1 Study participants

Five residents participated from two sites: George and Mark from one site, and Jim, Lilian and Gerry from the other (for the purposes of anonymity, pseudonyms have been used). Another resident was enrolled but dropped out at the assessment stage because he did not want to complete the pre-driving assessments. Table 12 gives a general description of the residents. Refer to Appendices 22 and 23 for additional details.
<table>
<thead>
<tr>
<th>Resident</th>
<th>MMSE* Score</th>
<th>Primary diagnoses</th>
<th>Manual wheelchair mobility</th>
</tr>
</thead>
</table>
| George (68) | 20/30 | • degenerative disorder of nervous system (not specified) for 25 years, left basal ganglia cavernoma, right frontal gliosis  
• spinal stenosis, degenerative disc disease  
• stroke 10 years ago, multi-infarct dementia  
• hypertension  
• chronic obstructive pulmonary disease  
• diabetes type II | • wheels slowly with legs, going backward often, pulls along handrails in hallway frequently  
• mobile in room and common areas |
| Mark (63) | 24/30 | • acquired brain injury 1 year ago, intracranial (subarachnoid) haemorrhage  
• depression  
• cardiomyopathy, hypertension, coronary artery disease, ischemic heart disease  
• alcohol abuse | • wheels with legs and sometimes arms, pulls along handrails in hallway frequently  
• mobile in room and common areas |
| Jim (76) | 24/30 | • Parkinson's disease  
• multi-infarct dementia  
• right hip fracture 1 year ago with open reduction internal fixation  
• depressive episode | • wheels minimally with arms and legs in room, says wheelchair is heavy  
• wheeled by others outside room |
| Lilian (86) | 24/30 | • stroke 2 years ago, intracerebral haemorrhage, right hemiplegia  
• left lower leg amputation  
• acute and chronic renal failure  
• right malleolus ulcer | • can only turn left (only left arm has functional mobility) in room  
• wheeled by others outside room |
| Gerry (74) | 13/30 | • left middle cerebral artery stroke, right hemiplegia, hypertension  
• depression | • wheels slowly with left arm and leg for short distances inside room or lounge area  
• wheeled by others for longer distances |

* MMSE – Mini Mental State Examination
7.4.2 Usability evaluation

Results from the five residents indicated that the device had high usability. Residents were accepting of the multimodal user interface on the simulated collision-avoidance power wheelchair. Each domain of the usability evaluation is discussed below.

7.4.2.1 Effectiveness

Effectiveness was defined as “being able to complete a task” (Tullis & Albert, 2008). Overall, the device was considered to be effective in enabling the two residents who had indoor mobility goals to complete their self-identified goals, and effective to help residents to achieve most if not all of the basic driving tasks outlined in the PIDA.

7.4.2.1.1 Achievement of mobility goals

All residents, with the exception of Gerry, verbalized mobility goals. Achievement of self-identified indoor mobility goals using the device was high. Outdoor mobility was not explored as most residents required further practice to achieve indoor driving proficiency prior to driving outdoors. Interestingly, George and Mark only identified goals outside of the facility. Lilian and Jim expressed goals that were both outside and inside the care home. Table 13, Self-identified mobility goals and goal achievement, summarizes these findings.
Table 13: Self-identified mobility goals and goal achievement

<table>
<thead>
<tr>
<th>Resident</th>
<th>Mobility goals</th>
<th>Indoor Achieved</th>
<th>Outdoor Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>George</td>
<td>“…go to the store in the morning… yeah, get a paper”</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td>Mark</td>
<td>“… go out more…I would go out to the variety shop to get something … all the bad things you aren’t allowed in here”</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td>Jim</td>
<td>“Going to the dining room”</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Jim</td>
<td>“Going down to the lobby” (to physiotherapy exercise class or communion)</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Lilian</td>
<td>… go into the fridge (in room)…and look out the window (in room) and then, I don’t know, everything.”</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Gerry</td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

7.4.2.1.2 Driving performance on the PIDA

The basic driving tasks, under the Skilled Driving section, were applicable to all residents. The relevance of other sections of the PIDA depended on the residents’ daily routines. Scoring for the PIDA was completed over several sessions, and based on the last performance of each applicable task that was practiced. A summary of the performance on the PIDA for each resident is provided in Table 14 (refer to Appendix 25 for details). Mark was able to complete the
applicable driving tasks within two sessions. The other four residents, George, Jim, Lilian and Gerry, required three to four sessions to perform the applicable tasks. At the end of the six driving sessions, residents were able to perform most of the basic driving tasks under the Skilled Driving section, with passing scores between 3 - “Completes task hesitantly, requires several tries, requires speed restriction, and/or bumps wall, objects, etc lightly (without causing harm)” and 4 - “Optimal performance: able to perform task in one attempt smoothly and safely”. Of note, two residents, George and Jim required more repetitions of the instructions or prompting assistance from the investigator for the driving backward item, and Jim additionally for the manoeuvrability item and hence scored 1 – “Unable to complete task” on these items. The more complex driving tasks under the Bedroom, Bathroom, Elevators and Parking sections were not applicable to all residents, but for some, these tasks necessitated more practice than was possible in the six driving sessions. Residents scored more 3’s or 1’s under this section. Negotiating the elevators was found to be the most challenging task and all residents scored 1’s in two or more components of the task (“entering elevator”, “spacing in elevator”, or “exiting elevator”). Mark who had a lot of previous driving experience was able to master the majority of the tasks within the first three driving sessions, with the exception of entering and exiting the elevator. The time that residents required to complete the elevator task may be considered non-functional, particularly if others were waiting to use the elevators. More time was necessary because of the device’s slow speed and the residents’ need to renegotiate when obstacles were nearby. Notably use of the device with the simulated collision-avoidance feature effectively eliminated the likelihood of achieving a score of 2 (“Bumps objects or people in a way that causes or could cause harm”). Therefore, the collision-avoidance feature increased driving safety and assisted residents to complete these driving tasks guided by the feedback when obstacles were encountered.

Table 14: Summary of performance on Power-mobility Indoor Driving Assessment

<table>
<thead>
<tr>
<th>Resident</th>
<th>George</th>
<th>Mark</th>
<th>Jim</th>
<th>Lilian</th>
<th>Gerry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of applicable items scored*</td>
<td>25</td>
<td>27</td>
<td>20</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Total score</td>
<td>76%</td>
<td>91%</td>
<td>64%</td>
<td>66%</td>
<td>88%</td>
</tr>
</tbody>
</table>

* Maximum possible: 30
Total score (%) = \( \frac{\text{sum of scores for each applicable item}}{4 \times \text{number of applicable items}} \) \times 100
7.4.2.2 Efficiency

Efficiency was “the amount of effort required to complete the task” (Tullis & Albert, 2008). Two scales were used to evaluate efficiency. The first scale measured whether residents were able to operate the power wheelchair and user interface within six - 1 h driving sessions according to the PIDA and the second was self-reported workload using the NASA-TLX. According to these scales, the device was fairly efficient.

7.4.2.2.1 Time to learn operation

Residents were able to operate the power wheelchair and user interface within six - 1 h driving sessions. That is, they performed a majority of the basic skills to drive the device. Additional practice was necessary for all residents, with the exception of Mark, to achieve proficiency.

There were varying levels of performance achieved at the end of the six driving sessions even though the basic skills were achieved. The pace and activities carried out in the sessions were dictated by the activity tolerance of each resident, their performance with each successively more difficult task, and the speed at which they completed tasks. Mark, who had the most experience with driving and navigating many types of vehicles, was able to use the device within three driving sessions and satisfactorily completed most of the tasks on the PIDA. The other residents required more practice with the complex tasks, which were not achievable within six sessions. Jim and Gerry were limited in their activity tolerance, and hence the pace was slower than with Mark and George. Lilian had limited experience operating a vehicle, had not driven a car before, and more time was allocated to getting accustomed to navigating with the joystick.

7.4.2.2.2 Workload

Table 15 summarizes the results of the NASA – TLX. Most residents reported low levels of overall workload, suggesting that the personal cost for operating the device was low. Gerry could not respond to the weighting section for the assessment. Likely due to his language difficulties, he was not able to select between the two words when they were presented on a card. However, even when the two words were presented verbally and explained, he did not select one. Nevertheless, he was able to complete the rating scales which indicated that workload on the six individual domains were low.
Table 15: Summary of NASA-Task Load Index

<table>
<thead>
<tr>
<th></th>
<th>George</th>
<th>Mark</th>
<th>Jim</th>
<th>Lilian</th>
<th>Gerry*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Workload (out of 100)</td>
<td>15.3</td>
<td>14.7</td>
<td>39.3</td>
<td>27</td>
<td>incomplete</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>W</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>25</td>
<td>15</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>W</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>35</td>
<td>15</td>
<td>65</td>
<td>15</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>W</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>15</td>
<td>15</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>Performance</td>
<td>W</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>10</td>
<td>25</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Effort</td>
<td>W</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>5</td>
<td>10</td>
<td>55</td>
<td>15</td>
</tr>
<tr>
<td>Frustration</td>
<td>W</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>

Maximum weight (W) = 15, maximum rating (R) = 100 (lower scores indicating “low” or “good”)

* Did not select weights

7.4.2.3 User satisfaction

Evaluation was based on comments offered during driving sessions, interviews, and from the results of two questionnaires, the QUEST 2.0 and PIADS. Overall, residents were very satisfied with the device. Refer to Table 16 for a summary of device acceptance, and satisfaction with the device and individual modes of feedback. Aspects of user satisfaction found in the analysis of resident comments and interviews were grouped into four categories: 1. Overall device, 2. Multimodal feedback interface, 3. Ease of use, and 4. Speed.
Table 16: Summary of device acceptance and satisfaction with device and multimodal feedback

<table>
<thead>
<tr>
<th>Resident</th>
<th>“Liked” and “would use” device if available</th>
<th>Satisfaction with device</th>
<th>Satisfaction with feedback for moving away from obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Auditory</td>
<td>Visual</td>
</tr>
<tr>
<td>George</td>
<td>Y</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Mark</td>
<td>N</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Jim</td>
<td>Y</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Lilian</td>
<td>Y</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Gerry</td>
<td>Y</td>
<td></td>
<td>Y</td>
</tr>
</tbody>
</table>

7.4.2.3.1 Overall device

The simulated collision-avoidance power wheelchair and the user interface with different modes of feedback were reported by residents to be useful. With the exception of Mark, the residents were interested in using a device like the one they tested. Jim even asked whether such a power wheelchair would be available for him to rent. Related to the collision-avoidance feature of the power wheelchair, they recognized that the device assisted them to be more mobile and independent, but also prevented accidents. George said, “…it stops before it hits it, or have an accident…I think it’s a great idea.” (DS.5). Jim said that it was a lot easier moving the power wheelchair compared to his manual one where he struggled to move even a short distance inside his room. The added safety and assistance features were beneficial, as he said, “I got a lot of help with…the driving…I prefer to have the computer’s help” (DS.4). Lilian could only use her left arm to move her manual wheelchair (in circles) and focused on the independence that a power wheelchair offered. At the end of the study, she said, “I can get around better…you don’t always have to wait for somebody …you feel obligated to somebody be able to help ya, and this way you do things yourself.” (Interview). Like George, she supported the idea of the collision-avoidance feature saying “It’s good because it stops before you are in trouble …” (Interview). Gerry liked the collision-avoidance feature as well, since he was surprised but appreciative when movement of the power wheelchair stopped and he was prompted to navigate around an obstacle that he had not noticed. Mark did not feel he personally needed a power wheelchair or the extra
features that the device offered, but supported it for other people: “for the right person, it’s a great idea, and device…I know there are a number of people in here who it would just be absolutely wonderful for because they really struggle…” (Interview).

7.4.2.3.2 Multimodal feedback interface

Residents thought that the added assistance to move away from obstacles once the power wheelchair stopped was a good idea, and generally felt that the different feedback modalities were helpful. However, there were nuances identified with each of the modalities that warranted mention.

Auditory feedback was perceived to be useful throughout the driving sessions by all residents. Residents said during the driving sessions and final interviews that the recorded messages were clear and easy to understand. They also did not have concerns with the tone of voice, nor a preference for a woman’s or man’s voice. Nevertheless, Mark jokingly commented that a woman’s voice was a good choice: “…obviously they know the way to get things done - put it in a lady’s voice, right?” (DS.3). Residents reported that they followed the audio recorded directions given to them. During the follow-up interview, George concluded that, “she [audio prompt] gave good advice’. Lilian found that the prompts gave the correct directions, and said that she did not catch situations when the prompts were unsuitable. Interestingly, George and Mark noted astutely that the audio prompts did not give what they felt were appropriate directions in a few situations while navigating within small spaces and multiple obstacles were nearby. The simple one-step prompts did not communicate the number and proximity of all surrounding obstacles, and multiple small manoeuvres in different directions were often necessary to negotiate around them. Thus in one instance (DS.4), George turned away from an obstacle and the prompt delivered was “all clear”, but because he was in a tight space, he then became close to the wall on the left side. He laughed and noted, “It’s telling all clear and I’m hitting the wall”. In another case with Mark, multiple chairs and tables were in close proximity during a parking task in the dining room and Mark noted, “It’s telling me to turn left, but if I turn, I’m going to turn my back into the table” (DS.3). In these cases residents used their observation skills and judgment before automatically following the directions. Lilian, during the final interview, suggested that it was possible, but she did not want to become dependent on the audio prompts and automatically follow directions without thinking.
The visual prompts or indicator lights were perceived to be useful during certain circumstances. With the exception of Jim who was not consistent with his responses regarding the lights, most of the residents understood that the lights indicated the directions of allowed movement. Residents such as Lilian tended to look down at the joystick in the early stages of learning to drive the power wheelchair. Mark, the experienced driver, acknowledged this behaviour as he said in response to whether he used the indicator lights, “not a whole lot other than when you are first starting out you want to know, the lights at least let you know because they show…” (DS.3). George and Gerry looked at the indicator lights when movement stopped. Gerry reported during the final driving session that he thought the indicator lights were useful, but not while driving. When he stopped, he said he would look down, but for “just seconds”. Interestingly, Lilian articulated that she used the indicator lights in combination with the auditory prompts. In the final interview discussing what helped her understanding of how the power wheelchair worked, she said, “all the numbers [lights] all around it [joystick], and she [audio prompt] says forward and to the left, right, and they light up and you go from there.” She also suggested that the lights were useful as back up to show which directions to go after the auditory prompts were presented. Mark said that the indicator lights were the least useful feedback strategy for him (Interview). He said in an early driving session (DS.3) that operating a joystick was more based on “feel”, alluding to the importance of a more tactile feedback strategy. During the final interview he said that most joysticks do not have lights around them and that operation of a joystick is mostly based on “instinct or response of the machine”.

Similar to the visual feedback, responses to the haptic feedback were mostly positive. George, Jim and Gerry felt that the haptic feedback, described to the residents as the directions that were blocked because of an obstacle, was very useful. It was unclear whether Lilian found the haptic feedback to be useful. She did not seem to recall that this was a special feature of the device she tested when asked during the final interview. During the driving sessions, however, she appeared to readily adapt to using the device and understood how it operated. Mark thought the blocked directions were too restricting, while he understood that it was a safety feature and why it would be in place. He suggested that a warning at a certain proximity to obstacles would be more beneficial. A warning prompt would give him more of an opportunity to redirect his course, and that he would have more choice with what he could do (DS.3). A warning prompt would likely
7.4.2.3.3 Ease of use

Residents had varying levels of prior experience with operating wheeled devices and joystick controllers, ranging from never having driven a car or power mobility device (Lilian) to experience with various vehicles including cars and trucks, and joystick-controlled construction equipment such as skid steer loaders (Mark). All residents indicated at the end of the sessions that they were able to easily understand how to drive the power wheelchair and understand the feedback. This suggested that the device was intuitive to use, and easy to learn how to operate. Lilian who had the least experience, initially thought that driving was, “very nice…if you’re used to it” indicating some hesitation about her comfort level (DS.1). By the sixth driving session, she said driving with the joystick controller was effortless or, “Just sitting here and pressing the button [joystick].” During the last driving session, Gerry reported that when initially using the joystick he felt “clumsy and then you learn” and that the factor that helped him to understand how it worked was the investigator giving him instructions (DS.6). Mark indicated that his previous experience helped him to easily and proficiently operate the joystick controller to drive the power wheelchair. He reported, “I’m sure that anything like this would be second nature after a very brief time” and that it was “a very simple to operate the machine” (DS.4).

7.4.2.3.4 Speed

One source of dissatisfaction with the device was the slow driving speed. George, Jim, and Lilian’s only recommendation to improve the device was to make it go faster. George identified as early as the third driving session that he wanted it to go faster. When asked about a desirable driving speed for an environment with many people walking with walkers or others using wheelchairs he suggested “about 10 miles an hour”. During the initial sessions, Jim felt the driving speed was slow, but tolerable. After completing the last driving session, he asked whether the device would eventually go faster, suggesting 50% faster. He also stated that while driving, especially “proceeding down the corridor…. the chair’s speed is… a nuisance” (Interview). The slow driving speed was a significant concern for Mark, from the time he started testing the device. He felt the slow speed was not functional for him as he could go faster in his manual wheelchair. He identified that the speed restricted the possibility of getting on and off the
elevators independently because the timed doors were not designed for the slow speed of the device. It seemed a reasonable speed for Mark was merely to keep up with other residents as he said, “I know we are in trouble when this older gentleman and this older lady with her walker pass me [says jokingly].” (DS.1). He reiterated during another session (DS.2), that he wanted only to go at a speed at which he would normally walk. Gerry, who tended to take things very slowly, did not feel that he wished it to go faster in the initial sessions. He suggested that once he got better with his driving, then he could speed up. During the third driving session, he indicated that he wanted it to have the option of going faster and going slower. This suggested that he preferred to have good control over driving and that correct speed modulation was important for him. In the follow-up interview, he said that his driving speed was dependent on the situation so maximum speed was not a big concern for him.

7.4.2.3.5 Questionnaires

7.4.2.3.5.1 User satisfaction

User satisfaction was confirmed by results of the QUEST 2.0. Table 17 shows the summary scores (total and subscale scores) for each resident. Gerry felt that he needed more experience with using the device and more driving sessions to complete this assessment. Device subscale scores were high, ranging from 3.75 to 5 out of a maximum of 5, which indicated a range of “satisfied” to “very satisfied”.

<table>
<thead>
<tr>
<th>Resident</th>
<th>Total Score</th>
<th>Device Subscale Score</th>
<th>Services Subscale Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td>George</td>
<td>4.89</td>
<td>5.00</td>
<td>4.67</td>
</tr>
<tr>
<td>Mark</td>
<td>3.91</td>
<td>3.75</td>
<td>4.33</td>
</tr>
<tr>
<td>Jim</td>
<td>4.00</td>
<td>3.88</td>
<td>4.33</td>
</tr>
<tr>
<td>Lilian</td>
<td>4.36</td>
<td>4.25</td>
<td>4.67</td>
</tr>
<tr>
<td>Gerry**</td>
<td>incomplete</td>
<td>3.75 (uncertain of validity)</td>
<td>incomplete</td>
</tr>
</tbody>
</table>

Maximum for Total and Subscale Scores = 5, 3 = more or less satisfied, 4 = quite satisfied, 5 = very satisfied
* Item number 12 - “Follow-up Services” omitted as this was not applicable
** Did not feel many of the questions were valid because he did not use the device long enough to evaluate
7.4.2.3.5.2 Psychosocial impact on well-being

The PIADS examined the impact of assistive device use on subjective well-being. Table 18 gives the summary scores of each of the three subscales of the PIADS. Use of the device did not negatively impact well-being, that is, no scores were below zero. However, for George, Mark and Gerry, using the device had little impact on well-being. For Jim and Lilian, use of the device was reported to contribute to positive well-being. Subscale scores ranged from 1.88 to 2.25 for Jim indicating “somewhat more” to “very much more”, and 2.13 to 2.50 for Lilian which suggested “very much more”.

<table>
<thead>
<tr>
<th>Resident</th>
<th>Competence Subscale Score</th>
<th>Adaptability Subscale Score</th>
<th>Self-Esteem Subscale Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>George</td>
<td>0.50</td>
<td>0.33</td>
<td>0.38</td>
</tr>
<tr>
<td>Mark</td>
<td>0.75</td>
<td>1.12</td>
<td>0.38</td>
</tr>
<tr>
<td>Jim</td>
<td>2.25</td>
<td>2.25</td>
<td>1.88</td>
</tr>
<tr>
<td>Lilian</td>
<td>2.17</td>
<td>2.50</td>
<td>2.13</td>
</tr>
<tr>
<td>Gerry</td>
<td>0.17</td>
<td>1.67</td>
<td>0</td>
</tr>
</tbody>
</table>

Score range from – 3 to 3, 0 = not any more or less, 1 or 2 = somewhat more, 3 = very much more

7.5 Discussion

Little work has been reported on interfaces for modified power wheelchairs for older adult users with cognitive impairments and the technology features to promote power mobility use. Hence there is little previous research evidence with which to compare our findings. Results from this usability study have important implications for the development of advanced power wheelchair technology. The interface with multimodal feedback tested was intended to be used as an add-on feature to any future collision-avoidance power wheelchair to help users navigate away from obstacles. Results indicated that a power wheelchair with collision-avoidance capability and auditory, visual and haptic feedback to aid navigation may be effective, efficient and user satisfying for residents with mild or moderate cognitive impairments.
Appropriate feedback or prompts for user actions is essential to improve driving performance, minimize confusion and frustration of users, and enable users to maintain as much control of their mobility as possible. The absence of such assistance was found to be a usability problem resulting in decreased device effectiveness and user satisfaction, and contributing to device non-acceptance in a previous study that evaluated an anti-collision power wheelchair (Wang, et al., in press). In this previous study the impact of an anti-collision power wheelchair with a contact sensor system was tested with long-term care home residents with mild or moderate cognitive impairments related to dementia. The user interface consisted of a standard joystick controller, indicator lights, and embedded control logic that only allowed movement in directions away from obstacles after the power wheelchair stopped upon obstacle contact. The indicator lights were a set of six directional arrows mounted in front of the joystick that lit up to visually display the directions of allowed movement. However, residents did not notice the lights were there or did not understand their meaning. Additionally, joystick movement was allowed in all directions even when power wheelchair movement was not. Only movement of the joystick to directions programmed into the logic produced movement of the power wheelchair. This was confusing for users, particularly when obstacles such as those low to the ground or in the back were not recognized by the users but were detected by the sensors. Users then moved the joystick randomly with frustration to find a direction that allowed for power wheelchair movement. The user interface was difficult and frustrating for users because there were ineffective prompts or feedback for correct and incorrect joystick movements.

Guided by findings from this previous study, we developed an improved user interface and tested it with a simulated collision-avoidance power wheelchair. A simulation was used as it was expected that development of a fully reliable non-contact sensor based collision-avoidance system, sensitive and robust to variable environmental conditions and safe for testing in the long-term care environment would not be available for several years. Furthermore, before proceeding with the design of a more advanced power wheelchair we needed a better understanding of this user population and their technology requirements. One of the main benefits of testing with a simulated system applied to a conventional power wheelchair is that it removes concerns about the appearance of a prototype collision-avoidance power wheelchair, lacking the aesthetics of a manufactured product that may affect the user’s perception of the device. This addressed
findings from the previous study where the appearance of the prototype confounded perceptions of the device’s capabilities (Wang, Kontos, Holliday, & Fernie, 2010).

7.5.1 Usability evaluation

Effectiveness, efficiency and user satisfaction were generally high and the user interface and simulated collision-avoidance power wheelchair is considered to have good usability for residents with mild or moderate cognitive impairment when used in the institutional care context. Related to the collision-avoidance feature of the power wheelchair, residents recognized that the device assisted them to be more mobile and independent, but also prevented accidents.

A notable finding was that residents found using the device to be low in workload and frustration. A summed overall score of 40 and above on the 100 point scale has been previously used as a criterion for high workload (Knapp & Hall, 1990). Only one resident, Jim, was close to the threshold. Completion of the weights component of the NASA - TLX has been considered by some researchers to be unnecessary, as the correlation between weighted and unweighted workload scores was found to be +0.94 (Moroney, Biers, Eggemeier, & Mitchell, 1992). In the case of Gerry, who did not respond to the questions on weights, it can still be concluded based on his workload ratings, that overall workload was low. Residents with multiple chronic conditions living in long-term care homes often have low tolerance for activities. Power wheelchair use may result in energy conservation and decreasing physical workload for self-mobility (Miles-Tapping & MacDonald, 1994; Trefler, Hobson, Taylor, Monahan, & Shaw, 1993), but mental workload must also be taken into consideration. An increase in mental workload due to the need for increased alertness is a possibility with power wheelchair use with this user population (Wang, et al., 2010). Additionally, in a study comparing manual, autonomous and semi-autonomous driving modes in an intelligent power wheelchair, users, who were 18 years old or older, indicated that the autonomous driving mode required the least effort, but was frustrating as they did not experience control over their mobility (Parikh, et al., 2007). As expected, users felt the most control using the power wheelchair in the manual mode, but this required the greatest amount of effort. Users preferred the semi-autonomous mode as an intermediary between excessive effort and the feeling of frustration related to lack of control. Users in this study who tested the simulated collision-avoidance power wheelchair with the multimodal interface were in more direct control of the movement of the power wheelchair compared to a semi-autonomous
driving mode. Only a momentary loss of control was experienced when an obstacle was nearby and power wheelchair movement stopped. Overall workload considerations are very important as use of technology is beneficial and acceptable only if the cost of using the technology for physical and mental input is considered low (Lindenberger, Lovden, Schellenbach, & Li, 2008).

User satisfaction was generally high for the device. Indeed, four of the five users felt they would like a power mobility device like the one they tested. This was in contrast to the device tested in Wang, et al. (2010) where acceptance of the device was low because of the poor interface usability, appearance, decreased functionality, and slow driving speed. Not surprisingly, the speed of the device evaluated in this study was found to be an area of dissatisfaction. Despite the somewhat higher speed of approximately 40% of an average walking pace for the device tested in this study compared to the 20% in Wang, et al. (in press) driving speed was still a problem. Slow speed in a power wheelchair has functional and social implications for the user (Wang, et al., 2010). Nevertheless, speed needs to be catered to the resident’s needs and abilities and the driving environments. As indicated by Jim and Gerry, it depends on the location of driving, for example, in a straight corridor with few people, it may be appropriate to go at a faster speed. It may be necessary to investigate different modes of driving to accommodate driving in large spaces that are relatively free of obstacles and in smaller spaces where contact with obstacles may be more likely. The maximum speed will ultimately be determined by the capability of the collision-avoidance technology to detect both static and dynamic obstacles and stop or turn the power wheelchair in time. This may require the technology to also track and predict movement paths of dynamic obstacles such as ambulatory residents whose behaviour may be erratic.

7.5.2 Multimodal feedback

Several interesting points were raised in the residents’ responses to the multimodal feedback. Rationales for using audio, visual and haptic feedback in this user interface are to accommodate for declines in sensory and perceptual system functioning often seen with older adult care home residents, and to offer redundancy (Charness & Holley, 2001) to increase the possibility of correct responses and thus improve driving performance. Use of multisensory assistance has enhanced the performance of many complicated motor actions by compensating for information that is not reliable or when one sensory modality is already engaged (Gray, 2008).
Gathering from the residents’ responses to the feedback provided, it seemed that different modes of feedback may be more useful at different times during driving. All residents reported that the auditory prompts were helpful. This can be understood, as audition is often used in alerting systems to readily catch a user’s attention (Sarter, 2006). Once movement of the power wheelchair stopped and they were alerted by the audio prompts, most residents seemed to look down to the indicator lights for additional guidance. This was the sequence that Lilian described as well. Unimodal visual feedback or visual feedback aimed to be the first source of information is possibly not useful as during driving and navigation activities the visual system is often already attending to multiple sources of stimuli in the environment. Indeed skilled driving requires that the driver look up and ahead to drive straight, scan the environment, and anticipate obstacles. Hence the placement of the visual prompts in the device tested in this study was likely appropriate as it was not in the front field of view to detract from the optimal viewing of the environment.

Also, certain modes of feedback seem to be more or less dominant for the progression from inexperienced to experienced driver. The residents, including Mark, the most experienced driver, said they would look down at the joystick and indicator lights when they were first starting to use the new power wheelchair. Once they were more familiar with operating the device, they looked up to the environment in front of them. At a more skilled level, driving and navigation seemed to be what Mark called based on “feel”. These observations suggest that haptic information in general may be useful with skilled motor performance, and that visual input is primarily engaged when first learning to manipulate the joystick, but haptic information may eventually be integrated into skilled driving to free up the visual system to be more observant of surroundings.

The haptic feedback used in this study is powerful as it ensures the correct directions of movement if residents try to direct the power wheelchair toward the obstacles. Even so, the haptic feedback did not seem to leave an impression on Lilian. She discussed more the auditory and visual feedback (and the combination of these). She potentially did not require the haptic feedback as she was responding appropriately to the other modes already. In contrast, Mark felt that the haptic feedback was too controlling and did not want any driving directions to be locked out. The other three residents did not voice concerns about feeling a loss of control with the haptic feedback. It is interesting to note that we wanted to encourage the experience of control for users by avoiding autonomous driving modes and by offering as many allowable directions to
negotiate away from obstacles as possible, but this may still be perceived as restricting for some users such as Mark. However, the results found here suggest that some residents with cognitive impairment may not mind this form of haptic feedback and the momentary loss of control with the power wheelchair stopping and offering a limited set of allowed directions.

The use of warnings, as suggested by Mark, for nearby obstacles may be a good solution to enable more user control. Since audio feedback may be best for capturing attention, an auditory prompt indicating the presence of or locations of obstacles may be a viable solution. Additionally, a haptic warning might be possible if gradually increasing force feedback is exerted on the joystick (versus a complete blocking) as the user nears obstacles. This proportional haptic feedback would be delivered prior to stopping of the power wheelchair and locking directions of joystick movement. This type of warning would not be abrupt compared to the instantaneous blocking of directions and would alleviate the “unexpectedness” that Jim voiced. This proportional type of force feedback for manual joystick operation was previously discussed. The technology is still in development and has not been tested with the specified population of users with severe motor impairments (Bourhis & Sahnoun, 2007; Fattouh, et al., 2004), or in real environments (Bourhis & Sahnoun, 2007; Fattouh, et al., 2004; Protho, et al., 2000).

Unimodal and multimodal warnings using visual, auditory and tactile modalities have been explored to improve automobile driving performance, such as warning alerts in the prevention of rear-end collisions (Scott & Gray, 2008; Spence & Ho, 2008). Research indicates that incorporation of alerting signals in all modalities (auditory, visual or tactile) can decrease driver response times, although tactile alerts either unimodally or multimodally are useful to decrease driver response times as visual and auditory attention is already heavily in use during driving (Scott & Gray, 2008). The timing and other delivery features of warning prompts need to be explored further for power wheelchair operation. For example, more detailed investigation is needed to elucidate the appropriate time to deliver prompts given the user’s reaction time, driving speed and proximity to the obstacles; the number of repetitions of auditory prompts to be given; and the ideal range of perceivable resistance for joystick movements. Another area needing to be examined further may be the ideal modality to be used in different driving scenarios, such as in a dining room, where multiple obstacles are in close proximity. Multiple auditory prompts for single directions in rapid succession may be confusing or ineffective if
short term memory is limited. Haptic feedback that allows the user to explore and “feel” the surrounding environment of obstacles may be more useful.

Further research is necessary to determine what prompts are tolerated, safe and effective for users with cognitive impairments. However it is conceivable that different users will have different abilities, including impaired vision or hearing, which will limit the usefulness of specific modalities or will have specific preferences or environments of use such that some degree of customization at the assessment and provision level must be accommodated.

7.5.3 Power mobility and resident users

The focus was to evaluate how residents responded to the device in the real context of use, that is, in the long-term care home environment following a training procedure similar to that used in clinical practice. While this approach may take longer than trials in a laboratory test course, we felt it would give a more realistic and valid representation of residents’ experiences. In this protocol, we recognized that tailoring the driving training to the resident was essential, so we did not plan all sessions in advance, but used the resident’s self-identified mobility goals and items from the PIDA as a guide for training activities. We also recognized that for some residents, learning to use a power mobility device, may take several months (Hall, et al., 2005) and so we did not set out to train until their skills reached a plateau.

The residents who participated in this study were not power wheelchair users and were not previously considered for power mobility by the care home staff because of cognitive and other issues that may restrict residents from operating conventional power wheelchairs safely and independently. These residents were ideal candidates for testing this device. Their driving performance indicated that with modifications, safe and independent operation of power wheelchairs may be possible. Residents driving a collision-avoidance power wheelchair may take longer to achieve their targets, but they are self-mobilizing with the minimized risk of bumping into people or objects that could cause harm. Also feedback offered by the device tested may assist them to use modified power wheelchairs more effectively and efficiently.

Some of the residents, including Lilian and Gerry, were able to learn new skills. Longer term training and practice with a modified power wheelchair might enable them to progress to using a conventional power wheelchair. Hence the application of a power wheelchair with collision-
avoidance and multimodal feedback features might be used as a training tool to allow a greater number of residents to experience safe and independent mobility. The device may also be useful as an assessment tool, especially for users who may have potential to drive, but whose capability is unclear. Power wheelchair users and therapists may have more confidence with testing a power wheelchair with added safety features. Two power mobility training devices, the CALL Smart Wheelchair and the C300-TIRO, are currently commercially available and have been tested with varied purposes and outcomes with children with severe disabilities (CALL Centre, 2000; Nisbet, et al., 1996) and children and adults with profound cognitive disabilities (Nilsson, 2007). An area that warrants further exploration is whether special features such as collision detection or line following augments or hinders learning as users may require the feedback or self-directed activity to develop power wheelchair skills (Durkin, 2002). While technology and training approaches have been developed and evaluated primarily with children with different degrees of disability and adults with severe cognitive disabilities to achieve a variety of goals there is still much that needs to be explored related to older adults with mild or moderate cognitive impairments and the best training tools and strategies to enable power wheelchair use with this population.

7.5.4 Study limitations

Testing was completed with a relatively small number of residents, so generalizability to the wider population of long-term care residents with mild or moderate cognitive impairments is restricted. However, in studies of usability it is often recommended to test with a small number of potential users (approximately five) to identify the majority of usability issues before moving to an improved iteration for further testing, and to ideally balance resources and the number of issues identified (Tullis & Albert, 2008).

Another limitation of this study is that the device evaluated is a simulation of a future collision-avoidance power wheelchair with the investigator acting as the sensors and “intelligence”. In this case, the system was evaluated under more ideal conditions than may be possible with the current state of development in technology and artificial intelligence. Implementation of a system that can mimic the observational and decision-making abilities of a human has yet to be realized so many more usability issues may arise when a prototype system rather than a simulation becomes available for evaluation. However, the value of using a simulated system
with a population of older adult residents with cognitive impairments in the real life setting is that it uncovers vital information about users needs’ and responses to technology to guide further development without the complications of testing with less developed prototypes with flaws that may result in a biased evaluation of the overall concepts being investigated.

7.6 Conclusions

Usability evaluation of a power wheelchair with collision-avoidance capability and auditory, visual and simple haptic feedback to aid navigation away from obstacles demonstrated that the device is effective, efficient and satisfying for care home residents with mild or moderate cognitive impairment. This suggests that the modalities and automated delivery system of prompts evaluated in this study are acceptable and useful. Future collision-avoidance power wheelchairs for this population might benefit from the addition of 1) simple audio feedback; 2) visual indicators around the joystick controller to display the available directions of movement; 3) blocks to joystick movement in the directions of obstacles, with a consideration for applying proportional haptic feedback; and 4) increased driving speed to an average walking speed only if the technology can safely operate at that speed. Areas for further development include refining the delivery features of the multimodal feedback; investigating the modes of feedback, ideal logic for navigation away from obstacles and driving speed in different driving environments such as wide open spaces or spaces with many potential obstacles; adding warning prompts; and integrating the multimodal interface with a collision-avoidance power wheelchair. The simulated system was also found to be useful potentially as an assessment and training tool. Future evaluation will include testing the device as a training tool in addition to an augmentative power mobility device to promote independence in a larger number of long-term care residents who are currently mobility dependent.
Chapter 8

8 Discussion

Long-term care home residents with mobility limitations and restricted access to power mobility owing to cognitive impairments must rely on caregivers to move them from place to place. Advanced power wheelchair technology has the potential to assist residents to mobilize safely and more independently. Significant resources have been devoted to designing modified power wheelchairs for people with complex physical, sensory and cognitive impairments. Clinical testing with these devices has thus far been limited. Little is known about the abilities of users to operate power wheelchairs, what features need to be included to promote use, what features users would like, and how they experience using new power wheelchairs. There are also unique challenges for the design and use of modified power wheelchairs by residents in the long-term care home setting. One challenge relates to ensuring the safety of frail ambulatory residents who are at risk for falls if contacted by a power mobility device. Hence, when implementing new interventions the needs of the majority of residents must also be considered. The operational safety of new technology must be confirmed and the responses of others to new devices need to be explored.

The research reported in this thesis is the first to holistically examine the functional mobility of this often neglected population using new power wheelchair technology. This research evaluated new technology, explored users’ needs and experiences with these devices, examined technology design requirements, explored the responses of staff and other residents to the technology, and investigated environmental factors important for implementation of technological interventions in this setting. Outcomes of this research may help to lay the foundation for future work in the development and implementation of new power wheelchair interventions to enable mobility independence and enhance the well-being of long-term care home residents with complex physical and cognitive impairments.

In this final chapter, the progression from the first to the second study is discussed, highlighting findings from each of the studies. The contributions to knowledge are discussed in a review of
the research approach taken, and the technological and clinical findings. Suggestions for future research are considered.

8.1 Study highlights

In the first study, a prototype anti-collision power wheelchair with a novel contact sensor skirt and indicator lights to guide user movements was developed and evaluated with long-term care home residents with mild and moderate cognitive impairments. Development of a contact sensor interface was necessary as investigation into non-contact or proximity sensors at the time demonstrated that proximity sensors including ultrasound or infrared lasers were insufficiently reliable and presented safety risks for use in a care home setting. The benefits of using contact sensors were that they were not susceptible to failure in varying lighting conditions or with interference from other similar sensors, and were able to be set up to reliably detect low lying obstacles such as people’s feet or canes. The contact sensors were implemented in the form of a soft sensor skirt surrounding the base of the power wheelchair such that a low contact force was required to activate the sensors and cause movement of the power wheelchair to stop. There was no change in force from the point of contact to the 10cm stopping distance of the power wheelchair. These features were imperative for safety, as the anti-collision power wheelchair was intended to be used by residents independently and without continuous supervision by another person, while occasional assistance was expected. Future versions of the anti-collision power wheelchair were anticipated to combine proximity sensors but the fail-safe technology was felt to ultimately be the contact sensor skirt, or portions of the skirt. Early evaluation of the prototype was determined to be essential. If demonstrated to be safe, operable and acceptable by resident users, and acceptable to others in the long-term care home setting, the anti-collision power wheelchair was intended to be left with the residents to use as a primary means of mobility for as long as they were benefitting from it. It was hoped that despite the device being a prototype, users would be motivated to accept it as it offered some degree of mobility independence, even if the functions and appearance were not yet perfected. It was also hoped that in addition to improved independence, the well-being or quality of life of residents would be enhanced with use.

Upon evaluation of the device, it was found that only two of the six residents tested were able to operate the power wheelchair. One of these residents chose to stop using the power wheelchair
after the training sessions were completed and declined using it as his primary means of mobility. The other resident however, used it beyond the duration of the study. In this case the measured independent distances traveled in the power wheelchair were notably greater than the independent distances traveled in his manual wheelchair. This resident also reported improved well-being with use of the power wheelchair. In spite of this, he eventually discontinued use of the power wheelchair for various reasons. One additional resident had potential to operate it but chose to stop driving the power wheelchair and discontinue participation in the study.

Qualitative exploration of these three cases revealed technology design and environmental factors that impacted acceptance of the device. The design of the prototype did not meet the functional and aesthetic requirements of these users. Considerations for improvement included the capability to drive on uneven surfaces such as outdoors, effort-reducing driving modes, a more usable interface, options for faster driving speed, and a more attractive appearance. Additionally, for technological interventions to be accepted in the long-term care home setting, increased opportunities for social interaction and greater flexibility in routines and practices must be incorporated into the care of residents.

The remaining three of the six residents were unable to use the prototype device. The participation of one of these residents was discontinued at an early training stage because of verbally aggressive behaviour while in the power wheelchair. It was difficult to know whether additional driving training sessions would enable his operation of the device; however the risk of psychological harm to other residents was not tolerable. The final two residents were unable to operate the power wheelchair without ongoing prompting or other assistance within the time frame of the study. The device was unable to compensate for their particular cognitive limitations, which included decreased initiation, motor planning and new learning for one resident, and lack of awareness or understanding of obstacles above the level of the sensor skirt for the other. With these residents, more advanced control strategies and a more reliable system with coverage for obstacles above the sensor skirt, such as the edges of tables, may be necessary to enable them to benefit from power mobility. Other features, such as automated prompting strategies and a more usable interface for the user, may also assist these residents. An additional case analysis of the resident with the most significant degree of cognitive impairment enrolled in the study was completed to explore the possible uses and benefits of such a device. In this case, even though the resident was unable to operate the device without ongoing prompting, potential
benefits may be to encourage social engagement, participation and positive affect through exploratory mobility.

Qualitative exploration of how the device was perceived was also conducted. Examination of usefulness of the anti-collision power wheelchair indicated that resident users, long-term care home staff and other residents were generally supportive of the purpose and concept of new power wheelchair technologies to enable safe and independent mobility with residents with cognitive impairments. Qualitative findings also showed that the device was generally perceived as safe by resident users, however, features related to the appearance including size, form and construction required modification to improve the perception of safety particularly for resident bystanders.

Observations of safety in the long-term care home setting, demonstrated that the device was able to detect most obstacles found in the environment and that the stopping function worked as it was designed. The primary safety concern was that additional sensors would be required for complete environmental coverage to further decrease the injury risk owing to obstacles and wheelchair components above the sensor skirt and in advance of direct contact. This confirms the need to combine an even more reliable contact sensor interface with proximity sensors in future designs.

The second study aimed to address some of the acceptance issues identified by residents in the first study. Acceptance of the anti-collision power wheelchair was impacted by the appearance, driving speed, and the usability of the user interface which offered limited feedback to residents to navigate away from obstacles. Because of the lack of availability of a sufficiently reliable proximity and contact sensor system for this application, it was determined that development of a simulated collision-avoidance power wheelchair would allow investigation of other functionalities of the power wheelchair while avoiding concerns with regard to altered appearances of prototype devices, significantly reduced driving speeds and delays in necessary evaluation with targeted users. Use of a simulated collision-avoidance system allowed further development and testing of user interfaces, such as a multimodal feedback interface with auditory, visual and haptic feedback. When movement of the power wheelchair was stopped by the investigator because of a nearby obstacle, resident users were given feedback to assist them
to navigate away from the obstacle. This second study examined the interface usability, which included the domains of effectiveness, efficiency and user satisfaction.

Five long-term care home residents with mild to moderate cognitive impairments tested the device. Findings indicated that it was effective in enabling residents to achieve basic driving performance tasks and self-identified indoor mobility goals. Regarding efficiency, residents were able to operate the power wheelchair within six driving sessions; however, further practice was required for them to perform more complex driving tasks. Moreover, workload was perceived to be low for learning to operate and use the device. Residents were satisfied with the device, and four of the five users wished to have a device like the one they tested. Despite the slight increase in driving speed of this power wheelchair, driving speed remained the main criticism of the device tested. Residents did not report concerns or dissatisfaction with the appearance of the power wheelchair. Residents felt that the additional feedback was useful to help them to navigate away from obstacles. Three of the five residents indicated that all the modes of feedback were helpful. Auditory feedback seemed to be the overall preferred mode. One resident did not think the visual feedback was useful. Haptic feedback was observed as an effective mode to guide users away from obstacles. However, one resident indicated that she did not notice the haptic feedback. Another resident felt the haptic feedback was too controlling and that warning prompts prior to a full stop of the power wheelchair would be helpful. Overall, a multimodal feedback interface on a joystick controller appeared to be a promising approach to improve usability and acceptance. The device evaluated also has potential for use as a power mobility training tool to enable more residents with a wider range of abilities to trial power wheelchairs.

8.2 Contributions to knowledge

8.2.1 Review of research approach

The research approach undertaken in this thesis was selected to enhance the credibility of findings and offer the best opportunities for resident users to evaluate the new technologies. This approach to development and evaluation of advanced power wheelchair technology has not been applied with this population previously.

The integrated mixed methods approach was found to be highly appropriate. In a research field where there is currently little knowledge, combined use of quantitative and qualitative methods
broadens the understanding of the phenomena under investigation. A mix of data collection strategies can elicit information on different facets of users’ and others’ experiences and can compensate for limitations of individual data collection methods. In exploring the mobility impact of using a modified power wheelchair, a comparison of daily mobility, or distances travelled each day in manual or power wheelchairs can determine if actual mobility behaviours were altered over the course of the study. However, other components of the mobility experience were derived from detailed observation of contexts and circumstances surrounding the behaviours. Observation and interviews were found to be tremendously useful in constructing a more comprehensive picture in explaining the underlying reasons for residents’ behaviours and their decisions to accept or not accept the power wheelchair.

The development of technology necessitates direct involvement of users and evaluation in a context that is as close as possible to the real world. These beliefs are consistent with the user-centred design philosophy for technology (Schuler & Namioka, 1993). In this research long-term care residents with restricted manual wheelchair mobility and cognitive limitations, who are the likely candidates for modified power wheelchair technology, were recruited. By targeting evaluation with anticipated users rather than surrogate users, a holistic understanding of the physical, cognitive and affective personal components of targeted users is achieved. Additionally, testing in the real-world context necessitates consideration of all facets of the physical, social, cultural and institutional environments. Moreover, it is important to incorporate a process of provision that is similar to current clinical practices in occupational therapy or other disciplines involved in the delivery of power mobility devices. Clinical practice procedures include assessment of users and fitting of power wheelchair seating for safety, comfort and function; training that is tailored to the users’ capabilities; and performance assessment. The research process offered residents the opportunity to trial the technologies under conditions aimed to optimize their performance such as ensuring seating comfort, including their daily routine or desired occupations or goals (if any) into the study procedures, and allowing ample time for residents to experience using the devices under realistic conditions of their lives. The possibilities for eliciting and receiving feedback during power wheelchair use in context may be greater and the quality of the evaluation may be superior. This may be true for users with cognitive limitations including changes in abstract thinking or short-term memory loss where familiar environments better support performance in addition to stimulating more authentic
responses. Evaluation in context over a period of months (or years in the case of the first study site) also facilitated more realistic feedback from others including long-term care staff and other residents. Extended exposure to devices allowed staff to envision devices being used by residents as a means of primary mobility and also to observe or contemplate how devices might impact users, staff and other residents. The research approach applied was in direct contrast to more time-limited laboratory evaluation under structured driving contexts, which inherently limit the validity of the findings.

An important lesson learned through completing the two studies was the value of early testing with end users using prototypes and simulations. Early testing is especially useful when technological concepts are unproven; technological advances are not at the necessary levels for safety, function or feasibility; and ongoing development is time and labour intensive. Development of technology needs to occur in parallel with evaluation of technology with targeted users. For the intervention to succeed the focus of research cannot be strictly on development of the technology; attention also needs to be directed to holistic elements of the problems to be addressed. Hence it is necessary to test prototypes early in the design process to gain a better understanding of users, how they use power wheelchairs and the environments of use. Findings can be incorporated into future design iterations earlier and then tested with other users. This approach is similar to that currently used by clinicians in the provision of seating and mobility equipment. That is, users are assessed and mock-ups of seating system components and configurations are made for users to trial for several days or weeks. Feedback from users is then used to improve the system. The important difference is that the mock-ups consist of new prototype technology for more complex user groups. In the first study, a prototype was designed with the hope that it would be used as a primary means of mobility. While there was support for the concept of such a device, it was found to be insufficiently safe and unsatisfactory for those targeted users involved in the study. Much information was gained that can be incorporated into the design of improved prototypes. The absence of reliable sensor technology to address the safety concerns and the need to further knowledge on user needs for technology led to the use of a simulation of a collision-avoidance power wheelchair in the second study. The simulation was an invaluable tool and possibly a new research strategy to conduct user testing with novel power wheelchair features in real environments without the concerns for ideally reliable sensor technology and the appearance of the prototype.
8.2.2 Technological and clinical findings

The findings from this research could be used to form the foundation for further work on developing, evaluating and providing new power wheelchair technology for this population. Several technology design specifications and suggestions for further exploration can be made. For older adult long-term care home residents with cognitive impairments, acceptance of new power wheelchair technology was influenced by several design features. These included:

- **Appearance and size:** For some residents, the appearance of even a prototype device had a strong influence on the acceptance of the concept of a power wheelchair modified to enable safe and independent use. Devices designed to explore the usefulness of a concept still required aesthetic consideration as social factors including the stigma of assistive device use influenced the overall perception of the usefulness.

- **Appropriate speed:** Slow driving speed was found to elicit frustration and dissatisfaction in some users. These responses were associated with the decreased functionality of being slow to get to places, and the stigma of using devices that functioned differently to those commonly seen. A suggestion of the speed of walking pace was offered as a target speed, but only if future technology allowed for this. The difficulty is that the system must be capable of predicting collisions with other moving objects or people and allow sufficient time for a comfortable deceleration to a stop.

- **Interface usability:** The user interface in the first study was found to be difficult to understand and did not offer feedback for correct and incorrect actions to navigate away from obstacles that were encountered. This resulted in confusion and frustration for some users. A multimodal feedback joystick interface offering auditory, visual and haptic feedback in the second study was found to require light workload and had high user satisfaction. This is a promising approach for interface design for future collision-avoidance power wheelchairs.

- **Capability for uneven ground surface or outdoor use:** Negotiation of uneven surfaces (indoors and outdoors) was necessary to minimize the number of transfers to and from the manual and power wheelchairs for one user in the first study. The majority of users in both studies voiced the wish to use their mobility devices outdoors. A major technical difficulty here is that the system must be able to discriminate between objects low to the floor such as
the toes of an outstretched limb and uneven surfaces commonly encountered outdoors and indoors including the height difference between the floor and the elevator cab as found in the first study.

Other findings pertaining to design features that may improve safety and functionality and expand the range of user who may benefit include:

- Sensor reliability and full environmental coverage: The contact sensor skirt tested in the first study was found to be unsatisfactory given the rigorous criteria for safety. To ensure safety, further development of sensor technology for this application is necessary. It is expected that use of proximity sensors such as computer vision coupled with contact sensors will be necessary to ensure coverage and redundancy.

- Perception of safety: The appearance of new technology also needs to convey the message of “safe”. The contact sensor skirt on the device tested in the first study was black, and appeared large and solid resulting in the perception that the device was overpowering or even scary. Further consideration for the appearance of safety is necessary to promote security and confidence in others, especially other residents with cognitive impairments living in the long-term care home.

- Effort-reducing driving strategies: Physical and mental fatigue are possible with older adult care home residents and driving a modified power wheelchair was reported by one resident in the first study to require a lot of effort. Alternative driving modes such as semi-autonomous operation warrant further investigation with this population.

- Assisted use: One resident in the first study required ongoing prompting to operate the modified power wheelchair owing to decreased initiation and motor planning. Development of advanced control strategies may enable more users with cognitive impairments to operate power wheelchairs. Such assisted use may include automated prompting for driving or reminders for activities or locations to drive toward.

- User interface: An interface with multimodal feedback was reported to be beneficial to users in the second study. Further exploration of the qualities of the feedback strategies and usability evaluation with this population is necessary.
An improved understanding of the users and the context in which they live was also gained from this research. These findings are valuable in understanding the influences on device acceptance and in conceiving of provision strategies. Results demonstrate that resident users, staff, and other long-term care residents support the continued development of modified power wheelchairs to enhance the safe and independent mobility of users with mild and moderate cognitive impairments. However, barriers to the full implementation of technology to improve mobility are evidenced during the first study that was conducted over multiple months for individual residents. Mobility independence was shown to be improved by power wheelchair technology for one resident, but full independence was not achieved or the potential of the technology could not be completely realized because of the structured care routines that did not accommodate residents’ choices. The identified need for increased resident autonomy was not a new finding but findings affirmed that resident autonomy must be in place for residents to truly benefit from mobility-enhancing technologies. Moreover, severely limited or restricted social opportunities may unintentionally force residents to choose between mobility independence and social interactions with those who assist them. Both mobility independence and social engagement are important to high quality of life in long-term care home settings. But for residents to benefit from the independence offered by mobility technology, support for increased social opportunities must be in place to ensure residents do not experience increased isolation.

8.3 Suggestions for future research

Multiple areas are identified for future research. Many facets of the problem are explored in this thesis, and others, while speculated to be important could not be addressed in detail within the scope of this thesis. A framework, shown in Figure 12, is proposed for organizing factors pertinent to enabling mobility through the use of new power wheelchair technology by long-term care home residents with cognitive impairments. This framework or conceptual map was devised using an iterative process to relate the findings from this research, anticipated impact areas and areas that require technology development and further investigation. Findings identified resident, power wheelchair intervention, and long-term care home characteristics that impact resident responses, mobility outcomes, and ultimately use or non-use of power wheelchair technology. The proposed framework is by no means comprehensive and further validation from research and clinical evidence is necessary. However, the framework perhaps serves as a starting point for discussion and further research into new technology and approaches to address the mobility
issues of long-term care home residents for whom no interventions currently exist. Several areas of the framework are discussed in further detail, and proposed studies are briefly described.
Figure 12: Proposed framework for the use of novel power wheelchair technology to enable mobility with long-term care home residents with physical and cognitive impairments.

**Long-term care home environment**
- has criteria for safe, functional use of power wheelchairs
- institutional routines or practices: may restrict full independence and autonomy
- social factors: need for help, perceived burden to staff, isolation or loneliness may be motivating factors to receive help

**Technological design**
- reliable sensor system, full environmental coverage
- dynamic obstacle avoidance
- steering/navigation assistance: haptic feedback, audio and visual prompts
- intuitive interface: minimal training needed to operate
- speed: ‘walking pace’
- ‘normal’ appearance and size
- semi-autonomous driving
- incorporation of driver intent

**Power wheelchair mobility intervention**
- technology - ‘anti-collision’ for safety, navigation assist for obstacle avoidance
- learning to use process and training strategies

**Intervention**
- acceptance or non-acceptance

**Mobility outcomes**
- able to use or unable to use power wheelchair
- dependence or independence: some independence but not full, still need help from caregivers
- social interactions: increase or decrease
- occupational engagement, activity, participation
- well-being, quality of life

**Mobility**

**Responses to use**
- physical: fatigue
- affective: confusion, frustration, happiness, embarrassment
- sensory/cognitive - alertness

**Characteristics**
- physical
- cognitive: attention, executive function, procedural memory, learning, motivation

**Resident**

**Mobility**

**Long-term care home environment**
8.3.1 Power wheelchair mobility intervention

The focus of this research was on the evaluation of the power wheelchair component of the intervention, and looking at technology to compensate for performance deficits owing to cognitive impairments. Findings related to improving future iterations of technology have already been outlined. Future research may look at better tailoring the sensor arrangements and user interface features to fit resident abilities and limitations, or even look at modular features that clinicians can add on depending on the needs or changing needs of residents. The learning or training element of the intervention could not be systematically examined within the scope of this thesis. The case study discussed in Chapter 6 involved a resident with dementia and used a neurorehabilitative approach that consisted of procedural memory stimulation, grading and the method of least prompts to promote power wheelchair use. New learning was not expected in this case and the approach was found to be satisfactory under the circumstances, but further exploration is necessary. Observations of other residents in the two studies suggested that there was a capacity for some residents with mild or moderate cognitive impairment to learn the use of a modified power wheelchair given suitable conditions. Approaches to enabling or encouraging power wheelchair use can and need be trialed with residents with different cognitive abilities and limitations. Research looking at power mobility use with children with multiple and profound cognitive disabilities, and children, adults and older adults with less profound cognitive disabilities has advocated for an exploratory, development-oriented learning approach, rather than a structured and clinician-directed approach (Nilsson & Durkin, 2010). Nilsson (2010) worked on enabling power mobility use with a group consisting of 21 older adults with cognitive limitations resulting from dementia, stroke or other undiagnosed conditions. However, for the five participants with dementia, performance was inconsistent with periods of good and lost joystick steering control. Approaches to enabling power mobility use through training warrant investigation in order to determine the best strategies for older adults with dementia-related cognitive disabilities. It is possible that people with different cognitive abilities and etiologies of cognitive disabilities have the same underlying progression of learning joystick tool use (Nilsson, 2010). However, further research is necessary to determine if different strategies for enabling power wheelchair use are necessary. The role of technology in augmenting learning is also an area that requires further investigation. There is a paucity of research evidence in this
field and it is debatable whether technology truly augments or impedes the learning process (Durkin, 2002).

### 8.3.2 Intervention acceptance or non-acceptance

Whether residents ultimately accept a new intervention was found to be dependent on personal responses to using the device, the outcomes related to mobility, and the influences of the environment. It can be speculated that if the device had performed and looked better, residents would have been able to achieve a greater degree of mobility independence, been more inclined to accept use of the device, required less additional care support from caregivers, and participated in more valued activities or occupations. The extent of impact may continue to be moderated by the rigid routines and practices in long-term care home settings if these are not changed.

A seeming contradiction surfaces in findings related to social interactions. Presumably, residents who are independently mobile are able to access more people with whom to interact as they are able to move to different social locations or activities. However, one of the residents felt that self-mobility would limit the opportunities for social interactions he had while being wheeled from place to place. Given the general dearth of social opportunities already in long-term care home settings, maintaining these interactions is a priority. An improved device may induce residents to use the power wheelchair to seek more social interaction or generate new opportunities between mobility device users if the technology is more widespread. New prototypes need to be evaluated to examine the benefits to socialization, occupational engagement, participation, well-being and quality of life. However, these consequences cannot be further explored until technology better addresses the safety, usability and user acceptance concerns.

### 8.3.3 Proposed future studies

Two main studies are proposed to further the research presented in this thesis.

1. Development and performance evaluation of a modified power wheelchair for long-term care home residents with mild and moderate cognitive impairments
Development of a modified power wheelchair may continue in two directions: 1. combining a computer vision system and detachable segments of a contact sensor system to offer improved environmental coverage, and 2. investigating feedback modes and delivery characteristics to improve joystick navigation in a power wheelchair with collision-avoidance features. Ultimately, the two resulting components will be integrated to form a complete system for larger scale evaluation of mobility independence, participation and well-being.

Performance of the combined sensor systems may be evaluated in the long-term care home setting by trained actors. The actors may be people without physical or cognitive impairments, but trained to demonstrate behaviours associated with different conditions resulting in cognitive limitations. In this evaluation, driving routes may include typical activities and locations within and outside the home. Evaluation of system performance may include obstacle detection rates (hits and misses) for non-contact, contact and combined sensors and documentation of observed circumstances of performance failures. In this evaluation, it may be possible to track the frequency and locations of obstacle contacts and determine the need for specific locations of contact sensor segments and the feasibility of having detachable and customizable segments of a contact sensor system.

Investigation of the different feedback modes (auditory, visual and haptic) and delivery characteristics may be conducted with a simulated collision-avoidance power wheelchair system similar to the one used in the second study. The new testing system may incorporate the ability to separate the delivery of the feedback modes and fine tune the delivery characteristics (for example, timing of the delivery, number of repetitions) depending on the hypothesis being tested. This set up will enable testing with residents with mild or moderate cognitive impairments in the long-term care setting, and allow more direct and systematic comparison of the effectiveness and usefulness of the feedback to guide navigation. Outcome measures for these studies may include the numbers of correct and incorrect user actions following delivery of the feedback, and perceived usefulness, mental demand and satisfaction with the feedback. These studies will also help to determine the need and feasibility of a customizable user interface system for future modified power wheelchairs.

2. Exploration and evaluation of power wheelchair skills learning and training approaches for older adults with dementia-related cognitive impairments
This study may include two parts. The first part may be to explore current approaches used by clinicians to enable power mobility skills learning. Clinicians may be recruited for interviews to discuss cases they have encountered where clients with mild or moderate cognitive impairments related to dementia were offered training in power mobility use. Cases may include information on client characteristics, the types of technology used, whether there were modifications to the power wheelchair, the facilitation strategies used by the clinician, the setting, and the outcomes of the training. Cases may be analyzed using thematic analysis techniques to explore relationships between the client, therapist, technology and environment. This may inform the development of a training approach that is based on current practices. The second part of the study may be to compare three potential approaches: 1. the current practices training approach, 2. an exploratory, development-oriented learning approach described by Nilsson & Durkin (2010), and 3. an approach using a simulated collision-avoidance power wheelchair with multimodal feedback as described in the second study of this thesis. Evaluation of the approaches may involve older adult clients with mild or moderate cognitive impairments related to dementia. Outcome measures may include the number of required skills learned and performed satisfactorily, total duration of training (or clinician time), and client and clinician satisfaction with the training program. Other data to be collected may include observations of client behaviours and affect.

8.4 Implications

The work in this thesis has broad implications for the fields of rehabilitation science and engineering, users and their caregivers, clinicians, and technology developers. The complexity of the problem to be addressed necessitates a holistic approach and collaboration of various clinical, engineering, and computer science disciplines. The findings stress the importance of ongoing partnership between disciplines such that development and evaluation of technological interventions can occur in concert and findings from different aspects of the problem can serve to inform others so that novel, realistic, and contextually-relevant solutions can be found. It is thus possible that a new breed of researchers evolves who are conversant in multidisciplinary languages and problem-solving approaches and who possess a range of technical and clinical skills. These researchers will be essential for advancing technology in the industrial, commercial and clinical settings so that users may fully benefit.
This research is the first to explore the issues around enabling mobility with long-term care home residents with cognitive impairments using new power wheelchair technology. Continued progress in this line of research offers hope to residents and their families as researchers develop solutions to improve mobility independence and ultimately to enhance well-being and quality of life in the long-term care home setting. New technology will help clinicians to better serve the clients who currently have no options for mobility independence. Technology developers should be encouraged by support expressed by multiple stakeholders for continued research in this field, and also by the many avenues identified thus far in this thesis as needing further development. The research approach applied in this thesis is recommended for future research in developing and evaluating new technologies for use by residents in long-term care homes. Elements of this approach include the combination of quantitative and qualitative methods and involvement of users and others while testing prototypes or device simulations in the real environments of technology use.

8.5 Concluding remarks

This research is the first to test in the care home setting power wheelchairs modified to be used safely and independently by residents with complex physical and cognitive impairments. Furthermore, this was the first to explore the capacity of residents with cognitive impairments for functional power wheelchair mobility and their experiences with using these new devices. Findings provide insight into users with cognitive impairments living in the care home setting, their technology design needs and the environmental factors that support or limit implementation of new interventions. Further research and development is necessary before new power wheelchair technology is clinically and commercially available for users; however, results from this research could play a fundamental role in shaping technology development, the methodological approach to developing and evaluating new technology and mobility interventions for this often neglected population.
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residents with cognitive limitations. Paper presented at the Festival of International Conferences on Caregiving, Disability, Aging and Technology, Toronto, Canada.


Appendices

Appendix 1

Study 1: Structured (Time-sampled) Observation Form and Sample Observation Schedule

### Observation Form

<table>
<thead>
<tr>
<th>Wheelchair</th>
<th>M</th>
<th>manual wheelchair</th>
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<tbody>
<tr>
<td></td>
<td>AC</td>
<td>anti-collision powered wheelchair</td>
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</table>

<table>
<thead>
<tr>
<th>Location of Activity</th>
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<tbody>
<tr>
<td>* specify room number</td>
</tr>
<tr>
<td>bedroom - specify if resident’s own, or other</td>
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<tr>
<td>bathroom - specify if resident’s own, or other</td>
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<tr>
<td>shower room - indicate which one</td>
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<tr>
<td>dining room - indicate if it is resident’s regular dining room</td>
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<tr>
<td>hallway - indicate by closest resident room</td>
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<tr>
<td>activity room - off unit, indicate where</td>
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Data to be documented for 30 seconds within every 5 minute period.

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<th>Mobility Characteristics</th>
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<td>FP</td>
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<tr>
<td>HPF</td>
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If attendant is pushing resident and resident is propelling at the same time, indicate both (e.g. A and FP)

<table>
<thead>
<tr>
<th>Activities</th>
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<tbody>
<tr>
<td>1. status of wheelchair, e.g. if brakes on, or power on/off for powered wheelchair</td>
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<tr>
<td>2. position or posture in wheelchair, document only for changes in original observation</td>
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<tr>
<td>3. orientation of wheelchair, e.g. parked sideways at table; and opportunities for mobility, e.g. blocked by another resident or furniture</td>
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<tr>
<td>4. activity itself, e.g. continuously or discontinuous propelling, rocking back and forth, talking (to whom), eating at table, getting on elevator, changing TV channels, verbalising, eyes closed (not necessarily sleeping)</td>
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<tr>
<td>5. interactions with others, with whom, by whom</td>
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<table>
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<tr>
<th>Collisions</th>
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<tr>
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Note: form has been modified from legal size format to fit letter size paper.
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<th>Location</th>
<th>Mobility Characteristics</th>
<th>Activity</th>
<th>Collisions</th>
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<td></td>
<td>M or A/C</td>
<td>descriptive</td>
<td>S/M I/A H/P/HF</td>
<td>descriptive</td>
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Note: Form for 1 observation block
## Anti-collision Observation Schedule

**Study Participants:** R4, R5

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**Notes:**
- for each study participant, 5 x 2-hr observation blocks were randomly selected each week, between the times of 8am to 6pm or 8:30am to 4:30pm
- 2-hr blocks were randomly selected using Microsoft Excel 2003 RandBetween Function (1,25)
Appendix 2

Study 1: Training Log

**ANTICOLLISION: TRAINING LOG**

*Notes:*
- One document for each resident (study participant), for each day of training
- Training will consist of a minimum of 12 Training Days (sessions)

<table>
<thead>
<tr>
<th>Study Participant:</th>
<th>Date of Training:</th>
<th>Training Day Number:</th>
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<tbody>
<tr>
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<td>Data file number:</td>
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<table>
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<tr>
<th>Location of Training: (unit, including area of training)</th>
<th>Time</th>
<th>Individuals Present: (include study participant, trainer, others present during most of session)</th>
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**Transfer** (describe transfer, assistance required, number of people, specific equipment needed, by whom)

**Seating** (describe seating equipment in place, sitting position/comfort, alterations required)

**Skills Instructed/Practiced**
- □ operation of on/off, controls, indicator lights, other safety features
- □ forward driving, turning R/L, 180 degrees, backward driving
- □ maneuvering and driving in busy areas
- □ parking beside bed, table or wall, under table
- □ backing in or out of small space
- □ driving through narrow doors
- □ elevators on/off, pressing button, asking for help
- □ negotiating out of collision

**Skills Needing More Practice**
- □ operation of on/off, controls, indicator lights, other safety features
- □ forward driving, turning R/L, 180 degrees, backward driving
- □ maneuvering and driving in busy areas
- □ parking beside bed, table or wall, under table
- □ backing in or out of small space
- □ driving through narrow doors
- □ elevators on/off, pressing button, asking for help
- □ negotiating out of collision
### Strategies used by Trainer
- repetition of information, strategy or technique
- gestures
- demonstration
- hand over hand guidance
- 1 step instructions, breakdown steps, short brief instructions or descriptions, small chunks of information
- errorless learning, immediate correction and reinsertion
- encouragement/positive feedback
- immediate feedback
- summarising feedback
- free practice
- step by step working through problem
- allow to problem solve on own
- backwards chaining
- forwards chaining
- spaced retrieval
- vanishing cues

### Driving Performance and Behaviour
(descriptions of driving performance, context, skills achieved, specific observations)

### Resident’s Affective State
(comments about resident’s expressions of emotions and behaviours prior to, during or after training session)

### Verbatim Comments
(include comments by resident, trainer, staff, other residents and other people passing by)

### Anticollision Powered Wheelchair Considerations
(comments regarding modifications to chair required, observations about performance of chair)

### Other Observations and Events
(observations not covered anywhere else)
Appendix 3

Study 2: Training Log

<table>
<thead>
<tr>
<th>Subject: (ID Number)</th>
<th>Driving session: (Number)</th>
<th>Date:</th>
<th>Observer: Video recorder:</th>
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<tr>
<td>(1) List names of video files</td>
<td>Document includes:</td>
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<td>Total session: Total video:</td>
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<td></td>
<td>• Observation notes from videos</td>
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<td></td>
<td>• Transcriptions of verbal comments</td>
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Notes/comments:
- Who reviewed videos, notes, transcriptions
- Other comments about session (e.g., subject's general concerns, other activities that influence session)
- Seating (e.g., equipment in place, sitting position/comfort, equipment modifications required)

**Video 1**

<table>
<thead>
<tr>
<th>Time</th>
<th>Description of activities</th>
<th>Skills instructed/practiced</th>
<th>Locations of driving</th>
<th>Driving performance and behaviour</th>
<th>Verbatim comments made by subject, observers (investigators), or others</th>
<th>Analysis Notes</th>
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Appendix 4

Study 1: Staff Focus Group Sessions

Focus groups were conducted before and after the full study was completed.

Staff members invited:
- Patient Care Managers
- Nursing Managers
- Nurses
- Resident Care Associates
- Occupational Therapists and Assistants
- Physical Therapists and Assistants
- Social Workers
- Recreation Therapists and Assistants
- Music Therapists
- Chaplain

Before

Topics to review and discuss:
- Anti-collision power wheelchair project and study process
- Targeted population for current anti-collision power wheelchair / criteria for selection of residents for single subject studies

(Anti-collision power wheelchair was available for participants to see, test and comment on.)

Questions to discuss:
- What are some common resident mobility problems you encounter?
- Given the description of the study, what may be some potential staff concerns?
- What are some suggestions to ensure that the study will minimally impact the operation or routine of the long-term care unit?

After

Topics to review and discuss:
- Brief overview of study completed

(Pictures of anti-collision power wheelchair were available to remind participants about details of the device.)
Questions to discuss:

- Describe your thoughts on the prototype anti-collision powered wheelchair.
  - appearance
  - how it worked for residents
  - observations from residents driving it, family members, other staff members
  - benefits, drawbacks
  - environmental fit
  - safety of user and others

Describe your thoughts on a modified powered wheelchair to improve resident mobility

- for residents with cognitive limitations
- for residents with other impairments

Do you have any comments on the study itself?

- how it was run
- process
- duration
- resident concerns
Appendix 5

Study 1: Sample Interview Guides – Staff and Other Residents

Staff Individual Interviews: Semi-structured Interview Topics and Questions

Re: Anti-collision powered wheelchair, specific residents in single subject studies, perceived safety, and workload

Individual interviews were conducted at the start and at the end each single subject study.

Possible staff members to be invited:

- Nurses
- Resident Care Associates
- Occupational Therapists and Assistants
- Physical Therapists and Assistants
- Recreation Therapists and Assistants
- Music Therapists
- Chaplain

Start

Topics to review:

- Anti-collision power wheelchair project and study process
- Targeted population for current anti-collision power wheelchair / criteria for selection of residents for single subject studies

Questions to discuss:

- Describe your thoughts related to the level of assistance you provide residents in getting around the unit.
  - Are there concerns related to the level of assistance you provide?
  - What are these issues?

- What are the experiences you have had with the powered wheelchair mobility of long-term care residents?
  - Describe your thoughts related to safety.

- What interventions do you think will help residents to become
  - more independent and
  - safer
  in getting around the unit?
• Can you describe _____’s current activities? What does he/she normally do during a typical day?

• Can you describe _____’s mobility right now? How does he/she get around?

• Describe the assistance that you provide _____ in moving around to places
  • Do you have concerns or issues related to the assistance that you provide?
  • How important is this issue to you, on a scale of 1 to 10 (10 being extremely important)?
  • How would you rate how you are able to do this, on a scale of 1 to 10 (10 being extremely well)?
  • How satisfied are you about this concern, on a scale of 1 to 10 (10 being extremely satisfied)?

• Do you think there are places _____ would like to go?

• What might mobility goals for _____ be?

• Do you have any mobility goals for him? What would you like to see him do?
  • How important do you think this is for him, on a scale of 1 to 10 (10 being extremely important)?
  • How would you rate how he is able to do this, on a scale of 1 to 10 (10 being extremely well)?
  • How satisfied are you with how he does this, on a scale of 1 to 10 (10 being extremely satisfied)?

End

Topics to review:
• Anti-collision power wheelchair project and study process

Questions to discuss:
• What are your thoughts about the anti-collision powered wheelchair that ___ tested?
• What do you think about the anti-collision powered wheelchair for ___?
• Do you think using the anti-collision powered wheelchair has made a difference for him/her in any way? Describe.
• As a _______ do you think use of the anti-collision powered wheelchair by ____ will impact you in any way? Describe.
• Do you have any comments or suggestions to improve the anti-collision powered wheelchair?
• Do you have any comments or suggestions to improve the mobility of long term care residents?
• Do you have any general comments about the study itself or how it is being conducted?
Other Resident Feedback Interviews: Semi-structured Interview Topics and Questions

Re: Anti-collision powered wheelchair and perceived safety

Interviews with other residents were completed at the end of each single subject study.

Questions to discuss:

- Some residents have participated in a study to see if a new anti-collision powered wheelchair will help them to move around more independently and safely. (Describe as necessary)
  - How do you feel about this type of wheelchair?
  - Does the presence of the anti-collision power wheelchair impact your day to day activities? (i.e. for residents who share a room) If so, how?
  - Are there any problems you might foresee with having this type of chair around?

- What are the experiences you have had with other residents driving powered wheelchairs?
  - Describe your thoughts related to safety.

- What changes do you think will help residents to become
  - more independent and
  - safer
in getting around the unit?
Appendix 6

Study 2: Sample Interview Guide for Residents on Effectiveness and User Satisfaction

After the completion of the driving sessions, residents were interviewed regarding their perceptions on the usability of the powered wheelchair user interface.

1. What are your thoughts on the appearance of the modified joystick?
2. What are your thoughts on how the modified joystick works?
3. When you first started using the powered wheelchair, were you able to understand how it works?
   a. What helped your understanding?
   b. What did not help your understanding?
4. What are your thoughts on the prompts provided to you?
   a. Did they help you to move away from obstacles?
5. What are your thoughts on the usefulness of the device?
6. What might you suggest to improve the device?
Appendix 7

Study 1 and 2: Power-mobility Indoor Driving Assessment (PIDA)

The Power-Mobility Indoor Driving Assessment (PIDA) was developed to be a valid and reliable instrument to assess the power wheelchair or scooter mobility of long term care residents (Dawson, Chan, & Kaiserman, 1994; Dawson, Kaiserman-Goldenstein, Chan, & Gleason, 2006). The PIDA was also intended to evaluate change over time after a mobility intervention. Items to be performed and assessed relate to mobility around the bedroom, bathroom, doors, elevators, parking, and ramps, and skilled driving. Only items relevant to the resident’s environment or daily requirements are scored. Items are scored on a performance scale of one to four, one being unable to complete task and four being completely independent. A total percentage score is calculated by summing all the scored items and dividing by four times the number of items scored. Content validity was ensured from rigorous review of the literature and other assessments, and critique of the assessment by occupational therapists across Canada. Reliability studies have found intra-class correlation coefficients for test-retest reliability to be 0.67 (p<0.001) and inter-rater reliability to be 0.87 (p<0.001) (Dawson, et al, 1994). The PIDA is used clinically and has been described in a study that looked at two driving training protocols for older adults living in institutions (Hall, Partnoy, Tenenbaum, & Dawson, 2005).

Instructions for the PIDA and the score sheets are available in full from:
http://fhs.mcmaster.ca/powermobility/pida.htm

References


Appendix 8

Study 2: NASA – Task Load Index (TLX)

The NASA-TLX is a widely used measure of workload that evaluates workload in six subscales - mental demand, physical demand, temporal demand, performance, effort and frustration (Hart & Staveland, 1988). Ratings for the subscales are selected from 1 to 20, and converted to a rating out of 100. Weights are assigned by the subject based on 15 pair-wise comparisons of the relevance of the task on workload subscales, and an overall workload score from 0 to 100 is calculated based on the subjective weights given. The NASA-TLX has been shown to be sensitive to different tasks (Hart & Staveland, 1988). Convergent validity was shown to be very high (Pearson Correlation Coefficients >0.97, p<0.001) when the NASA-TLX was compared with other global mental workload measures including the Subjective Workload Assessment Technique (SWAT) and the Workload Profile (WP) (Rubio, Diaz, & Martin, 2004). Also in this study, concurrent validity was best with the NASA-TLX when comparing subjective ratings with task performance. The NASA-TLX has been used in many studies looking at the perceived workload of automobile drivers, including older adult drivers, under various driving conditions (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Matthews, Legg, & Charlton, 2003; Sullivan, Bargman, Adachi, & Schoettle, 2007).

The NASA-TLX is available from:

E-Mail: joe.mcdaniel@wpafb.af.mil
Human Systems IAC Program Office
ATTN: Product Sales Manager
AFRL/HEC/HSIAC Bldg 29, 2245 Monahan Way
Wright-Patterson AFB, OH 45433 7008
Commercial Telephone: 937-255-4842 x219
DSN: 785-4842 x219, Fax: 937-255-4823

References


Appendix 9

Study 2: Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0)

The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0) assesses user satisfaction with an assistive device. The QUEST was designed to be an outcome measure and assesses user satisfaction with devices and services using 12 items on a five-point scale (Demers, Weiss-Lambrou, & Ska, 2002). The overall QUEST score is calculated by averaging the results for all items. Details of the psychometric properties are found in the QUEST manual (Demers, Weiss-Lambrou, & Ska, 2000). Reliability evaluation was based on a sample of 139 mobility device users. Test-retest stability for items making up the QUEST, calculated as weighted kappas were found to be at moderate to substantial levels of agreement. Inter-rater reproducibility, also determined using weighted kappas, ranged from fair to substantial agreement. Internal consistency, calculated using the Cronbach alpha coefficient was found to be very good. Content validity was based on evaluation by 12 international experts who evaluated the importance and relevance of items making up the QUEST. Construct validity was determined by factor analysis of data collected from 150 mobility device users. Analysis of the factors produced two subscales: device factors (8 items) and service factors (4 items). The Danish version of the QUEST has been used in a study looking at power wheelchair use by older adults (Brandt & Iwarrson, 2001). The QUEST has also been used in a study looking at seating and positioning device interventions in older adults in nursing homes and community based users of mobility devices (Brandt & Iwarsson, 2001; Samuelsson & Wressle, 2007; Trefler, Fitzgerald, Dobson, Bursick, & Joseph, 2004).

The QUEST 2.0 is available from:

http://matchingpersonandtechnology.com/
Marcia J. Scherer, Ph.D., Director
The Institute for Matching Person & Technology
486 Lake Road
Webster, New York 14580
585/671-3461 (phone/fax)
IMPT97@aol.com (email)
References


Appendix 10

Study 2: Psychosocial Impact of Assistive Devices Scale (PIADS)

The Psychosocial Impact of Assistive Devices Scale (PIADS) evaluates the psychosocial effects of an assistive device on the user. The PIADS is a questionnaire consisting of 26 items that measure impact in three subscales: competence, adaptability and self-esteem (Day & Jutai, 2003). The scale is comprised of items that are elemental to an individual’s quality of life. The user rates the items on a seven point scale, ranging from -3 (maximum negative impact) to 3 (maximum positive impact). The PIADS was designed to be used either before the device is provided to assess the user’s expected impact of the device or after the device is provided (Day & Jutai, 2003). The scale can be administered repeatedly to monitor the impact over time. The psychometric properties of the PIADS (internal consistency, test-retest reliability, stability, sensitivity, and responsiveness) are documented to be good overall. There is also good agreement in scores between device users and their caregivers (Jutai, Woolrich, Campbell, Gryfe, & Day, 2000). The PIADS has been validated with clients of varying diagnoses including stroke (Jutai, Bayley, Teasell, & Hartley, 2003) and multiple sclerosis (Devitt, Chau, & Jutai, 2003). The instrument has been used with older adult wheelchair users (Devitt, et al., 2003) and power wheelchair users (Buning, Angelo, & Schmeler, 2001).

The PIADS is available from: http://www.piads.ca/email_form.htm

References


Appendix 11

Study 1: Consent and Information Forms for Resident Users, Staff and Other Residents

Enabling Independent Powered Wheelchair Mobility in Long Term Care Residents with Cognitive and Other Impairments that Currently Limit Powered Mobility Use

Powered Wheelchair Testing
Patient and Substitute Decision Maker
Consent and Information Form

You are being asked to participate in this study to test a new powered wheelchair that has been modified for safe use by long term care residents who are not able to safely drive currently-available powered wheelchairs.

Sponsor:
This research study is funded by the Canadian Institutes of Health Research (CIHR) and has been reviewed by the Research Ethics Board at Sunnybrook. You may contact Sunnybrook’s office of Research Administration if you have any questions about your rights as a research subject. Research office phone: 416-480-4276.

Investigators:
You may contact Dr. Fernie, Pam Holliday or Rosalie Wang about any questions or concerns you have regarding this study.

Dr. Geoff Fernie (Principal Investigator):
Associate Scientist, Sunnybrook Health Sciences Centre, and VP Research, Toronto Rehabilitation Institute
Phone: 416-597-3422 ext 3738 E-mail fernie.geoff@torontorehab.on.ca

Pam Holliday (Project Coordinator):
Research Associate, Centre for Studies in Aging (responsible for coordinating and conducting the testing)
Phone: 416-480-5858 Fax: 416-480-5856
E-mail holliday.pam@torontorehab.on.ca

Rosalie Wang (Doctoral Student):
Centre for Studies in Aging (responsible for coordinating and conducting the testing)
Phone: 416-480-5858 Fax: 416-480-5856
E-mail rosalie.wang@utoronto.ca
Purpose:
The Centre for Studies in Aging at Sunnybrook is conducting a study to see if a powered wheelchair can be modified so that long term care residents, who would not usually be allowed to drive a powered wheelchair, can become independent and safe drivers.

Being able to move about independently is important to quality of life. Most residents (or patients) in long term care settings use a manual wheelchair to help with their mobility, but many are not strong enough to propel their own manual wheelchairs effectively. Use of a powered wheelchair may assist some of the people who have difficulty using manual wheelchairs. However, the use of powered wheelchairs is often restricted for reasons of safety, especially for many of the residents who have cognitive impairment such as with Alzheimer’s disease.

The powered wheelchair that will be used in this study has been designed at Sunnybrook by the Centre for Studies in Aging. The Rocket is commercially available (but not in production at the present time). The Rocket wheelchair will be modified by adding a collision avoidance system that will stop the chair when it gently comes into contact with an object and will only allow movement of the chair away from the object. It will also be fitted with a device that will measure the distance that you travel and the number of bumps or collisions that you have. The Rocket may also be fitted with other features that make driving easier, such as a new steering device to help the driver. It will also be possible to restrict the maximum speed to a low value.

PROCEDURES:
Your participation in this research study may continue for up to four (4) months in duration.

In the first part of the study you will be observed using your current manual wheelchair. Your current manual wheelchair will be fitted with a device that automatically measures the distance your chair is moved. The measuring device is removable and will not damage your current wheelchair. After the researchers have observed you in your current wheelchair, you will then be seated in the modified Rocket powered wheelchair by the researcher in consultation with the Occupational Therapy Seating Consultant. The researcher will train you in the use of the powered wheelchair and the powered wheelchair movement will also be automatically recorded. You will keep your usual method of mobility and will only use the modified powered wheelchair on your own when the researcher and your caregivers are comfortable with your use of the powered wheelchair.

You will be asked to move your manual wheelchair or the powered wheelchair
around a special course to measure your ability and safe driving skills. You will be asked questions about your abilities and activities. The questions have been taken from standardized questionnaires used by many researchers, and will ask about:
- your driving history, age, medications, relevant medical problems;
- your memory;
- your ability to do everyday tasks such as washing, dressing, using the toilet;
- any concerns you have about your ability to do things for yourself;
- your health and how it affects your activities;
- your participation in activities;
- how the use of your wheelchair affects your feelings about yourself; and,
- how satisfied you are about your life and your control over it.

The questions will be asked over the course of a week, and you will not spend any more than one hour at a single session. In total the questions will take about 2 and one-half to 3 hours.

The researcher will make observations of you in your wheelchair on specific days during the duration of the study. The modified powered wheelchair will have a special device to measure collisions. A device attached to the wheel will measure distance, and this wheel counter will be read each day by the researcher.

**BENEFITS:**
During the trial with the modified powered wheelchair, your independent mobility may improve.

If at the end of the study you have been able to achieve independent use of the powered wheelchair with a practical level of supervision and maintenance, you will be able to continue to use the powered wheelchair on loan. The clinical and research staff, along with you will make this decision. Any future change in your ability will necessitate review of the use of the powered wheelchair.

This study, if successful, may produce findings that may benefit you and others who are currently excluded from driving a powered wheelchair. The modifications added to the powered wheelchair system will be made available for manufacture and distribution. Thus, some independent mobility may be available to significant numbers of residents in long term care facilities who presently are totally dependent on others for mobility.

**DISCOMFORTS and POTENTIAL HARMs:**
You and your caregivers will be given training to learn how to operate the wheelchair. You will receive one-hour training sessions for at least two weeks or until you and your caregivers are satisfied that you are able to independently
operate the wheelchair.

The wheelchair has special modifications to reduce your chances of hurting yourself, other people or the environment should you accidentally bump into them. The chair will automatically stop if you touch an object or a person. The contact made by the wheelchair is barely noticeable. The maximum speed of the chair will be adjusted so that the chair will move very slowly. The wheelchair may also have a new steering device.

You will keep your own manual wheelchair.

ALTERNATIVES TO PARTICIPATION:
If you do not take part in this study you will continue to use your current wheelchair for mobility.

CONFIDENTIALITY:
The information collected about you will remain strictly confidential and will not affect your care or treatment. Your name will not be associated with any of the information. All data will be securely stored at the Centre for Studies in Aging at Sunnybrook.

COMPENSATION:
There is no remuneration or product purchase advantage for participating in this study.

LEGAL RIGHTS AS A PARTICIPANT:
You are free to ask questions about this study at any time.

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled.

You waive no legal rights by participating in this study.
CONSENT

I have read the entire consent form and my questions about the study have been answered by the researcher. I agree to participate in this study:

________________________________________  __________________________________________  
print name of participant                     signature of participant                     date

________________________________________  __________________________________________  
print name of witness                        signature of witness                        date

OR

________________________________________  
print name of resident

________________________________________  __________________________________________  
Print Name of Substitute Decision Maker       Signature of Substitute Decision Maker       date

Substitute Decision Maker Relationship to Patient
Enabling Independent Powered Wheelchair Mobility in Long Term Care Residents with Cognitive and Other Impairments that Currently Limit Powered Mobility Use

Invitation (Staff) to Participate in a Research Study

Dear Colleagues:

You are being asked to participate in a pilot cross-sectional study to see if a powered wheelchair can be modified for safe independent use by long term care residents who have no other alternative means of independent mobility. It is anticipated that this enhanced use of powered wheelchairs will impact the caregivers.

Principal Investigator: Dr. Geoff Fernie
Phone 416-597-3422 ext 3738
E-mail fernie.geoff@torontorehab.on.ca

Coordinator and Clinical Researcher: Pam Holliday
Phone 416-480-5858
Fax 416-480-5856
E-mail holliday.pam@torontorehab.on.ca

Graduate Student and Clinical Researcher: Rosalie Wang
Phone 416-480-5858
Fax 416-480-5856
E-mail rosalie.wang@utoronto.ca

Funding Agency: Canadian Institutes of Health Research (CIHR)

Objective of the Project:
To increase the quality of life of long term care residents and their caregivers by enabling independent mobility for residents who have previously been excluded from driving powered wheelchairs for reasons of safety, and who have no alternative means of independent mobility. This study proposes to train long term care residents with complex physical and cognitive impairments to use a powered wheelchair that is modified with new safety features.
Brief Overview of the Research Study:
The clinical trials will be conducted in long term care at Sunnybrook. Long term care residents will be excluded if they have a history of aggression or are currently successful powered wheelchair or scooter users. The residents will be selected through consultation with caregivers and health professionals involved in their care. Each resident will be trained to use the modified powered wheelchair. The duration of the study for each subject will be a maximum of 4 months.
Standardized methods will be used to measure quality of life and functional status. Self-initiated wheelchair movement will be measured by observation, distance loggers and switches on the seat of the wheelchairs (and the handles of the manual wheelchair). Collisions will also be recorded by sensors in the bumpers.

All staff will receive training on the operation of the modified powered wheelchair. The powered wheelchair is modified so that it moves very slowly and stops moving if the chair comes into contact with an object. The force of contact, about 100 grams or 3-4 ounces, is “barely noticeable”. The wheelchair is fitted with other safety features such as an emergency stop switch and if any component of the system fails the chair will automatically stop. The wheelchair may also have a new type of steering device to replace the usual joystick control.

Staff (Your) Participation:
We will be asking for volunteers to participate in focus groups and/or interviews that will be conducted at the beginning and end of the study (about 12 months apart). At the start of the project, participants will be asked to document concerns, establish priorities to maintain smooth operation of the nursing unit during implementation of the research study and identify specific resident mobility problems. At the end of the study, participants will evaluate incidents, establish the relative safety and risk of the expanded use of powered mobility and re-visit resident mobility problems. Group sessions will be audio taped. Your name will not be associated with any of the information.

You are also being asked to participate in this study by completing individual interviews at the beginning and the end of the clinical testing for residents (about 4 months apart). During these interviews you will be asked questions about the wheelchair mobility of residents, wheelchair use by residents, and your work. Completion of the interviews takes up to 30 minutes, and you will be able to do this during your regular working time. Interviews will be audio taped. Your participation is voluntary and completely confidential.

Risk and Benefit:
There are no risks for participation in the focus groups and/or interviews.
Increased use of powered wheelchairs on the nursing units may cause congestion and may affect your ability to get around the nursing unit. All staff will be shown how to operate the modified wheelchair. The risks for collisions are minimized by the collision avoidance devices on the chair and the very slow speed in which it moves.

The outcomes of this study, if successful, may benefit significant numbers of elderly residents in long term care facilities who presently are totally dependent on others for mobility. If successful, the modified powered wheelchair system will be made available for manufacture and distribution.

**Confidentiality and Privacy:**
The information collected about you will remain strictly confidential and will not affect your employment or future care at Sunnybrook. Your name will not be associated with any of the information about you, for either your participation in a focus group and/or interviews. All data will be securely stored at the Centre for Studies in Aging at Sunnybrook.

**Compensation:**
There is no remuneration for participating but you will be given time during your regular working hours to participate in the groups and/or interviews.

We hope that you will participate in this important research project. Please feel free to contact Rosalie Wang, Pam Holliday or Geoff Fernie to discuss any concerns or questions you may have.

Please contact Rosalie Wang or Pam Holliday if you are interested in participating in one of the group and/or interview sessions.
Enabling Independent Powered Wheelchair Mobility in Long Term Care Residents with Cognitive and Other Impairments that Currently Limit Powered Mobility Use

Staff Consent and Information Form for Focus Groups, Interviews and Audio Tape Recording

You have been asked to participate in a group session and/or interview to discuss the expanded use of powered wheelchair mobility for residents in long term care who have complex physical and cognitive impairments.

Most residents (or patients) in long term care settings use a manual wheelchair to help with their mobility, but many are not strong enough to propel their own manual wheelchair effectively. Use of a powered wheelchair may assist some of the people who have difficulty using manual wheelchairs. However, the use of powered wheelchairs is often restricted for reasons of safety, especially for many of the residents who have cognitive impairment such as with Alzheimer’s disease.

The Centre for Studies in Aging at Sunnybrook is conducting a study to see if a powered wheelchair can be modified so that long term care residents, who would not usually be allowed to drive a powered wheelchair, can become independent and safe drivers. This study will examine whether residents with complex physical and cognitive impairments are able to safely and independently use the modified powered wheelchair. We will measure the amount of self-initiated wheelchair movement with the residents ‘usual’ manual wheelchair and with the modified powered wheelchair. The impact of using the powered wheelchair on the wheelchair users and their caregivers (the nurses) will also be examined using standardised measures and interviews. The residents will retain their current mobility device. The duration of the study for each resident will be a maximum of four months and the clinical trials will continue over about 12 months.

Dr. Geoff Ferrie, Associate Scientist, Sunnybrook, is the Principal Investigator of the study. Pam Holliday, Research Associate, and Rosalie Wang, Graduate Student, at the Centre for Studies in Aging, are coordinating and conducting all of the testing in this study. You may contact
either Dr. Fernie, Pam Holliday or Rosalie Wang about any questions or concerns you have regarding this study:

- Dr. Geoff Fernie  (Principal Investigator)  
  (Office at Toronto Rehabilitation Institute)  
  Phone: 416-597-3422 ext 3738  
  E-mail fernie.geoff@torontorehab.on.ca

- Pam Holliday  (Project Coordinator)  
  Phone: 416-480-5858  Fax: 416-480-5856  
  E-mail holliday.pam@torontorehab.on.ca

Rosalie Wang  (Graduate Student)  
Phone: 416-480-5858  Fax: 416-480-5856  
E-mail rosalie.wang@utoronto.ca

This research study is funded by the Canadian Institutes of Health Research (CIHR), and has been reviewed by the Research Ethics Board at Sunnybrook.

Purpose:  
You have been asked to participate in an interview or group session to identify resident mobility problems and / or to discuss your concerns and suggestions for the smooth operation of the nursing unit (pre-trial focus groups) during implementation of a study to enhance the use of powered wheelchairs by residents in long term care. Interviews or groups will also be convened to discuss adverse incidents and risk created by the use of the modified powered wheelchair by residents with complex physical and cognitive impairments. You are also being asked to participate in this study by completing individual interviews at the beginning and the end of the clinical testing of residents.

Risk / Benefit:  
By providing your feedback at the beginning and end of this study, the researchers will be able to better understand the implementation and impact of enhanced powered mobility on the staff, residents and nursing unit environment in long term care.

Procedures:  
The focus groups and interviews will be conducted and facilitated by Pam Holliday or others she may designate. Other research team members may be present to assist. You have been asked to participate in one to four sessions that will last about one hour. You will be asked to complete a brief questionnaire which asks about your age range, education and clinical experience. You will also be asked to
identify resident mobility problems. You may also be asked questions about the wheelchair use by residents and your work.

You understand that the group or individual sessions will be audio taped so that the researchers have an accurate record of the discussion. The audio tapes will be safely stored in a locked room in the Centre for Studies in Aging.

Confidentiality:
The information collected about you will remain strictly confidential and will not affect your employment status or future care at Sunnybrook. Your name will not be associated with any of the information. All data will be securely stored at the Centre for Studies in Aging at Sunnybrook.

Compensation:
There is no remuneration for participating in this study but staff will be given time from regular duties to attend the focus group and / or interview sessions.
CONSENT

I understand that I am free to ask questions about the study at any time. I understand that I am free to refuse to answer any questions during the discussions. I understand that my participation is voluntary and that I am free to withdraw or discontinue participation at any time and it will not affect my current or future status or care at Sunnybrook Health Sciences Centre.

I have read the entire consent form and my questions about the study have been answered by the researcher. I consent to participate in this study:

________________________________________________________________________
Print Name of Participant Signature of Participant date

________________________________________________________________________
Print Name of Witness Signature of Witness date
Enabling Independent Powered Wheelchair Mobility in Long Term Care Residents with Cognitive and Other Impairments that Currently Limit Powered Mobility Use

Resident Feedback Interviews
Patient and Substitute Decision Maker
Consent and Information Form

You are being asked to participate in this study to provide feedback on the use of a new powered wheelchair that has been modified for safe use by long term care residents who are not able to safely drive currently-available powered wheelchairs.

Sponsor:
This research study is funded by the Canadian Institutes of Health Research (CIHR) and has been reviewed by the Research Ethics Board at Sunnybrook. You may contact Sunnybrook’s office of Research Administration if you have any questions about your rights as a research subject. Research office phone: 416-480-4276.

Investigators:
You may contact either Dr. Fernie, Pam Holliday or Rosalie Wang about any questions or concerns you have regarding this study.

Dr. Geoff Fernie (Principal Investigator):
Associate Scientist, Sunnybrook Health Sciences Centre, and VP Research, Toronto Rehabilitation Institute
Phone: 416-597-3422 ext 3738  E-mail fernie.geoff@torontorehab.on.ca

Pam Holliday (Project Coordinator):
Research Associate, Centre for Studies in Aging (responsible for coordinating and conducting all of the testing).
Phone: 416-480-5858  Fax 416-480-5856
E-mail holliday.pam@torontorehab.on.ca

Rosalie Wang (Graduate Student):
Centre for Studies in Aging (responsible for coordinating and conducting the testing).
Phone 416-480-5858  Fax 416-480-5856
E-mail rosalie.wang@utoronto.ca
Purpose:
The Centre for Studies in Aging at Sunnybrook is conducting a study to see if a powered wheelchair can be modified so that long term care residents, who would not usually be allowed to drive a powered wheelchair, can become independent and safe drivers.

Being able to move about independently is important to quality of life. Most residents (or patients) in long term settings use a manual wheelchair to help with their mobility, but many are not strong enough to propel their own manual wheelchairs effectively. Use of a powered wheelchair may assist some of the people who have difficulty using manual wheelchairs. However, the use of powered wheelchairs is often restricted for reasons of safety, especially for many of the residents who have cognitive impairment such as with Alzheimer’s disease.

The powered wheelchair that will be used in this study has been designed at Sunnybrook by the Centre for Studies in Aging. The Rocket is commercially available (but not in production at the present time). The Rocket wheelchair will be modified by adding a collision avoidance system that will stop the chair when it gently comes into contact with an object and will only allow movement of the chair away from the object.

Resident (Your) Participation:
You are being asked to participate in this study by completing an interview. During the interview, you will be asked questions about your views on powered wheelchair use in long term care facilities and about use of a powered wheelchair that has been modified to be safe. The interview will take up to 30 minutes. Your participation is voluntary and completely confidential. Interviews will be audio tape recorded.

BENEFITS:
This study, if successful, may produce findings that may benefit others who are currently excluded from driving a powered wheelchair. The modifications added to the powered wheelchair system will be made available for manufacture and distribution. Thus, some independent mobility may be available to significant numbers of residents in long term care facilities who presently are totally dependent on others for mobility.

DISCOMFORTS and POTENTIAL HARMs:
There are no risks for participation in the interviews. By providing your feedback the researchers will be able to better understand the implementation and impact of enhanced powered mobility on the staff, residents and nursing unit environment in long term care.
CONFIDENTIALITY:
The information collected about you will remain strictly confidential and will not affect your care or treatment. Your name will not be associated with any of the information. All data will be securely stored at Centre for Studies in Aging at Sunnybrook.

COMPENSATION:
There is no remuneration or product purchase advantage for participating in this study.

LEGAL RIGHTS AS A PARTICIPANT:
You are free to ask questions about this study at any time.

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled.

You waive no legal rights by participating in this study.
CONSENT

I have read the entire consent form and my questions about the study have been answered by the researcher. I agree to participate in this study:

<table>
<thead>
<tr>
<th>print name of participant</th>
<th>signature of participant</th>
<th>date</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>print name of witness</th>
<th>signature of witness</th>
<th>date</th>
</tr>
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</table>

OR

print name of resident

<table>
<thead>
<tr>
<th>Print Name of Substitute Decision Maker</th>
<th>Signature of Substitute Decision Maker</th>
<th>date</th>
</tr>
</thead>
</table>

Substitute Decision Maker Relationship to Patient
Appendix 12

Study 2: Consent and Information Forms for Resident Users

Study Participant and Substitute Decision Maker
Consent and Information Form

Study Title: Usability Testing of a User Interface for an Anti-collision Powered Wheelchair for Long Term Care Residents with Cognitive Impairment

You are being invited to participate in this study to test a new powered wheelchair control device (joystick). The device has been modified to help drivers to move away from obstacles. This control device may be used in future collision avoidance powered wheelchairs to help long term care residents to use powered wheelchairs safely.

Principal Investigator:
Dr. Geoff Fernie, Ph.D., P.Eng
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ferniede@torontorehab.on.ca

Study Coordinator (Researcher):
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wang_rosalie@torontorehab.on.ca

Sponsor / Funding

Funded in part by a grant from the Canadian Institutes for Health Research (CIHR) and Toronto Rehabilitation Institute; Nomad Powered Wheelchair donated in kind by Dynamis Mobility.

Background and Purpose

The iDAPT Technology Research and Development Team at Toronto Rehabilitation Institute (Technology Team) is working on a project to modify a powered wheelchair to allow long term care residents who are usually not allowed to drive a powered wheelchair to drive safely.

Being able to move about independently is important to quality of life. Most residents in long term care settings use a manual wheelchair to move around. However, many residents are not strong enough to move...
their own manual wheelchairs. Use of a powered wheelchair may help some of the people who have difficulty moving manual wheelchairs. However, use of powered wheelchairs is often restricted for reasons of safety, especially for many people who have memory problems such as Alzheimer’s disease, stroke, brain injury or other conditions.

We are looking mostly at the powered wheelchair control device (joystick) to see if we can modify it so that it will help drivers to easily move away from obstacles when they are detected by the powered wheelchair. This project is part of a larger study to modify a powered wheelchair so that it may be driven safely.

Eligibility

To take part in this study, you must:

- be able to read and understand English
- have mild or moderate memory problems (according to a commonly used screening test)
- be able to sit up in a wheelchair for up to two hours
- sign the consent form, or if you have a substitute decision maker, he or she must sign the consent form and you must sign the assent form.

You cannot take part if you have a history of aggressive behaviour leading to a risk of harm to others.

Time Commitment

Your part in this research study may occur over a 6 week period. In the first part of the study, you will be asked questions by the researcher. The questions will be asked over the course 1 week. You will not spend any more than 1 hour 30 minutes at a single session. In total the questions will take about 2 hours 30 minutes. You will then have up to 6, 1-hour driving sessions. More time may be required before and after each driving session (up to 30 minutes) for preparation and moving to and from the powered wheelchair. After all the driving sessions are complete, you will be asked other questions. This session may last up to 1 hour 30 minutes.

Powered Wheelchair Control Device

The control device (joystick) used in this study has been modified by the Technology Team. The device has been added to a commercially available powered wheelchair called the Dynamics Mobility Nomad. The control device may have indicator lights, pre-recorded voice prompts and restricted driving directions to guide your driving when an obstacle is nearby. To ensure safety, the powered wheelchair is set at slow speed.
(maximum 1.8 km/h, which is approximately half the normal walking speed) and the researcher will be present during all driving sessions. The powered wheelchair is connected by a wire to a computer that will be operated by the researcher. The computer will let the researcher stop movement of the powered wheelchair when it comes close to an obstacle (e.g. within 40 cm at maximum 1.8 km/h). When movement of the powered wheelchair is stopped, the researcher will give you feedback to help you move away from the obstacle. The feedback may be indicator lights, voice prompts and limited movement of the joystick in some directions. There may be additional boxes on the powered wheelchair to show where sensors (cameras) will be placed in a future version of the powered wheelchair. This will help you to see what the future powered wheelchair may look like.

The device has been safety tested according to the required standards and any risks have been addressed.

Procedure

You will be asked questions about your abilities and activities. Most of the questions have been taken from standardised questionnaires used by many researchers, and will ask about:
- your age, driving history, relevant medical problems
- your memory and vision
- your ability to do everyday tasks
- how you get around from place to place
- your participation in activities
- your health and how it affects your activities
- how use of your wheelchair affects your feelings about yourself
- how satisfied you are about your life and your control over it

Your responses may be audio recorded.

The seat and back support of the powered wheelchair will be adjusted for your comfort by the researcher with the help of your Occupational Therapist. The researcher will train you in the use of the powered wheelchair. You will be asked to move the powered wheelchair around to different areas inside your building. The researcher will be present at all times while you are driving and will make observations of you while you are driving. You will have up to 6, 1-hour driving sessions. Pictures or video recordings may be taken of you while you are in the powered wheelchair.

After completing all the driving sessions you will be asked:
- what you think of the powered wheelchair and control device
- about your experience with using the powered wheelchair and control device
- how you feel about using the powered wheelchair and control device

Voluntary Participation and Early Withdrawal

Participation in this study is voluntary. If you decide not to take part, or if you stop participating at any time, your decision will not result in any penalty or adverse effects. Your decision will have no effect on your treatment or services at Toronto Rehabilitation Institute. You may refuse to answer any question and continue on with other questions.

Risks and Benefits

There may be minimal risks associated with taking part in this study. The risks of injury to the driver or others will be minimised. The device has been safety tested and engineering risk analysis has been completed according to required standards. Daily safety inspections will be completed to ensure proper function of the device. The equipment will be disinfected between drivers according to hospital standards. Use of the powered wheelchair will be supervised by the researcher at all times. Instruction will be provided to all drivers before and during driving sessions. The powered wheelchair will be set at a slow speed. The researcher will stop movement of the powered wheelchair if it approaches an obstacle.

You may feel frustration, confusion or embarrassment when operating the powered wheelchair. You may feel distress when answering questions about the driving experience or having your driving ability observed. These feelings will be monitored by the researchers, and you may discuss them with the researchers at any time during the study.

You may experience enjoyment while participating in the study. You will also be helping to test a device that may be of significant benefit to many long term care residents who currently have no other means of moving around independently.

Potential Conflicts of Interest

There are no conflicts of interest. The powered wheelchair from Dynamis Mobility has been donated in kind with no contracts or agreements made on the outcomes of research or commercialization of products. No personal health information from study participants, research data or results (including images, or audio or video recordings) will be available to the corporate donor. Researchers will not benefit financially from the outcomes of this work.
Privacy and Confidentiality

The information collected about you will remain strictly confidential and will not affect your care or treatment. Your name will not be associated with any of the information. The data collected about you will be identified by a numbering system created by the researchers. All information will be stored in a locked cabinet at Toronto Rehabilitation Institute (180 Elm St. site) and/or on a secured computer server that requires a password for access. Only the researchers involved in the study will have access to the information. All data, including audio and video recordings, will be destroyed after 10 years. Only information on your age at time of the study, any history of aggressive behaviour leading to actual or risk of harm to yourself and or other people, and your primary medical problems will be collected from your medical record.

Publication of Research Findings

Results from this study will be used in future publications and reports. If the audio recording(s), image(s) or video recording(s) collected during the research are used in any reports, presentations, or documentation following this study, your identity will be made secret by blocking out your face and any other distinguishing features. Your name will not be associated with any data or images.

Compensation

There will be no monetary compensation for participating in this study.

Rights of Subjects

By participating in this study and by signing the consent form you waive none of your legal rights.

You will be given a copy of this informed consent form to keep for your own records. If at a later date you have any further questions or concerns, you may contact Rosalie Wang at 416-849-4340 ext 208, or by email at wang.rosalie@torontorehab.on.ca

If you have any questions about your rights as a research participant please contact Dr. Gaetan Tardif, Chair of the Toronto Rehabilitation Research Ethics Board at 416-597-3422 x 3730.
Consent

By initialing in the space provided, I verify that I have been told that audio recordings may be taken during question sessions, and video recordings and/or photographs may be taken during the driving sessions. If the audio recordings, image(s) or video recording(s) collected during the research are used in any reports, publications, presentations, or documentation following this study, my identity will be made secret by blocking out my face and any other distinguishing features.

Participant’s initials: ______ or Substitute Decision Maker’s initials: ______

By signing below, I am indicating that I have read the entire information and consent form, that this study has been explained to me, that my questions have been answered, and that I agree to take part in this study.

Participant’s Name
(Print):________________________________________

Participant’s Signature:______________________ Date:________

OR

Name of Participant
(Print):________________________________________

Name of Substitute Decision Maker
(Print):________________________________________

Substitute Decision Maker’s Signature:______________________ Date:________

Substitute Decision Maker’s Relationship to Participant: __________________________

Researcher:
I have discussed the above points with the participant. It is my opinion that the participant understands the procedures involved with participation in this study.

Name of Person Obtaining Informed Consent:
__________________________________________

Signature of Person Obtaining Consent:______________________ Date:________
Study Participant Assent and Information Form

Study Title: Usability Testing of a User Interface for an Anti-collision Powered Wheelchair for Long Term Care Residents with Cognitive Impairment

Principal Investigator:
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fernie.geoff@torontorehab.on.ca

Study Coordinator (Researcher):
Rosalie Wang, BSc (OT), PhD Candidate
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iDAPT, 180 Elm St.
Toronto, ON, M5T 3M4
416-840-4340 ext. 208
wang.rosalie@torontorehab.on.ca

We are doing a research study. We are trying to find out if a new powered wheelchair steering device (joystick) will be helpful to drivers. The joystick may be used in powered wheelchairs made to improve driving safety.

If you decide that you want to be in this study, we will ask you to do several things. You will be asked questions about your abilities and activities. These questions will include how well you are able to see things, remember things, or how you are able to get around day to day. You will then be seated in a modified powered wheelchair with a new type of joystick. The researcher will ask you to drive the powered wheelchair around your building. The researcher will be present while you drive and she will train you to use the powered wheelchair for up to 6 sessions. After all the driving sessions are done, you will be asked questions about how you feel about the powered wheelchair and joystick. Your part in the study may take up to 6 weeks.

Your responses to the questions may be recorded with a voice recorder. Pictures or video recordings of the driving sessions may be taken.

We want to tell you about some things that might happen if you are in the study. You may feel frustration, confusion or embarrassment when using the powered wheelchair and joystick. You may feel distress when...
answering questions or being watched by others. These feelings will be monitored by the researchers and you may talk to the researchers at any time if you are not comfortable. You may feel enjoyment while participating in the study. You may not directly benefit from being in this study. But you may help to test a new device that may help other people in the future.

When we are done with the study, we will write a report about what we found out. We will not use your name. If we use images of you, your face and other features will be blocked.

You do not have to be in this study. It is up to you. If you say okay now, but you want to stop later, that is okay too. All you have to do is tell us.

If you want to be in this study, please sign your name.

I, __________________________________ want to be in this research study.

(Print your name here)

_________________________________________ (Signature of person obtaining consent)  __________ (Date)

Name of Person Obtaining Informed Consent

_________________________________________ (Signature of person obtaining consent)  __________ (Date)
Appendix 13

Study 1: Resident Data Collection Form

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Appendix 14

Study 2: Resident Data Collection Form

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<td>Far Acuity</td>
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<td>Visual Fields / Peripheral Vision</td>
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**Perception and Cognition**

| MVPT - 3 |
| Trail Making A |
| Trail Making B |
| Clock Drawing Test |
| General Cognition Comments |

**Behavioral Observation Comments**

**Distractability**

**Inattention**

**Mental Slowness**

**Difficulty Following Directions**

**Driving Performance**

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**Targeted Mobility Activities**

**Outcome Evaluation Tools**

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Appendix 15

Study 1: Risk Analysis for an Anti-collision Device for a Powered Wheelchair

Risk Analysis for an Anti-collision Device for a Powered Wheelchair
Completed following European Standard EN 1441: 1997

Anti-collision Device for a Powered Wheelchair Risk Analysis

Qualitative and Quantitative Characteristics of Device

The device reviewed in this risk analysis is an anti-collision device for a wheelchair. The device detects if and where a collision has occurred on the wheelchair, stopping and preventing movement toward the collided object. It also records the movement of the chair and logs the time and location of the collision on the chair.

Intended Use
It is intended that the device will be used as an add-on to a powered wheelchair, allowing the driver to negotiate an environment safely. The powered wheelchair will stop before inflicting serious injury or damage if contact is made with a person or obstacle. The chair will be set to move at a very slow speed with caregiver present to assist an individual to move the wheelchair in a situation where the anti-collision system has intentionally denied movement in any direction. It is anticipated that the inner components of the device will be accessed only by CSiA personnel. This system is intended for use in an indoor, institutional setting with dry environment and level flooring.

Materials, Components and Device Description
The anti-collision system interacts with a Nimble Rocket, a FDA-approved, powered wheelchair. The anti-collision device components attached to the wheelchair include a bumper, control box, display, emergency stop switch, override switch, lock and data logger (including wheel rotation counter and seat switch). The same logging device will be also added to a manual wheelchair, so will be included in the following risk analysis. The manual system will include the data logger, consisting of the wheel rotation counter and seat switch as was as additional hand grip switches.

Bumper
The bumper rings the bottom of the powered wheelchair. The outermost surface of the device is a removable material skirt constructed from a black, non-ripping fabric. This skirt is attached over the rest of the bumper assembly as a protective and aesthetic shell. It is fastened with Velcro onto an EVA padded microswitch assembly. The padding on the assembly helps cushion the impact of a collision. The microswitch mechanism consists of 3 polyethylene sections connected by 2 living hinges. The first section is attached to a solid frame with the living hinge at the bottom. The rising next section contains the microswitches at the upper most corner. Weighted at the top with a small bar, the final polyethylene section hangs from the other hinge. The polyethylene panels are attached by chains to the solid frame and with Velcro to the skirt.

Two microswitches are mounted on each of the 7 sections of the bumper (2 front, 2 side front, 2 side back and 1 back). These switches are connected in series and are in the closed state when a collision has not occurred. The switches are held closed by the living hinges which are held open by gravity of the weighed bar in tension with the padded flaps as well as the plastic at the corners of the wheelchair. When a collision occurs the polyethylene assembly is compressed, the living hinges collapse and the microswitches...
spring open. The circuit is then open, a state which triggers the control box that a collision has occurred.

The bumper assembly is screwed onto the chair by a wooden frame bolted to the back of the wheelchair. The frame consists of two swiveling sections hanging from two piano hinges at the back of the chair and running along two bearing mounts at the front of the chair. When not used, the bumper can be separated and opened to allow the caregiver access to transfer the patient. In operation, the two pieces are latched together at the front, as well as zipped together by the material outer skirt. The bumper also rests on two pins on either side at the front of the wheelchair. A sensor mounted on the bumper assembly detects the opening of the bumper and does not allow any movement of the chair until the bumper sections come back together.

Foam wedges are fastened above the bumper at the sides and back of the chair to prevent objects, such as books, from being placed on the bumper. The surface of the foam is sealed with a plastic coating to enable cleaning.

*Control Box and Display*

The control box for the anti-collision device is connected between the wheelchair’s driving joystick and its controller. The control box intercepts any analog signals from the joystick and continuously receives the digital signals from the 14 microswitches in the bumper. The signals are converted to digital if necessary in a microprocessor and processed by a predetermined algorithm. This algorithm determines if a collision has occurred and by the programming conditions (i.e. joystick direction, where the collision has occurred) will restrict certain movements by modifying the signals. The modified signals are then converted back to analog. A back-up system also processes the signals in the same way. The modified signals of the two systems are then compared. If both systems produce the same outputs, the modified signal is sent to the controller of the wheelchair. The wheelchair will run, stop or will only move in constrained directions. In the event of a catastrophic failure in the circuitry, the systems’ outputs will not match and the controller will be shut down and the chair prevented from moving.

When a collision occurs, the anti-collision control box stops the wheelchair from traveling toward the collided object. A LED display, mounted beside the power display on the side of the joystick armrest, shows the acceptable directions by lit green arrows. If the patient pushes the joystick in an allowed direction, the wheelchair will move. Pushing the joystick in a denied direction will result in the wheelchair remaining stationary.

The power for the control box and display is provided by the joystick cable from the powered wheelchair. Power is therefore rerouted via the control box before reaching the wheelchair controller.

*Emergency Stop*

An emergency stop switch, in the form of a red button, is located on the top back of the chair. The button paralyses the chair and prevents all movement by stopping the
controller of the wheelchair. The only way to get the wheelchair to move again is to reset the wheelchair by turning it off and on again.

*Override Switch and Lock*
An override switch is also included on the wheelchair. This button sends a signal to the control box to ignore the inputs from the detection sensors. When the override switch is held down by an individual, the wheelchair will be able to move in all directions regardless of the detection of a collision. The override button is mounted on the underside of the casing for the emergency stop button, inaccessible to the person in the wheelchair. This switch can be used by a caregiver to free the wheelchair from situations where the patient has been intentionally denied movement in all directions due to collisions.

When the chair is not directly supervised by the CSiA, it will be locked off functionally from use. In this state, the batteries of the wheelchair can be charged and the wheelchair can be turned on, however the chair will not move. The anti-collision display indicates that the chair is locked by flickering.

*Data Logger*
The data logging device measures and records the distance the chair travels, the occurrence and bumper location of collisions and the presence of an occupant sitting in the wheelchair. This information is measured by a wheel rotation counter, a seat pressure sensor and the bumper microswitches, and is sent to the data logger black box. The same data logging system will be added on a manual wheelchair, with the wheel rotation counter and seat pressure sensor sending data to the black box. An addition of handle switches on the manual chair's logging system records caregiver initiated movement.

The wheel rotation counter device is mounted on a spring loaded bracket bolted to the Nimble Rocket wheelchair between the two drive wheels. On the manual version, the counter is mounted on a bar secured between the drive wheels. It consists of a small wheel and bar with a transducer. The transducer detects the number and direction of the wheel revolutions and this signal is sent to the data logger black box.

The seat sensor is manufactured of 2 pieces of brass screening sandwiching a Mylar isolating strip. The Mylar strip has holes in it that allow contact of the brass screening pieces with the pressure of an individual sitting on the sensor. The contact of these pieces creates the signal sent to the data logger black box. The sensor has a RF welded, vinyl covering and can be mounted directly on top of the seat or under the fabric of the seat cushion, depending on the seat properties and the seating requirements of the occupant.

The handle bar switches, on the manual wheelchairs, consist of half an aluminum channel connected to a switch within a casing. The casing is attached to the chair handle supports. Each channel is positioned above the wheelchair handles and held open by a spring. Any use of the handles by a caregiver to push the wheelchair is recorded.

The bumper microswitch data is sent to the data logger black box via the microswitch cables, which split before connection to the anti-collision control box. Steering diodes on
the input cables to the data logger prevents the data logger from short circuiting the microswitch lines. The data logging device merely records the signals and does not interfere with the function of the anti-collision control box.

The data logger black box contains the circuitry and logic for the data logger, recording signals from the wheel rotation counter, seat sensor, handle switches and bumper microswitches. Its power is drawn from the wheelchair's batteries. Recorded data can be downloaded from the box to a microcomputer.

A backpack is attached to the back of the seat of the wheelchair by adjustable straps to house the datalogger black box circuitry. The pack fastens and locks to prevent interference. The padded pack is fabricated from abrasion and puncture resistant, high tear strength, 500 denier Cordura (nylon with polyester and cotton). It is urethane coated for moisture protection.

**Interaction with Patient (i.e. Driver)**
The anti-collision device will not directly contact the patient. Energy and substances will not be delivered to or extracted from the patient. The device will not modify the patient environment (temperature, humidity, pressure, etc.). There are no unwanted outputs of energy or substances, such as noise, vibration, radiation, contact temperatures, leakage currents and electrical and/or magnetic fields. The only direct contact with the device with the user is the constant surface contact, through the seat pressure sensors.

**Interaction with Others and the Environment**
The bumper of the anti-collision device is expected, with some drivers, to regularly contact other persons and objects. The force of this contact will not involve the weight of the chair, only the force required to crumple the living hinges to activate the microswitches. This force has been estimated to be less than 1 N.

**Cleaning and Disinfection**
The anti-collision device is not sterile, nor intended to be sterilized by the user. For purposes of microbiological control and preventing cross contamination, the wheelchair will be cleaned and/or disinfected. This process will occur between different chair users and should the chair be soiled.

Following Sunnybrook & Women's College Health Sciences Centre hospital policy for the Infection Prevention and Control: Reprocessing of Equipment (Section Q, Policy No. II-Q-1725, revised August 2004), non-critical inanimate objects are first cleaned (the physical removal of foreign material, e.g. dust, soil, organic material such as blood, secretions, excretions and microorganisms) and low-level disinfected (the process of killing most vegetative bacteria and some fungi and viruses, but not mycobacteria or bacterial spores). The anti-collision chair is categorized as a non-critical device as it will ordinarily only touch the patient’s intact skin and not ordinarily come in contact with mucous membranes. For this type of disinfection a 1/10 dilution of a 5.25% hypochlorite solution (bleach) will be used to wipe the patient and caregiver contacting surfaces clean, with the exception of fabric pieces (cushions, skirt) which will be laundered.
As with other powered wheelchairs, the anti-collision chair is not designed to be submerged or exposed to a continuous flow of liquids.

**Environmental Influences**
The device is susceptible to extreme cold, heat and moisture. In standard temperature ranges (e.g. 0 to 30 degrees Celsius) the device will be unaffected. It is expected that these extreme temperatures will affect the patient before the chair. For moisture environments, the chair is protected against a casual splash; however continuous pouring or submersion will be a problem. The chair is intended for a dry environment.

**Maintenance and/or Calibration**
The switches and overall operation of the anti-collision device need to be checked regularly, on a daily basis, for preventative maintenance.

**Software**
The device does not contain software that can be changed by a user and/or operator. Instead, firmware is programmed into the hardware of the control box which can only be changed by physically removing the component and plugging it into a specialized microcomputer.

**Device Lifetime**
The anti-collision system is expected to last the lifetime of the wheelchair (typically 5 years for most powered wheelchairs). The electronic components should last indefinitely and wear and tear damage on the mechanical components will be fixed or replaced in the maintenance of the device.

**Other Qualitative and Quantitative Considerations**
The device is intended for re-use. Biological materials will not be processed by the device for subsequent re-use. Patient/care measurements are not made by the device. There are no unwanted outputs of energy or substances from the anti-collision device. There are no essential consumables or accessories associated with the device. The device does not have a restricted shelf-life. There are no possible delayed and/or long term use effects associated with the device use.

**Possible Hazards**

**Hazard Rating System:**

Severity of an event is determined by the level of harm:
- High – Death or serious injury.
- Moderate – Long term pain, loss of function, or recoverable non-life threatening injury.
- Low – Minor injury, discomfort and nuisance.
- Very low – No injury, irritation and discomfort only.
Probably of the event occurring:
   Frequent – Greater than once per week.
   Probable – Less than once per week but greater than once per month.
   Occasional – Once per device over its intended life (or 6 months).
   Remote – Unlikely but may occur over the range of users.
   Improbable – So unlikely that it is assumed it will never occur.

Risk the resultant estimate of potential for hazardous occurrence:
   Intolerable – Risk must be eliminated or reduce by protective measures.
   Undesirable – Risk is acceptable only if it cannot be mitigated by product
                 enhancement. Warnings required.
   Tolerable – Risk acceptable subject to appropriate warnings.
   Negligible – No action necessary.
## Energy Hazards

<table>
<thead>
<tr>
<th>Harm</th>
<th>Result</th>
<th>Severity</th>
<th>Probably</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Electricity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact with control box</td>
<td>Electrical hazard.</td>
<td>Low</td>
<td>Remote</td>
<td>Electrical components are not accessible to the caregiver or patient. Control box draws power from the joystick cable, so is limited to a maximum current of 200 mA. Wires from joystick are enclosed.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Contact with wires</td>
<td>Possibly feel a shock (right on the threshold of sensation).</td>
<td>Very Low</td>
<td>Remote</td>
<td>The wires in the bumper run at extremely low current (~1-3 mA) and voltage (maximum of 5 V). Wires are sealed and switches enclosed. Only a service person will have access to them. Attendee will warn against interfering with the bumper assembly.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Inadequate supply of power</td>
<td>Wheelchair, anti-collision and logger systems will not work.</td>
<td>Very Low</td>
<td>Probable</td>
<td>Wheelchair’s brakes will be engaged and chair will not move.</td>
<td>Negligible</td>
</tr>
<tr>
<td>Battery connected backwards (e.g., with attachment of data logger)</td>
<td>Smoke, fire, sparking hazards.</td>
<td>High</td>
<td>Occasional</td>
<td>Polarized connectors are added to prevent incorrect connection.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Electric shock from a faulty pressure sensor</td>
<td>Possibly feel a shock (right on the threshold of sensation).</td>
<td>Very Low</td>
<td>Remote</td>
<td>Low voltage (~5V) and low current (~1-3 mA, maximum possible 50 mA) used.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Wires between switches break or switches lose power</td>
<td>Chair will stop, same as a collision detected.</td>
<td>Very Low</td>
<td>Occasional</td>
<td>Non-collision situation is powered therefore any loss of power in any of the system’s components will stop the chair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td><strong>B. Heat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backpack overheating from electronics</td>
<td>Increased heat to occupant, possible fabric damage.</td>
<td>Low</td>
<td>Remote</td>
<td>Loose connections in backpack sections allow air circulation.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Harm</td>
<td>Result</td>
<td>Severity</td>
<td>Probably</td>
<td>Method to Minimize Risk</td>
<td>Risk After Precaution</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
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<td>------------------------</td>
</tr>
<tr>
<td>C. Mechanical (Moving Parts, Vibration, Pressure)</td>
<td>Impact of the chair moving at full speed against a moving or stationary object</td>
<td>Very Low</td>
<td>Frequent</td>
<td>The maximum speed of the chair is set lower than most powered wheelchairs at 1.2 km/h (0.8 mph) and the first reaction time of the control box result in the bumper hitting with minimal force. The crumple zone of the assembly has been set at more than the maximum stopping distance of the chair so that contact is only made with the collapsing bumper. CSAA estimates the force of the bumper hitting is less than 1 N.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Clothing caught between two pieces of bumper</td>
<td>Clothing could get caught under the chair and get wrapped around a drive wheel</td>
<td>Low</td>
<td>Occasional</td>
<td>There is only a small gap between the two sections when closed. Hazard is same as other powered wheelchairs.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Object(s) get caught under chair</td>
<td>Could affect wheels and/or anti-collision systems</td>
<td>Very Low</td>
<td>Occasional</td>
<td>If objects under chair affect the anti-collision system, they will cause the chair to stop.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Data logger wheel catches on object</td>
<td>Wheelchair will not move or logger will be pulled off and not function properly</td>
<td>Very Low</td>
<td>Remote</td>
<td>Device placed inside the skirt, between two drive wheels on chair and loaded on a spring. Mounting bracket will pull off chair before damaging chair</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Finger(s)/objects getting caught in the data logger wheel</td>
<td>Physical harm/property damage</td>
<td>Moderate</td>
<td>Improbable</td>
<td>Wheel on the powered chair is extremely inaccessible.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Impact with bumper transferring the patient</td>
<td>Hurt the caregiver and/or patient</td>
<td>Moderate</td>
<td>Frequent</td>
<td>Bumper splits apart to allow for easier access.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Trimming on the bumper</td>
<td>Caregiver or others could be injured</td>
<td>Low</td>
<td>Frequent</td>
<td>Clinical trials could prompt a change in bumper colour or flushing.</td>
<td>Unknown</td>
</tr>
<tr>
<td>Harm</td>
<td>Result</td>
<td>Severity</td>
<td>Probability</td>
<td>Method to Minimize Risk</td>
<td>Risk After Precaution</td>
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</tr>
<tr>
<td>Stepping on the bumper</td>
<td>1) Caregiver or others could be injured. 2) Bumper could be damaged.</td>
<td>Low</td>
<td>Probable</td>
<td>1) Attendant will warn against stepping on the bumper. 2) Damage minimized by physical design (plastic paneling will collapse, stronger linked chains). Daily inspection of bumpers will ensure integrity. 3) Foam wedges are attached to side and back bumpers to discourage stepping.</td>
<td>Unknown</td>
</tr>
<tr>
<td>Patient or caregiver running into the LED display</td>
<td>Patient or caregiver gets hurt.</td>
<td>Low</td>
<td>Occasional</td>
<td>Additional protrusion from current armrest will be kept to a minimum. The display will be mounted so that the anti-collision system will prevent another person hitting it.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Discomfort from sitting on pressure sensor or data logger backpack straps</td>
<td>Discomfort, irritation, increased perspiration or in the worst case, pressure sore development</td>
<td>Very low</td>
<td>Remote</td>
<td>The device is covered with soft vinyl and is extremely low profile. The seams of connecting the pieces are RF welded to minimize the addition of creases. If possible it will be put under the material of the seat cushion. Residents will be seated individually for testing tolerance and sessions in the anti-collision chair will be short in length.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Handle bar pinch</td>
<td>Caregiver pinched.</td>
<td>Very low</td>
<td>Occasional</td>
<td>The switch is constructed of half-centre, low profile aluminum to avoid pinching.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Biological hazards</td>
<td>Cross contamination could occur; patients and/or caregivers could become ill</td>
<td>High</td>
<td>Occasional</td>
<td>Anti-collision system can be cleaned and disinfected to minimize risk; skirt and cushions are cleanable, backpacks can be wiped clean and chair can be disinfected.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Environmental hazards</td>
<td>Device could be damaged and not operate as intended.</td>
<td>High</td>
<td>Remote</td>
<td>CSIA attendant will be present at all times with the chair while in operation and the chair will be locked in all other times. The chair will be labelled as for dry, flat, indoor use only.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Accidental damage to external environment</td>
<td>Damaged environment</td>
<td>Low</td>
<td>Remote</td>
<td>Soften impact and stopped motion of the chair before collision will minimize this risk when compared to other wheelchairs.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Harm</td>
<td>Result</td>
<td>Severity</td>
<td>Probable</td>
<td>Method to Minimize Risk</td>
<td>Risk After Precaution</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------</td>
<td>----------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Chair is driven over the top of a staircase or towards a hole.</td>
<td>The chair control system should stop the chair at the first step, as the front of the bumper tilts forward 3 degrees.</td>
<td>High</td>
<td>Improbable</td>
<td>The chair will exclusively be used in a controlled institutional setting where stairs are strictly unavailable to patients. In addition, chair detects a 3 degree change in inclination and is moving at a slow speed. CSIA attendant will be present at all times with the chair while in operation and the chair will be locked in all other times.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Damage to floor from data logger wheel</td>
<td>Floors damaged</td>
<td>Very Low</td>
<td>Remote</td>
<td>Non-marking wheel used</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Hazard related to the use of the device</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluids dropped on bumper</td>
<td>Microswitches could short</td>
<td>Very Low</td>
<td>Remote</td>
<td>Rip-stop fabric outer shell is splash resistant. Switches are doubled on each panel in case of failure and will be checked daily before use. Chair should only be used in a dry indoor environment.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Fluids in contact with black boxes</td>
<td>Could damage circuitry and system not work as intended</td>
<td>Very Low</td>
<td>Remote</td>
<td>Wires and circuitry protected against accidental splashing. Backpack is water-resistant. Chair should only be used in a dry indoor environment.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Caregiver interferes with bumper</td>
<td>Caregiver pinches fingers and/or bumper gets damaged or out of alignment resulting in the anti-collision system not working as intended.</td>
<td>High</td>
<td>Remote</td>
<td>Labeling and attendant will warn against interfering with the bumper assembly. Daily checks will ensure the anti-collision system is operating as intended. CSIA attendant will be present at all times with the chair while in operation and the chair will be locked in all other cases.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Patient engaging the override switch or</td>
<td>The chair would travel freely and would not prevent collisions.</td>
<td>High</td>
<td>Remote</td>
<td>The override switch is mounted out of reach of the patient at the back of the chair. The switch must be held down to be active and is placed on the underside of the switch’s housing to prevent accidental engagement.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>caregiver mistakenly leaving the override switch on</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
### Risk Analysis for an Anti-collision Device for a Powered Wheelchair

**Completed following European Standard EN 1441: 1997**

<table>
<thead>
<tr>
<th>Harm</th>
<th>Result</th>
<th>Severity</th>
<th>Possibly</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate operating instructions or operations by unskilled person</td>
<td>Operation will be no different than with a normal user, i.e. the chair will stop with collisions.</td>
<td>Very Low</td>
<td>Probable</td>
<td>Operating instructions will be provided in the form of in-service instructions to staff and written, uncomplicated instructions on the machine. CSIA attendant will be present at all times with the chair while in operation and the chair will be locked in all other times.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>An object is placed on the top of the anti-collision bumper</td>
<td>The panels will take slightly more force to compress.</td>
<td>Low</td>
<td>Probable</td>
<td>Foam triangular pieces discourage placing objects on the side and back bumpers. CSIA attendant will be present at all times with the chair while in operation and the chair will be locked in all other times.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Not detecting objects low to the ground (e.g. toes)</td>
<td>Low object will be run over by the powered wheelchair</td>
<td>Very Low</td>
<td>Improbable</td>
<td>Clearance of about ( \frac{1}{4} ) inch between the anti-collision system and the floor.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Chair driven under object, higher than the bumper height</td>
<td>Driver could be hit on object.</td>
<td>Low</td>
<td>Occasional</td>
<td>Chair is set at a low speed and bumper can detect objects up to 7-8 inches above the ground. This problem will be further addressed with future hybrid systems with non-contact sensors.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Tipping hazard from wheelchair base modified to have inboard wheels</td>
<td>Chair could tip over.</td>
<td>High</td>
<td>Remote</td>
<td>Device restricted to institution. Anything more than 3 degrees will stop the chair. The wheelchair is also moving at slow speeds with minimal moments.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Corner bumper piece lifts up as it contacts an object</td>
<td>No collision is detected and foot or object could be trapped within the bumper and be pushed or pulled around</td>
<td>Moderate</td>
<td>Probable</td>
<td>Corner pieces will be kept at a minimal distance from the ground to prevent most objects from slipping under. A high frictional material is added to the bumper corner to decrease its tendency to slip over an object and a line attached between the corner and frame restricts the range of travel of the bumper.</td>
<td>Tolerable</td>
</tr>
</tbody>
</table>

---

**Hazards arising from fault, failure, maintenance and aging**

- Both microswitches on a panel fail | A collision may not be detected. | High | Remote | Microswitches are in pairs on each panel. Power is low enough to not cause switch contacts to fuse. Daily checks will ensure the anti-collision system is operating as intended. | Tolerable |
<table>
<thead>
<tr>
<th>Harm</th>
<th>Result</th>
<th>Severity</th>
<th>Probably</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic failure in the anti-collision control box</td>
<td>Worse case, the wheelchair will drive uncontrolled in a certain direction at maximum speed.</td>
<td>High</td>
<td>Remote</td>
<td>The speed of the chair set is low at 1.2 km/h (0.8 mph). The control box will contain two controllers and will monitor that their outputs match before allowing the control box to affect the signals sent to the wheelchair controller. A large kill button is also included on the back of the chair to stop all function of the chair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Bumper becomes detached</td>
<td>Anti-collision will no longer work as intended.</td>
<td>High</td>
<td>Occasional</td>
<td>Warning in operational manual. CSSA attendant will be present at all times with the chair while in operation and the chair will be locked in all other times.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Anti-collision or data logger box cables becoming detached (e.g. plugs pulled out, wires cut)</td>
<td>Anti-collision system may not work.</td>
<td>Low</td>
<td>Occasional</td>
<td>In an extremely rare case, if all wires are cut and the anti-collision control board short-circuits at the same time, the wheelchair could operate as if the anti-collision system is not present. As it is doubtful that these two major failures will occur in tandem, cut or unplugged wires will more likely cause the chair to stop and not run. All wires will be as bundled and inconspicuous as possible and closely secured to be unavailable for damage or tampering. All plugs will be secured with electrical tape prevent being pulled out.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Data logger wheel falling off chair</td>
<td>Will disconnect at plug and not work as intended.</td>
<td>Very low</td>
<td>Improbable</td>
<td>Wheel assembly is bolted to chair and will be checked regularly.</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
Appendix 16

Study 1: Risk Analysis for a Wheelchair Distance Logging Device by Wheel Rotation

Risk Analysis for a Wheelchair Distance Logging Device by Wheel Rotation

This risk analysis was conducted following the methodology outlined in the European Standard EN 1441:1997.

Qualitative and Quantitative Characteristics of Device

The device is a distance logging device intended to be used on a powered or manual wheelchair to measure the distance traveled by the chair, with the ability to distinguish chair movement when pushed by a caregiver and by the rider. The device consists of four main components: a black box connected by wires to a battery with a fuse, a wheel rotation counter and seat and handle bar pressure sensors.

The black box contains the circuitry and logic for the data logger, recording signals from the wheel rotation counter and pressure sensors. Recorded data can be downloaded from the box to a microcomputer. The battery is a portable 6V battery for manual chairs and while the existing 24V batteries will be used on the powered. The wheel rotation counter device consists of a spring loaded bracket connected to a small wheel and bar with a transducer. The number of turns of the wheel is sent to the black box, which is calibrated to determine distance traveled. A mounting assembly will be necessary to attach the wheel rotation counter to a manual wheelchair; however, will be dependent on the type of wheelchair.

The handle bar sensors are a commercially available product in which two strips of metal are held separate by the tension in plastic casing. Any pressure on the sensors contacts the two strips, sending a signal to the black box that a caregiver is pushing the chair. The bar sensors will be mounted on the handle bars of the wheelchair, with a material covering if necessary. The seat sensor was manufactured of 2 pieces of brass screening sandwiching a Mylar isolating strip. The Mylar strip has holes in it that allow contact of the brass screening pieces with pressure, again sending a signal to the black box. The sensor has a rubber covering and will be mounted directly on top of the seat or under the fabric of the seat cushion, depending on the wheelchair. This sensor will determine if someone is occupying the seat with the recorded movement.

The only direct contact with the device with the patient or other persons is through the pressure sensors. It will not operate or control other devices. It will be used only indoors in an institutional environment.

Possible Hazards and Risk Associated

The possible harms are listed in the table on the following pages, under the following headings:
C.2 Energy Hazards
C.3 Biological Hazards
C.4 Environmental Hazards
C.5 Hazards related to the use of the device
C.6 Hazards arising from functional failure, maintenance and aging

Included are all potential physical injuries and/or damage to health or property caused by the device or its components.
<table>
<thead>
<tr>
<th>Harm</th>
<th>Severity</th>
<th>Probability</th>
<th>Result</th>
<th>Method to Minimize Risk</th>
<th>Risk After Minimizing Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Hazards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inadequate supply of power</td>
<td>Very Low</td>
<td>Frequent</td>
<td>Wheelchair and logger will not work.</td>
<td>N/A</td>
<td>Negligible</td>
</tr>
<tr>
<td>Power surge</td>
<td>Very Low</td>
<td>Occasional</td>
<td>Fuse will shut down to protect equipment.</td>
<td>Fuse</td>
<td>Negligible</td>
</tr>
<tr>
<td>Wheel rotation counter catches on object while moving</td>
<td>Very Low</td>
<td>Remote</td>
<td>Wheelchair will not move or device will pull off.</td>
<td>Placed between two drive wheels on powered chair and loaded on a spring. Will pull off before damaging wheelchair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>A person touches a live wire</td>
<td>Very Low</td>
<td>Remote</td>
<td>No/little shock felt (right on threshold of sensation).</td>
<td>Low voltage (~5V) and low current (~1-3 mA) used. Circuity in a black box and wires in plastic case.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Fingers/objects getting caught in the wheel rotation counter</td>
<td>Moderate</td>
<td>Occasional</td>
<td>Physical harm/property damage.</td>
<td>On powered chair is between the two drive wheels, on the manual wheel there is a protective housing for the device.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Batteries overheating</td>
<td>High</td>
<td>Improbable</td>
<td>Heat and/or fire hazard.</td>
<td>Very low operating current, charging at low levels. Fuse will also be mounted directly or very close to one of the battery terminals</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Electric shock from a faulty pressure sensor</td>
<td>Very Low</td>
<td>Remote</td>
<td>No/little shock felt (right on threshold of sensation).</td>
<td>Low voltage (~5V) and low current (~1-3 mA, maximum possible 50 mA) used.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Pinching hazard from pressure sensor</td>
<td>Low</td>
<td>Remote</td>
<td>Possibly physical harm</td>
<td>Sensors and accompanying wires will be as securely and safely mounted as possible (will vary with each chair).</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Harm</td>
<td>Severity</td>
<td>Probability</td>
<td>Result</td>
<td>Method to Minimize Risk</td>
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</tr>
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<td>----------------------------------</td>
</tr>
<tr>
<td>Discomfort from sitting on pressure sensor</td>
<td>Low</td>
<td>Occasional</td>
<td>Discomfort or irritation</td>
<td>The device is covered with rubber. If possible it will be put under the material of the seat cushion.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Biological Hazards</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Environmental Hazards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical damage to portable battery</td>
<td>Low</td>
<td>Remote</td>
<td>Chemical/electrical hazards.</td>
<td>Battery physically mounted the in a custom-built padded case to prevent damage.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Mechanical damage to circuitry</td>
<td>Very Low</td>
<td>Remote</td>
<td>Electrical hazard/device stops working.</td>
<td>Circuitry encased in black box.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Mechanical damage to sensor</td>
<td>Low</td>
<td>Remote</td>
<td>Device will not work or will not work as intended.</td>
<td>Spring loaded, between the two drive wheels or protected by a housing device on the manual chair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Water in contact with device</td>
<td>Very Low</td>
<td>Remote</td>
<td>Device stops working.</td>
<td>Low voltage (~5V) and low current (~1-3 mA) used.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Damage to floors</td>
<td>Very Low</td>
<td>Remote</td>
<td>Floors damaged.</td>
<td>Non-marking wheel used.</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Hazards related to the use of the device</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use by an unskilled person/misuse of device</td>
<td>Very Low</td>
<td>Probable</td>
<td>Device will not work or will not work as intended.</td>
<td>N/A</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Hazards arising from functional failure, maintenance and aging</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counter falling off chair (mechanical integrity)</td>
<td>Very low</td>
<td>Improbable</td>
<td>Will disconnect at plug.</td>
<td>Bolted to chair.</td>
<td>Negligible</td>
</tr>
<tr>
<td>Wires becoming loose (mechanical integrity)</td>
<td>Very low</td>
<td>Improbable</td>
<td>Device will not work or will not work as intended.</td>
<td>N/A</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
Appendix 17

Study 2: Risk Analysis for an Anti-collision Powered Wheelchair Controller

Risk Analysis

Anti-collision Powered Wheelchair Project

Involved in this analysis: Rosalie Wang, Gerry Griggs, Susan Gorski, Geoff Fernie, Pam Holliday

Date of analysis: August 1, 2008
Date risk management started: March 27, 2008
Last revised: October 7, 2008

This risk analysis was completed as outlined in CAN/CSA-ISO 14971:01 (ISO 14971:2000) Medical devices – Application of risk management to medical devices.

Qualitative and Quantitative Characteristics of Device

Materials, Components and Device Description

The core of the device is a Dynamis Mobility Nomad powered wheelchair (www.dynamismobility.com/products.html). An Amy Systems powered tilt seat (http://www.amysystems.com/index_HIGH.html) designed for powered wheelchairs has been added to the wheelchair base. The powered wheelchair and tilting seat are commercially available in Canada.

The added anti-collision system interfaces with the chair at the joystick. The joystick interface includes 8 radio controlled servo motors mounted around the joystick’s base. When activated, a servo motor rotates a small plate which in turn moves a bar towards the joystick. The joystick is attached to a plate which interfaces with the bars. When a bar is activated, the driver cannot move the joystick in that direction, preventing the movement of the wheelchair in the same direction. The added device does not affect the electronics of the wheelchair, but simply mechanically stops the movement of the joystick. A visual display of 8 large green LEDs around the joystick shows the allowed directions of travel to the driver and an automated voice prompt encourages movement in appropriate directions. The joystick addition is covered with a SLA, polypropylene-like, plastic case, painted black. All joystick buttons are covered and not accessible, and an extender for the power switch is included. The joystick add-on is powered by a rechargeable 6V battery.

An IBM laptop (running Windows 98 and MS-DOS) controls the joystick interface and is held by the attendant, an experienced iDAPT team member. The laptop is tethered to the wheelchair with a cable to ensure connectivity at all times. The laptop runs the program that controls the servo motors via the inputted information by the attendant. Two emergency stop switches are shunt off power to the wheelchair in the case of failure or safety concerns are also under the control of the attendant. One is located on the computer and the second on the back of the wheelchair seat. The stop switches are implemented on the same control as the interrupt switch on the wheelchair, which can be used, for example, to prevent the driver from driving the wheelchair if the chair seat is tilted in an extreme position. The distance required for the wheelchair to come to a
complete stop is dependent on the driving speed. For the maximum driving speed set for this study (1.8 km/h, approximately half the average walking speed), the stopping distance is 40 cm).

**Intended Use**

The device is intended to be used in a way similar to a new automobile driver with an instructor. If the user drives in a safe manner, he will remain in control of the wheelchair. Should the driver steer towards an object or person, the attendant will input on the laptop the location of the upcoming collision. This input information will first stop all movement of the wheelchair and then activate the appropriate servo motors around the joystick to prohibit any further motion of the wheelchair towards the obstacle. Visual and audio prompting of the permitted directions of the wheelchair encourages the driver to move in the allowed directions. The lifespan of the wheelchair is anticipated to be the length of the trials or approximately 1 year.

The device is intended to test the usability of a joystick interface that provides feedback for obstacle avoidance in a powered wheelchair. The device is intended to be operated (driven) by a person who has cognitive impairment. A skilled attendant will be present at all times to control movement of the wheelchair and deliver prompts. The wheelchair is intended for indoor use or for use in dry environments (e.g. outside on a sunny day). As with other powered wheelchairs, it is not designed to be submerged or exposed to a continuous flow of liquids. The device is not a life sustaining or life supporting device and is not intended to play any role in the diagnosis, prevention, monitoring, treatment or alleviation of disease.

The device is not sterile, nor intended to be sterilized by anyone using the wheelchair. For purposes of microbiological control and preventing cross contamination, the wheelchair will be cleaned and/or disinfected. This process will occur between different chair users and should the chair be soiled.

Following Toronto Rehab’s institutional policy for the Sterilization and Disinfection of Equipment, V8-2001, the chair will first be cleaned (the removal of foreign material, especially organic matter). As the wheelchair is classified as a non-critical item (as it ordinarily only touches intact skin and not mucous membranes), low-level disinfection will be then used (the process of killing most vegetative bacteria and some fungi and viruses, but not mycobacteria or bacterial spores). For this type of disinfection at least a 1/50 dilution of a 5.25% hypochlorite solution (bleach) will be used to wipe the patient contacting surfaces clean, with the exception of fabric pieces (cushions) which will be laundered.

**Possible Hazards**

**Hazard Rating System:**

Severity of an event is determined by the level of harm:

- High – Death or serious injury.
Risk Analysis for an Anti-collision Powered Wheelchair Controller

Moderate – Long term pain, loss of function, or recoverable non-life threatening injury.
Low – Minor injury, discomfort and nuisance.
Very low – No injury, irritation and discomfort only.

Probability of the event occurring:
Frequent – Greater than once per week.
Probable – Less than once per week but greater than once per month.
Occasional – Once per device over its intended life (or 6 months).
Remote – Unlikely but may occur over the range of users.
Improbable – So unlikely that it is assumed it will never occur.

Risk the resultant estimate of potential for hazardous occurrence:
Intolerable – Risk must be eliminated or reduced by protective measures.
Undesirable – Risk is acceptable only if it cannot be mitigated by product enhancement. Warnings required.
Tolerable – Risk acceptable subject to appropriate warnings.
Negligible – No action necessary.
### Risk Analysis for an Anti-collision Powered Wheelchair Controller

<table>
<thead>
<tr>
<th>Harm</th>
<th>Result</th>
<th>Severity</th>
<th>Probably</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Hazards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver hits joystick cover transferring into the chair</td>
<td>Driver could be hurt</td>
<td>Low</td>
<td>Occasional</td>
<td>As with all transfers, case will need to be taken to prevent injury. Sharp edges are minimized with joystick cover.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Driver’s fingers pinched between joystick and casing</td>
<td>Driver could be hurt</td>
<td>Low</td>
<td>Occasional</td>
<td>Joystick is fabricated from an elastic rubbery material to prevent injury from pinching. When the servo motors are engaged, the joystick is pushed towards the center of its range of motion, minimizing any hazard of pinching.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Line tethering computer to chair is severed.</td>
<td>Chair will no longer be under control of attendant; servos on joystick will remain in previous state, driver could drive chair into a person</td>
<td>High</td>
<td>Occasional</td>
<td>There will be no energy hazard as the voltage going through the wire is low (5V). The attendant will be able to hit the emergency stop button on the chair, preventing motion of the chair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td><strong>Biological hazards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-infection between different residents using the wheelchair</td>
<td>Nosocomial infection</td>
<td>High</td>
<td>Occasional</td>
<td>The wheelchair will be cleaned between each use using standard procedures (see description previous).</td>
<td>Tolerable</td>
</tr>
<tr>
<td><strong>Environmental hazards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>An individual trips on cord tethering computer to wheelchair</td>
<td>Individual could fall or be hurt</td>
<td>High</td>
<td>Occasional</td>
<td>Cord will be coiled up as short as possible. The attendant will be within close proximity to the chair, and will be able to verbally and physically prevent an individual from harm. The chair is used only with the attendant present and the attendant can stop all chair movement with the emergency stop switches.</td>
<td>Tolerable</td>
</tr>
</tbody>
</table>
### Risk Analysis for an Anti-collision Powered Wheelchair Controller

<table>
<thead>
<tr>
<th>Harm</th>
<th>Result</th>
<th>Severity</th>
<th>Probably</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joystick interface (case) increases the width of the chair.</td>
<td>Joystick and/or case may be broken by contact in confined spaces or could damage the environment.</td>
<td>Very low</td>
<td>Occasional</td>
<td>Attendant present at all times during use to monitor.</td>
<td>Tolerable</td>
</tr>
</tbody>
</table>

#### Hazards related to the use of the device

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Description</th>
<th>Severity</th>
<th>Probably</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver becomes agitated and attempts to force the joystick in desired direction</td>
<td>Servo motors could be broken allowing the chair to move in an unintended direction or to contact an object</td>
<td>Moderate</td>
<td>Remote</td>
<td>The joystick is mounted on a piano wire (spring steel), which gives the system elasticity to allow the joystick to be pushed, but prevent the servo motors from breaking. Wear and tear on the wheelchair will be monitored daily by IDAFT staff when charging the wheelchair’s batteries. The chair is used only with the attendant present and the attendant can stop all movement of the chair using the emergency stop switches.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Attendant in incapacitated (e.g. trip over cord and becomes unconscious or has medical event)</td>
<td>The driver will be able to move the chair freely and could hit a person</td>
<td>Moderate</td>
<td>Remote</td>
<td>Emergency stop and power buttons are clearly marked so that any passerby can immediately stop the chair. Risk is no greater than any wheelchair driver having a medical emergency. In the next generation wheelchair controller, a smaller computer and a wireless solution are planned.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Electronics get wet</td>
<td>Device could not function as intended.</td>
<td>Moderate</td>
<td>Remote</td>
<td>The electronics of the system are encased so that accidental splashing will not cause harm. The power of the system is kept to lower than 6V.</td>
<td>Tolerable</td>
</tr>
</tbody>
</table>

#### Hazards arising from functional failure, maintenance and usage

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Description</th>
<th>Severity</th>
<th>Probably</th>
<th>Method to Minimize Risk</th>
<th>Risk After Precaution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic failure of the computer</td>
<td>Chair will no longer be under control of attendant, servos on joystick will remain in previous state, driver could drive chair into a person</td>
<td>High</td>
<td>Occasional</td>
<td>Should the computer fail, the attendant will be able to hit one of the two emergency stop buttons, preventing motion of the chair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Harm</td>
<td>Result</td>
<td>Severity</td>
<td>Probably</td>
<td>Method to Minimize Risk</td>
<td>Risk After Precaution</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------</td>
<td>----------</td>
<td>----------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Line soldering computer to chair is broken or connector comes undone</td>
<td>As above</td>
<td>High</td>
<td>Occasional</td>
<td>There will be no energy hazard as the voltage going through the wire is low (2V). The attendant will be able to hit the emergency stop button on the chair, preventing motion of the chair.</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Batteries for computer or servo motors run out of power</td>
<td>As above</td>
<td>High</td>
<td>Occasional</td>
<td>As above. Batteries will be charged daily. Sessions are expected to be 1.5 hours maximum. The battery life is estimated to be a minimum of 3 hours.</td>
<td>Tolerable</td>
</tr>
</tbody>
</table>
Appendix 18

Study 1: Anti-collision Powered Wheelchair Inspection Forms and Incident Log

AC Chair ID: _______  Date: ____________
Phase: ______________

Anti-collision Powered Wheelchair – Phase Inspection Sheet

**Skirt**
- No rips or tears
- Snaps all working
- Latch working
- Fabric aging, distortion not affecting bumper function
- Disinfected/laundered

**Bumper Frame**
- Foot rest not damaged
- Foot rest switch stops all movement
- No frame distortion
- Frame, hinges and bearings working
- Floor clearance (<3/4” allowed, >1 1/8 ” not allowed)
- External parts disinfected

**Bumper Mechanism**
- No cracks or damage to living hinges or plastic
- Foam secured to plastic
- Weighted slugs in place and secure
- All chains intact
- Corner metal and plastic support intact
- Corner fabric snaps working
- Microswitches operational and without damage
- Switch cables securely mounted

**Controller**
- Logic is correct for panels
- Chair stops in allowable distance for all 9 panels (i.e. less than four inches)
- Cables securely mounted
- LEDs and display not damaged

**Emergency & Override Switches**
- Emergency switch stops all movement
- Override switch allows movement in ‘denied’ direction
- Emergency and override switches and cables securely fixed, without damage

**Data Logger**
- Not damaged or tampered with
- Measuring distance accurately
- Measuring collisions accurately (□ Location and □ Number)
Rocket
- Controller settings checked and recorded
- Tire pressure checked
- Batteries charged, charger working
- Seat, control display and coverings disinfected

Comments:

Calibration

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forwards for 5m (time in sec)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backwards for 5m (time in sec)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forwards Rotations (3.73cm/rotation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backwards Rotations (3.73cm/rotation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- Records when seat is in tilted position

Collision Locations and Allowable Distances

![Diagram of collision locations and allowable distances]
Anti-collision Powered Wheelchair – Daily Inspection Sheet

Switch Operation
☐ Switches are operational
☐ Logic is correct for 9 panels
☐ Foot rest switch stops all movement
☐ Emergency switch stops all movement
☐ Override switch allows movement in ‘denied’ directions

Comments:
________________________________________________________________________
________________________________________________________________________

Skirt
☐ No rips, tears, damage
☐ Latch working

Comments:
________________________________________________________________________
________________________________________________________________________

Data Logger
☐ Not damaged, not tampered with
☐ Previous data downloaded
☐ Toggle set to Measure Start time:_________ End time:_________

Comments:
________________________________________________________________________
________________________________________________________________________

Wheelchair
☐ Seat switch intact
☐ Tires inflated
☐ Battery charged

Comments:
________________________________________________________________________
________________________________________________________________________
## AC Incidents Log

<table>
<thead>
<tr>
<th>Date (day/month/year)</th>
<th>Location of Problem (skirt, switches, bumper, foot rest, data logger, seat)</th>
<th>Description of Incident/Problem (what was involved, observed/possible causes)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
Appendix 19

Study 2: Powered Wheelchair Joystick Controller Safety Inspection Form

| Power Wheelchair Joystick Controller Study |
| Safety Inspection Form                     |
| Completed prior to each driving session    |

<table>
<thead>
<tr>
<th>Date</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspector Initials</td>
<td></td>
</tr>
</tbody>
</table>

**User Interface Cover Intact**
- no breaks
- no sharp edges
- no pinch hazards (casing around joystick)

**Batteries Charged**
- servo motors
- computer
- wheelchair

**Line Tethering Computer to Chair Intact**
- emergency stop buttons working
  - wheelchair (behind backrest)
  - under computer
  - computer key

**Haptic Prompts**
- servo motors operating
- piano wires intact and in correct positions
- logic correct for restricted directions

**Audio Prompts**
- speakers working
- logic correct for restricted directions
- correct prompts for guided directions

**Visual Prompts**
- all LEDs working
- logic correct for restricted directions
# Cleaned According to Hospital Protocols

<table>
<thead>
<tr>
<th>Powered Wheelchair Maintenance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>tires inflated</td>
<td>--</td>
</tr>
<tr>
<td>no external damage</td>
<td>--</td>
</tr>
</tbody>
</table>

# Correct Setting/Positioning for Resident

<table>
<thead>
<tr>
<th>Back support</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>cushion</td>
<td>--</td>
</tr>
<tr>
<td>other accessories</td>
<td>--</td>
</tr>
</tbody>
</table>

# Programmer Settings

<table>
<thead>
<tr>
<th>Date:</th>
<th>Date:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>30</td>
<td>Acceleration</td>
</tr>
<tr>
<td>Deceleration</td>
<td>30</td>
<td>Deceleration</td>
</tr>
<tr>
<td>Turning Acceleration</td>
<td>10</td>
<td>Turning Acceleration</td>
</tr>
<tr>
<td>Turning Deceleration</td>
<td>40</td>
<td>Turning Deceleration</td>
</tr>
<tr>
<td>Forward Speed</td>
<td>50</td>
<td>Forward Speed</td>
</tr>
<tr>
<td>Minimum Forward Speed</td>
<td>20</td>
<td>Minimum Forward Speed</td>
</tr>
<tr>
<td>Reverse Speed</td>
<td>40</td>
<td>Reverse Speed</td>
</tr>
<tr>
<td>Turning Speed Max</td>
<td>30</td>
<td>Turning Speed Max</td>
</tr>
<tr>
<td>Turning Speed Min</td>
<td>20</td>
<td>Turning Speed Min</td>
</tr>
<tr>
<td>Torque</td>
<td>70</td>
<td>Torque</td>
</tr>
<tr>
<td>Tumor Dampening</td>
<td>0</td>
<td>Tumor Dampening</td>
</tr>
<tr>
<td>Power</td>
<td>70</td>
<td>Power</td>
</tr>
<tr>
<td>Sleep Timer</td>
<td>0</td>
<td>Sleep Timer</td>
</tr>
<tr>
<td>Forward Throw</td>
<td>100</td>
<td>Forward Throw</td>
</tr>
<tr>
<td>Reverse Throw</td>
<td>100</td>
<td>Reverse Throw</td>
</tr>
<tr>
<td>R/L Throw</td>
<td>100</td>
<td>R/L Throw</td>
</tr>
<tr>
<td>Invert Joystick</td>
<td>no</td>
<td>Invert Joystick</td>
</tr>
<tr>
<td>Steer Correct</td>
<td>0</td>
<td>Steer Correct</td>
</tr>
</tbody>
</table>

# Comments

---

---

---
Appendix 20

Study 1: Sample MATLAB code to process data collected from distance loggers and sample results

Example is for:
- distances traveled in manual wheelchair (not power wheelchair)
- one resident (coded as MH)

Raw data files from distance loggers (Centre for Studies in Aging, Toronto, ON)
- consisted of ‘HI’ and ‘LO’ files which coded forward or backward distances, seat switch on/off (indicated wheelchair occupied), hand grip switches on/off (indicated assisted mobility)
- files named by date at start of data collection period (for example, MH1013HI and MH1013LO)
- ‘HI’ and ‘LO’ files sequentially read by MATLAB program and processed to output total and independent distances travelled for each day (for manual wheelchair)

Partial list of sample raw data files (file name for list: MHmanualfiles.txt)

<table>
<thead>
<tr>
<th>File name</th>
<th>Start date</th>
<th>Start time</th>
<th>End date</th>
<th>End time</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH1017</td>
<td>17-Oct-2006</td>
<td>09:49</td>
<td>18-Oct-2006</td>
<td>18:00</td>
</tr>
<tr>
<td>MH1024</td>
<td>24-Oct-2006</td>
<td>14:00</td>
<td>25-Oct-2006</td>
<td>16:35</td>
</tr>
<tr>
<td>MH1031</td>
<td>31-Oct-2006</td>
<td>17:37</td>
<td>03-Nov-2006</td>
<td>14:35</td>
</tr>
<tr>
<td>MH1103</td>
<td>03-Nov-2006</td>
<td>14:37</td>
<td>04-Nov-2006</td>
<td>17:51</td>
</tr>
<tr>
<td>MH1106</td>
<td>04-Nov-2006</td>
<td>17:52</td>
<td>07-Nov-2006</td>
<td>16:32</td>
</tr>
</tbody>
</table>

Sample code (MATLAB Version 7.4.0)

```matlab
%Opening up the XXmanualfiles index file into a structure called Index.
fid=fopen('MHmanualfiles.txt');
Index=textscan(fid,'%6c %17c %17c');
fclose(fid);

%Changing the structure into a matrix, so can read off end row and
%element to open the files in the XXmanualfiles.
Index=cell2mat(Index);

%Extracting subject id from first 2 characters of Index
subid=Index(1,1:2);

filename = sprintf('%s%s',subid,'output.txt');
delete(filename);

%Getting variables in place to make the loop to look at each row and
%corresponding files in the XXmanualfiles.
[NumIndexRows,a]=size(Index);

%Making the dialog box to enter the start of wake up time (saved as UpTime).
%MH normally does not get up before 10, but he may get up early for
```
%appointments; conservative estimate may be 8am.
prompt={'Enter start of wake up time (HH)'};
name='Input start time';
umlines=1;
defaultanswer={'08'};
answer=inputdlg(prompt,name,numlines,defaultanswer);
UpTime = str2num(cell2mat(answer))/24;

%Making the dialog box to enter the start of down time (saved as BedTime).
%MH normally back to be by dinner time, but on occasion has been up later
%when daughter visiting; conservative estimate 21.
prompt={'Enter start of down time (HH)'};
name='Input down time';
umlines=1;
defaultanswer={'21'};
answer=inputdlg(prompt,name,numlines,defaultanswer);
BedTime = str2num(cell2mat(answer))/24;

%Big huge loop to run program for each line in XXmanualfiles.
k=1;
for k=1:NumIndexRows

%Opening the HI and LO dat files for the kth row item.
File=Index(k,1:6);
a='LO.dat';
Lofile=strcat(File,a);
a='HI.dat';
Hifile=strcat(File,a);

fid=fopen(Lofile);
Rawlo=fscanf(fid, '%g', [1 inf]);
Rawlo=Rawlo';
fclose(fid);

fid=fopen(Hifile);
Rawhi=fscanf(fid, '%g', [1 inf]);
Rawhi=Rawhi';
fclose(fid);

%Getting the start and end times of the kth row item.
StartTime=Index(k,7:23);
StartTime=datenum(StartTime);

EndTime=Index(k,24:40);
EndTime=datenum(EndTime);

%Taking the start and end times and making a matrix of numbers 5 seconds
%apart between the two. New matrix is called Times.
Times=StartTime:datenum(0,0,0,0,0,5):EndTime;
Times=Times';

%Using the Times matrix's rows as a counter of rows to crop the end of the
%two raw files to correspond to the Times matrix (i.e. taking off the zeros
%of non-data at the end of the file, so just saving disc space on this one)
NumRows=size(Times);
NumRows(:,2)=[];
Rawlo(NumRows+1:120959,:)=[]; %120959 is the max. no. rows the data logger can maintain!!!
Rawhi(NumRows+1:120959,:)=[];

%To remove all the 1 rotations:
%if there is 129 in Rawhi then change it to 128
%if there is 1 in Rawhi change it to 0
%if there is 129 in Rawlo then change it to 128
%if there is 1 in Rawlo change it to 0
for J = 1:NumRows
    if Rawhi(J,1)==129
        Rawhi(J,1)=128;
    end
    if Rawlo(J,1)==129
        Rawlo(J,1)=128;
    end
end
elseif Rawhi(J,1)==1
    Rawhi(J,1)=0;
end
end

for J = 1:NumRows
    if Rawlo(J,1)==129
        Rawlo(J,1)=128;
    elseif Rawlo(J,1)==1
        Rawlo(J,1)=0;
    end
end

%To find the number of errors 255/255
LoggerError = find(Rawhi==255 & Rawlo==255);

%If Rawhi=255 & Rawlo=255, and error has occurred; change both to the value
%above it
J=1;
for J = 2:NumRows
    if Rawhi(J,1)==255 & Rawlo(J,1)==255
        Rawhi(J,1)=Rawhi(J-1,1);
        Rawlo(J,1)=Rawlo(J-1,1);
    end
end

%To remove the "off" handle switches when they should be "on" given the
%ones around it are "on"; this will check 2 before and 3 after and change
%the skipped value to "on"
for J = 3:NumRows-3
    if (Rawhi(J-1)>=128|Rawhi(J-2)>=128) & (Rawhi(J+1)>=128|Rawhi(J+2)>=128|Rawhi(J+3)>=128) &
        Rawhi(J)<128;
        Rawhi(J)=Rawhi(J)+128;
    end
end

%To include maximum independent travel speed of resident: for each interval,
%the maximum number of rotations the resident is likely to travel based on
%time trial would be 18 rotations per interval (forwards, likely slower
%for backwards direction); using a 10% overestimation a conservative estimate
%would be max 20 rotations forwards or backwards. MH speed on timed test: 13.3cm/sec.
%If the hand switch is "off" (Rawhi<128) and Rawhi>20 or
%Rawlo>148 (20 rotations + 128 for seat switch) then the hand switch is changed
%to "on" (number of rotations + 128 for hand switch)
for J = 1:NumRows
    if Rawhi(J,1)<128 & Rawlo(J,1)>=148
        Rawhi(J,1)=Rawhi(J,1)+128;
    end
    if Rawhi(J,1)<128 & Rawhi(J,1)>=20 & Rawlo(J,1)>=128
        Rawhi(J,1)=Rawhi(J,1)+128;
    end
end

%To clear the times when resident is not sitting in the chair, but the
%seat switch is activated overnight i.e. if something is left on the chair.
%This is where the dialog prompts are from.

for i=1:length(Times)
    Day=floor(Times(i));
    if Times(i)-Day<=UpTime & Rawlo(i)>=128;
        Rawlo(i)=0;
        Rawhi(i)=0;
    elseif Times(i)-Day>=BedTime & Rawlo(i)>=128;
        Rawlo(i)=0;
        Rawhi(i)=0;
    end
end

%Calculating total distance travelled by the resident (include all distances
%when seat switch is on, Rawlo >128),
Calculating distance travelled by the resident independently
%(include only distances when seat switch is on, Rawlo >128, and hand switch is off, Rawhi <128)
%Using a for loop to go through each time interval (the rows) and an if/else loop to take out the 128's from the distance calculation.
%Distances calculated as 1 revolution x 0.0373 = number of meters travelled in time interval.

for MW: Lo(forwards) Hi(backwards) Lo(seat) Hi(grip)

Calculating the forwards distance when seat switch is on
Distance1 = [];
Distance2 = [];
IndDis1 = [];
IndDis2 = [];
Switch1 = [];
Switch2 = [];
SumDis1 = [];
SumDis2 = [];
SumDis = [];
SumIndDis1 = [];
SumIndDis2 = [];
SumIndDis = [];

Calculating the forwards and backwards distance when seat switch is on
for J = 1:NumRows
    if Rawlo(J,1)>=128
        Distance1(J,1) = (Rawlo(J,1)-128)*0.0373;
    else
        Distance1(J,1) = 0;
    end
    if Rawhi(J,1)<128
        Distance2(J,1) = Rawhi(J,1)*0.0373;
    else
        Distance2(J,1) = (Rawhi(J,1)-128)*0.0373;
    end
end

Calculating the independent distance forwards and backwards
for J = 1:NumRows
    if Rawlo(J,1)>=128 & Rawhi(J,1)<128
        IndDis2(J,1) = Rawhi(J,1)*0.0373;
        IndDis1(J,1) = (Rawlo(J,1)-128)*0.0373;
    else
        IndDis2(J,1) = 0;
        IndDis1(J,1) = 0;
    end
end

To determine the number of days in the set of data
Days = floor(Times);
NDays = max(Days)-min(Days)+1;

To calculate the distances travelled for each day
for J = 1:NDays
    SumDis1(J) = sum(Distance1(find(Days==min(Days)+J-1)));
    SumDis2(J) = sum(Distance2(find(Days==min(Days)+J-1)));
    SumDis(J) = SumDis1(J)+ SumDis2(J);
end

To calculate the independent distances travelled for each day
for J = 1:NDays
    SumIndDis1(J) = sum(IndDis1(find(Days==min(Days)+J-1)));
    SumIndDis2(J) = sum(IndDis2(find(Days==min(Days)+J-1)));
    SumIndDis(J) = SumIndDis1(J)+ SumIndDis2(J);
end

if (k==1)
    firstday=Days(1);
end
Dates = min(Days):max(Days);

Days = Days - firstday;

fid = fopen(filename, 'a+');
fclose('all');

Output=load(filename);

temp = [Dates' (min(Days):max(Days))' SumDis1' SumDis2' SumDis' SumIndDis1' SumIndDis2' SumIndDis'];

%If already process data for that day, adds the new data with the same day
to that total
if ~isempty(Output)& ~isempty(find(temp(1, 2)==Output(:,2)))
    Output(end,3:8)=Output(end,3:8)+temp(1,3:8);
    Output = [Output; temp(2:end, :)];
else Output = [Output; temp];
end
delete(filename);

fid=fopen(filename,'a+');
fprintf(fid,'%f %2.0f  %10.0f  %10.0f  %10.0f  %10.0f  %10.0f  %10.0f
');
fclose('all');

k=k+1;
end

Mobility data output
• outputs were total and independent distances traveled over each day in study

Partial list of sample output (file name for list: MHoutput.txt)

<table>
<thead>
<tr>
<th>Day in study</th>
<th>SumDis1</th>
<th>SumDis2</th>
<th>SumDis</th>
<th>SumIndDis1</th>
<th>SumIndDis2</th>
<th>SumIndDis</th>
</tr>
</thead>
<tbody>
<tr>
<td>732963.000000</td>
<td>0</td>
<td>36</td>
<td>4</td>
<td>40</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>732964.000000</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>732965.000000</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>732966.000000</td>
<td>3</td>
<td>308</td>
<td>38</td>
<td>346</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>732967.000000</td>
<td>4</td>
<td>162</td>
<td>31</td>
<td>193</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
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<td>650</td>
<td>35</td>
<td>685</td>
<td>1</td>
<td>2</td>
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<tr>
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<td>732970.000000</td>
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<td>13</td>
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<td>1</td>
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<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
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<tr>
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<td>116</td>
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<td>1</td>
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<tr>
<td>732973.000000</td>
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<td>5</td>
<td>9</td>
<td>4</td>
<td>4</td>
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<td>0</td>
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<td>647</td>
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<td>2</td>
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<td>4</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>732984.000000</td>
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<td>158</td>
<td>22</td>
<td>179</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>732985.000000</td>
<td>22</td>
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<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>732987.000000</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>732988.000000</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
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<td>0</td>
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<td>0</td>
</tr>
</tbody>
</table>
Appendix 21

Study 1: Summary tables of qualitative data collected

Focus Groups

<table>
<thead>
<tr>
<th>Study Phase (Groups)</th>
<th>Total Number of Participants</th>
<th>Approximate Duration</th>
<th>Documentation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre Study (3 groups)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>physical support unit</td>
<td>3 (2 nurses, 1 OT)</td>
<td>group was approx 1 h: 42min (recording)</td>
<td>audiotape /transcript</td>
<td>FG1</td>
</tr>
<tr>
<td>physical support unit</td>
<td>10 (8 nurses, 1 PCM, 1 PT)</td>
<td>group was approx 1 h: 43min (recording)</td>
<td>audiotape /transcript</td>
<td>FG2</td>
</tr>
<tr>
<td>cognitive support unit</td>
<td>12 (5 nurses, 3 students, 1 PT, 1 PTA, 1 PCM, 1 OT)</td>
<td>group was approx 1 h: 36min (recording)</td>
<td>audiotape /transcript</td>
<td>FG3</td>
</tr>
<tr>
<td><strong>Post Study (2 Groups)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>physical support unit</td>
<td>6 (nurses)</td>
<td>group was approx 1h: 19:59 min (recording)</td>
<td>digital audio/transcript</td>
<td>FG4</td>
</tr>
<tr>
<td>cognitive support unit</td>
<td>6 (4 nurses, 2 PCM)</td>
<td>group was approx 1h: 32:05 min (recording)</td>
<td>digital audio/transcript</td>
<td>FG5</td>
</tr>
<tr>
<td>total staff: 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total time: 121min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total staff: 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total time: 52min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>informal meeting with nursing unit/inservice - physical support unit</td>
<td>8 (day and evening staff)</td>
<td>group was approx 1h</td>
<td>notes</td>
<td>FG6</td>
</tr>
<tr>
<td>informal meeting with nursing unit/inservice - physical support unit</td>
<td>10 (day and evening staff)</td>
<td>group was approx 1h</td>
<td>notes</td>
<td>FG7</td>
</tr>
<tr>
<td>total staff: 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total time: 173min</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Interviews with Resident Drivers

<table>
<thead>
<tr>
<th>Resident 1 (R1)</th>
<th>Approximate Duration (min:sec)</th>
<th>Documentation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial interview</td>
<td>30</td>
<td>notes</td>
<td>Int1.2</td>
</tr>
<tr>
<td>initial (baseline)</td>
<td>15</td>
<td>notes</td>
<td>Int1.3</td>
</tr>
<tr>
<td>interview (after training re: recommendations)</td>
<td>20</td>
<td>notes</td>
<td>Int1.4</td>
</tr>
<tr>
<td>final interview (after training)</td>
<td>31 (recording)</td>
<td>audiotape /transcript</td>
<td>Int1.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resident 2 (R2)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>initial interview</td>
<td>15</td>
<td>notes</td>
<td>Int2.2</td>
</tr>
<tr>
<td>end of training</td>
<td>30</td>
<td>notes</td>
<td>Int2.6</td>
</tr>
<tr>
<td>use phase</td>
<td>23</td>
<td>audiotape /transcript</td>
<td>Int2.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resident 3 (R3)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>initial interview</td>
<td>15</td>
<td>notes</td>
<td>Int3.1</td>
</tr>
<tr>
<td>R3 + caregiver/sitter (baseline)</td>
<td>20</td>
<td>notes</td>
<td>Int3.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resident 4 (R4)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R4 + daughter (baseline)</td>
<td>10</td>
<td>notes</td>
<td>Int4.1</td>
</tr>
<tr>
<td>R4 + caregiver (baseline)</td>
<td>20</td>
<td>notes</td>
<td>Int4.4</td>
</tr>
<tr>
<td>R4 + daughter (end of training)</td>
<td>25:05 (recording)</td>
<td>digital audio/transcript</td>
<td>Int4.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resident 5 (R5)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>initial interview</td>
<td>20</td>
<td>notes</td>
<td>Int5.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resident 6 (R6)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>initial interview</td>
<td>9:31</td>
<td>digital audio/transcript</td>
<td>Int6.1</td>
</tr>
<tr>
<td>interview (after training phase)</td>
<td>15:53</td>
<td>digital audio/transcript</td>
<td>Int6.5</td>
</tr>
</tbody>
</table>

* Coding Scheme: Interview(Subject Number).(Interview Document Number)
### Resident Structured Observations

<table>
<thead>
<tr>
<th>Resident</th>
<th>Total Number of Sessions (2h each)</th>
<th>Approximate Total Duration (h)</th>
<th>Total Number of Observations</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>39</td>
<td>78</td>
<td>1031</td>
<td>Obs1.1-39</td>
</tr>
<tr>
<td>R2</td>
<td>88</td>
<td>176</td>
<td>2286</td>
<td>Obs2.1-88</td>
</tr>
<tr>
<td>R3</td>
<td>36</td>
<td>72</td>
<td>1050</td>
<td>Obs3.1-36</td>
</tr>
<tr>
<td>R4</td>
<td>31</td>
<td>62</td>
<td>1000</td>
<td>Obs4.1-31</td>
</tr>
<tr>
<td>R5</td>
<td>67</td>
<td>134</td>
<td>1842</td>
<td>Obs5.1-67</td>
</tr>
<tr>
<td>R6</td>
<td>67</td>
<td>134</td>
<td>1825</td>
<td>Obs6.1-67</td>
</tr>
<tr>
<td><strong>totals</strong></td>
<td>328</td>
<td>656</td>
<td>9034</td>
<td></td>
</tr>
</tbody>
</table>

* Coding Scheme: Observation Subject Number).(Session Number)*

#### Other Observations/ Fieldnotes

<table>
<thead>
<tr>
<th>Resident</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>-</td>
</tr>
<tr>
<td>R2</td>
<td>Obs2.90-2.117</td>
</tr>
<tr>
<td>R3</td>
<td>Obs3.37</td>
</tr>
<tr>
<td>R4</td>
<td>-</td>
</tr>
<tr>
<td>R5</td>
<td>Obs5.68-70</td>
</tr>
<tr>
<td>R6</td>
<td>Obs6.68-71</td>
</tr>
</tbody>
</table>

### Resident Driving Training

<table>
<thead>
<tr>
<th>Resident</th>
<th>Number of Sessions</th>
<th>Approximate Duration (h:min)</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>12</td>
<td>17:43</td>
<td>Obs1.DT1-12</td>
</tr>
<tr>
<td>R2</td>
<td>18</td>
<td>27:15</td>
<td>Obs2.DT1-18</td>
</tr>
<tr>
<td>R3</td>
<td>1</td>
<td>1:04</td>
<td>Obs3.DT1</td>
</tr>
<tr>
<td>R4</td>
<td>4</td>
<td>7:46</td>
<td>Obs4.DT1-4</td>
</tr>
<tr>
<td>R5</td>
<td>12</td>
<td>18:04</td>
<td>Obs5.DT1-12</td>
</tr>
<tr>
<td>R6</td>
<td>12</td>
<td>11:09</td>
<td>Obs6.DT1-12</td>
</tr>
<tr>
<td><strong>totals</strong></td>
<td>59</td>
<td>83h: 1min</td>
<td></td>
</tr>
</tbody>
</table>

* Coding Scheme: Observation(Subject Number).(Training)(Session Number)*

** Resident 1 had 12 driving sessions and training was completed; he drove another 5 times as practice sessions until a plan was worked out with research and nursing home staff re: usage and maintenance; 1 day of lost data due to technical error

*** Resident 2 - B phase officially ended after session 18; 2 days of lost data due to technical error
**Interviews with Family**

<table>
<thead>
<tr>
<th></th>
<th>Approximate Duration (min:sec)</th>
<th>Documentation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident 1 (R1)</td>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resident 2 (R2)</td>
<td>R2’s daughter, son-in-law (start of training) 20 notes</td>
<td>Int2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R2’s daughter (during training) 30 notes</td>
<td>Int2.5</td>
<td></td>
</tr>
<tr>
<td>Resident 3 (R3)</td>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resident 4 (R4)</td>
<td>R4’s dau (baseline) 10 notes</td>
<td>Int4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R4’s dau (phone call, end of training) 15 notes</td>
<td>Int4.8</td>
<td></td>
</tr>
<tr>
<td>Resident 5 (R5)</td>
<td>R5’s son (on phone) 10 notes</td>
<td>Int5.3</td>
<td></td>
</tr>
<tr>
<td>Resident 6 (R6)</td>
<td>none</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Coding Scheme: Interview(Subject Number).(Interview Document Number)*

**Interviews with Other Residents**

<table>
<thead>
<tr>
<th></th>
<th>Approximate Duration (min:sec)</th>
<th>Documentation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR1 + spouse</td>
<td>20</td>
<td>notes</td>
<td>IntR.1</td>
</tr>
<tr>
<td>OR2</td>
<td>13</td>
<td>audiotape /transcript</td>
<td>IntR.2</td>
</tr>
<tr>
<td>OR3 + OR4</td>
<td>36</td>
<td>audiotape /transcript</td>
<td>IntR.3-4</td>
</tr>
<tr>
<td>OR5</td>
<td>27</td>
<td>audiotape /transcript</td>
<td>IntR.5</td>
</tr>
<tr>
<td>OR6</td>
<td>10:17</td>
<td>digital audio/transcript</td>
<td>IntR.6</td>
</tr>
<tr>
<td><strong>6 residents + 1 spouse</strong></td>
<td><strong>total time: 106 min</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resident</td>
<td>Approximate Duration (min:sec)</td>
<td>Documentation</td>
<td>Code</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td><strong>Resident 1 (R1)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OT - phone call (baseline)</td>
<td>15</td>
<td>notes</td>
<td>Int1.1</td>
</tr>
<tr>
<td>2 nurses (after training)</td>
<td>20</td>
<td>notes</td>
<td>Int1.5</td>
</tr>
<tr>
<td><strong>Resident 2 (R2)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 primary nurses (baseline)</td>
<td>25</td>
<td>notes</td>
<td>Int2.1</td>
</tr>
<tr>
<td>R2’s primary nurse (end of training), same as one of above</td>
<td>10</td>
<td>notes</td>
<td>Int2.4</td>
</tr>
<tr>
<td>R2’s PT (end of training)</td>
<td>13</td>
<td>audiotape /transcript</td>
<td>Int2.8</td>
</tr>
<tr>
<td>R2’s chaplain (end of training)</td>
<td>22</td>
<td>audiotape /transcript</td>
<td>Int2.9</td>
</tr>
<tr>
<td><strong>Resident 3 (R3)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3’s primary nurse (after training session)</td>
<td>5</td>
<td>notes</td>
<td>Int3.3</td>
</tr>
<tr>
<td>R3’s primary nurse + another nurse (after training)</td>
<td>20</td>
<td>notes</td>
<td>Int3.4</td>
</tr>
<tr>
<td><strong>Resident 4 (R4)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4’s nurse (baseline)</td>
<td>5</td>
<td>notes</td>
<td>Int4.2</td>
</tr>
<tr>
<td>R4’s PCM (baseline)</td>
<td>5</td>
<td>notes</td>
<td>Int4.3</td>
</tr>
<tr>
<td>R4’s caregiver (baseline)</td>
<td>15</td>
<td>notes</td>
<td>Int4.5</td>
</tr>
<tr>
<td>R4’s PT (baseline)</td>
<td>7</td>
<td>audiotape /transcript</td>
<td>Int4.6</td>
</tr>
<tr>
<td><strong>Resident 5 (R5)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5’s nurse evening (baseline)</td>
<td>5</td>
<td>notes</td>
<td>Int5.1</td>
</tr>
<tr>
<td>R5’s nurse day (baseline)</td>
<td>10</td>
<td>notes</td>
<td>Int5.2</td>
</tr>
<tr>
<td>R5’s 1 nurse, 1 student nurse (baseline)</td>
<td>11</td>
<td>audiotape /transcript</td>
<td>Int5.5</td>
</tr>
<tr>
<td>R5’s music therapist (baseline)</td>
<td>23</td>
<td>audiotape /transcript</td>
<td>Int5.6</td>
</tr>
<tr>
<td>R5’s 1 rec therapist, 1 student rec therapist (baseline)</td>
<td>21</td>
<td>audiotape /transcript</td>
<td>Int5.7</td>
</tr>
<tr>
<td><strong>Resident 6 (R6)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R6’s PT (baseline)</td>
<td>11:57</td>
<td>digital audio/transcript</td>
<td>Int6.2</td>
</tr>
<tr>
<td>R6’s nurse (baseline)</td>
<td>4:12</td>
<td>digital audio/transcript</td>
<td>Int6.3</td>
</tr>
<tr>
<td>R6’s RT (baseline)</td>
<td>12:57</td>
<td>digital audio/transcript</td>
<td>Int6.4</td>
</tr>
</tbody>
</table>

* Coding Scheme: Interview(Subject Number).(Interview Document Number)
## Appendix 22

### Study 2: Characteristics of resident participants

<table>
<thead>
<tr>
<th>Resident</th>
<th>Cognitive Function</th>
<th>Vision and Perception</th>
<th>Behaviour and Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>George</td>
<td>MMSE score: 20/30</td>
<td>• glasses</td>
<td>• friendly and agreeable,</td>
</tr>
<tr>
<td></td>
<td>Clock Drawing Test score: 4 (cognitive deficit, moderate visuospatial disorganization of times)</td>
<td>• decreased near (20/100) and far (20/40) visual acuity</td>
<td>enthusiastic about participation</td>
</tr>
<tr>
<td></td>
<td>Trail Making Test A score: &gt;180 sec, below 10th percentile for age</td>
<td>• peripheral vision ok</td>
<td>• self-directed behaviour</td>
</tr>
<tr>
<td></td>
<td>Trail Making Test B score: did not complete</td>
<td>• good visual scanning</td>
<td>• slurred speech, many words unintelligible, expresses his basic needs and wishes well</td>
</tr>
<tr>
<td></td>
<td>Comments</td>
<td>• MVPT*: standard score 62 (range 53-71 for CI 90%), percentile rank 1 for age, very low performance; response time index 8.9s, 2-5 percentile for 55-69 age group, extremely low performance</td>
<td>• glasses</td>
</tr>
<tr>
<td></td>
<td>• long term memory mostly intact, short term memory seems intact (remembers people, events, locations of things)</td>
<td>• decreased near visual acuity (20/50)</td>
<td>• self-directed behaviour</td>
</tr>
<tr>
<td></td>
<td>• can be distractible by other people or sounds, follows 2 step instructions</td>
<td>• good far visual acuity (20/20)</td>
<td>• very agreeable and willing to participate, likes to do new things</td>
</tr>
<tr>
<td></td>
<td>• sometimes does not see obstacles, decreased attention, slow response to obstacles</td>
<td>• peripheral vision ok</td>
<td>• clear communication, very articulate, does not recall what he said from one day to next</td>
</tr>
<tr>
<td></td>
<td>• glasses</td>
<td>• good visual scanning</td>
<td>• very good social skills, can mask short term memory deficits well</td>
</tr>
</tbody>
</table>

Mark

| MMSE score: 24/30 | Clock Drawing Test score: 1 (no errors on task) | • glasses |
| Trail Making Test A score: 72 sec, below 10th percentile for age | • self-directed behaviour |
| Trail Making Test B score: 223 sec, below 10th percentile for age | • very agreeable and willing to participate, likes to do new things |
| Comments | • does not remember day to day events, remembers his routine (meal times, and locations of things), long term memory for events prior to injury | • clear communication, very articulate, does not recall what he said from one day to next |
| | • able to attend to task, follows 3 instructions | • very good social skills, can mask short term memory deficits well |
Jim

**MMSE score:** 24/30

**Clock Drawing Test score:** 5 (cognitive deficit, severe visuospatial disorganization of times)

**Trail Making Test A score:** 365 sec, below 10th percentile for age

**Trail Making Test B score:** did not complete

**Comments**
- Long term memory mostly intact, remembers names of people, events and locations of things
- Distractible, will ask for repetition of questions, sometimes does not see obstacles, decreased planning, does not always remember what he is to do, slow response to obstacles
- Follows 1 step simple directions

**Lilian**

**MMSE score:** 24/30

**Clock Drawing Test score:** 2 (minor visuospatial errors)

**Trail Making Test A score:** 161 sec, below 10th percentile for age

**Trail Making Test B score:** 870 sec, below 10th percentile for age

**Comments**
- Good long term and short term memory
- Generally attends well, inattention to right foot
- Follows directions well
• delayed response, decreased control of speed, doesn’t always notice obstacles, decreased attention for 70+ age group, below average performance

Gerry

MMSE score: 13/30 (language issues)

Clock Drawing Test score: 3 (cognitive deficit, inaccurate representation of time when visuospatial organization shows minor deviations)

Trail Making Test A score: 366 sec, below 10th percentile for age
Trail Making Test B score: did not complete

Comments
• generally slow to respond, decreased attention or neglect on R side?
• able to attend well to task
• long term memory patchy, some short term memory for people, times of events, locations of things
• follows simple verbal directions in context
• can only read numbers aloud for visual acuity testing
• decreased near visual acuity (20/70)
• decreased far visual acuity (could not read numbers at 20/50)
• peripheral vision ok
• prompting necessary to scan lower quadrants and to left
• MVPT*: standard score 74 (range 65-83 for CI 90%), percentile rank 4 for age, low performance; response time index 13.0s, 5 percentile for 70+ age group, extremely low performance
• willing to participate if willing to wait to find out what he wants
• expressive language difficulties, able to make many of his needs known through gestures and select words
• can be frustrated with expressing himself
• can be moody
• very delayed responses to questions, or sometimes no response

MMSE: Mini Mental Status Exam (Folstein, Folstein, McHugh, & Fanjiang 2001)
Clock Drawing Test: scoring based on Shulman, Gold, Cohen, & Zucchero (1993)
Trail Making Test A and B: norms and scoring from Tombaugh (2004)
MVPT-3: Motor Free Visual Perceptual Test – standard score compared to same-aged peers (normative sample, based on chronological age); CI = Confidence Interval (Colarusso & Hammill, 2003)
## Appendix 23

### Study 2: Summary of resident mobility

<table>
<thead>
<tr>
<th>Resident</th>
<th>Transfers</th>
<th>Manual wheelchair mobility</th>
<th>Driving history</th>
</tr>
</thead>
</table>
| George  | • self transfers | • wheels slowly with legs, wheels backwards often, pulls on handrails along hallway frequently, mobile in room and common areas | • driven car  
• used scooter a couple of times at shopping centre |
| Mark    | • self transfers | • wheels with legs and sometimes arms, pulls on handrails along hallway frequently, mobile in room and common areas | • operated many vehicles – cars, trucks, boats, plane, skid steer loaders  
• never used power mobility device |
| Jim     | • independent standing transfer with ceiling to floor pole with horizontal bar | • wheels minimally with arms and legs in room, says wheelchair is heavy, wheeled by others outside room | • driven car, sailed boats  
• never used power mobility device |
| Lilian  | • 1-person assist with sit to stand lift | • can only turn left (only left arm has functional mobility) in room, wheeled by others outside room | • never driven car  
• never used power mobility device |
| Gerry   | • 1-person assist with standing transfer | • wheels slowly with left arm and leg for short distances in room or lounge area, wheeled by others for longer distances | • driven car  
• never used power mobility device |
Appendix 24

Study 2: Summary table of qualitative data collected

<table>
<thead>
<tr>
<th>Resident</th>
<th>Total driving training time</th>
<th>Total interview time</th>
</tr>
</thead>
<tbody>
<tr>
<td>George</td>
<td>6h:44min</td>
<td>1h:3min</td>
</tr>
<tr>
<td>Mark</td>
<td>4h:43min</td>
<td>1h:37min</td>
</tr>
<tr>
<td>Jim</td>
<td>5h:25min</td>
<td>50 min</td>
</tr>
<tr>
<td>Lilian</td>
<td>6h:25min</td>
<td>70 min</td>
</tr>
<tr>
<td>Gerry</td>
<td>4h:31min</td>
<td>1h:34min</td>
</tr>
</tbody>
</table>
Appendix 25

Study 2: Results of the Power-mobility Indoor Driving Assessment (PIDA) for all participants

<table>
<thead>
<tr>
<th>Item / Score</th>
<th>George</th>
<th>Mark</th>
<th>Jim</th>
<th>Lilian</th>
<th>Gerry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bedroom</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Accessing bed - R</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2 Accessing bed - L</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3 Approaching dresser</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4 Approaching closet</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bathroom</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Into bathroom</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Approaching sink</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Approaching toilet</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Exit bathroom</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Doors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Sliding doors - mat trigger</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10 Swing open doors - mat trigger</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Automatic doors - button trigger</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Regular door</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Elevators</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Entering elevator</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>14 Spacing in elevator</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>15 Exiting elevator</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Parking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Parking under table</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>17 Parking beside table</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>18 Back-in parking</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>19 Parallel parking</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Ramps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Up a ramp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 Down a ramp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled driving</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Turning R</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Turning L</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>180 deg. turn</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Driving backwards</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Manipulating - congested area</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Manoeuvrability</td>
<td>4</td>
<td>4</td>
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<tr>
<td>Obstacles - unexpected</td>
<td>3</td>
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<tr>
<td>Speed selection</td>
<td>4</td>
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<tr>
<td>Sharing public space</td>
<td>3</td>
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</tbody>
</table>

| sum of scores for each applicable item | 76  | 98  | 51  | 58  | 53  |
| 4*number of applicable items         | 100 | 108 | 80  | 88  | 60  |
| number of applicable items            | 25  | 27  | 20  | 22  | 15  |
| **Total score (%)**                   | **76** | **91** | **64** | **66** | **88** |

Total score (%) = (sum of scores for each applicable item)/(4 * (number of applicable items)) * 100

* only applicable items scored (ones that resident identified as something he/she needs or wishes to do)
* if only did one time, not scored
* scoring was cumulative over several sessions (could not go through all items in one session)
* pacing of sessions determined by activity tolerance and performance of resident
* these were scores after minimal practice
* practicing of each item dependent on resident’s preference and investigator’s clinical judgement
* scored the last performance of items during 6 sessions
* scored with anti-collision system, which eliminates the “2” score
* residents would require more practice beyond 6 sessions before 2nd administration
* residents used power wheelchair device for 8 sessions
* investigator present at all times to give instructions to resident and operate computer
* sessions were approximately 1 hr duration
* first session - general orientation
* subsequent sessions - warm up, then tasks based on self-identified goals and items on PIDA