

USING A 3D HAND MOTION CONTROLLER FOR REACHING TASKS IN A POWERED WHEELCHAIR SIMULATOR

Gordon Tao

M.Sc. Rehabilitation Science

School of Physical and Occupational Therapy

Faculty of Medicine

McGill University

Montréal, Québec, Canada

August 15, 2014

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree
of Master of Science

ACKNOWLEDGMENTS

I would like to first thank my supervisor, Dr. Philippe Archambault, for his guidance and support through every step of this project and my thesis advisory committee, Dr. Mindy F. Levin and Dr. Anouk Lamontagne, for their reassuring support. This project would not have been possible without the help of Helen Zhu and Elise Busilacchi during data collection and processing. I would also like to thank Christian Beaudoin, Frederic Bobohn, and Frederic Vicaire for their help in software development. Furthermore, thank you to Igor Sorokin for building the wonderful props.

This project was funded in part by Le Projet Stratégique Innovant of CRIR.

To my parents, I dedicate this thesis to you. It is your drive, your wisdom, and your perseverance that has inspired me in this pursuit. To all my family, friends, and the gang at the JRH, thank you for your support, encouragement and understanding. Finally, thank you to my dearest of friends, Aleta Greunewald, for seeing me through all of the things.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES.....	v
LIST OF FIGURES	vi
ABSTRACT	vii
ABRÉGÉ	ix
PREFACE	xi
CHAPTER 1: REVIEW OF THE LITERATURE	1
1.1 INSUFFICIENT TRAINING FOR POWER WHEELCHAIR USERS	1
1.2 VIRTUAL REALITY SIMULATORS ARE USEFUL FOR TRAINING	2
1.2.1 Transferability	3
1.2.2 Training in the clinical setting	4
1.2.3 Application of VR to powered wheelchair training.....	6
1.2.4 Existing power wheelchair simulators	8
1.3 REACHING AND MOBILITY	10
1.4 REACHING IN VR: TECHNOLOGY OVERVIEW	11
1.5 COMPARING VR AND REAL WORLD.....	13
1.5.1 Task Performance	13
1.5.2 Sense of Presence	15
1.5.3 Population	16
CHAPTER 2: RATIONALE, OBJECTIVES, AND HYPOTHESES.....	18
2.1 RATIONALE.....	18
2.2 OBJECTIVES	19
2.3 HYPOTHESES	19
CHAPTER 3: MANUSCRIPT	21
3.1 ABSTRACT.....	22
3.2 INTRODUCTION	23
3.3 METHODS	25
3.3.1 Population and Sample	25
3.3.2 Procedures.....	25
3.3.3 Data Collection.....	28
3.3.4 Analysis	29
3.4 RESULTS.....	32
3.4.1 Task Times.....	33
3.4.2 Discrete Movements.....	36

3.4.3 Task Analysis	41
3.4.4 Presence.....	46
3.4.5 Questionnaire and Feedback	46
3.5 DISCUSSION	51
3.5.1 Task Performance	51
3.5.2 Presence.....	55
3.5.3 Participant Feedback	56
3.5.4 Limitations	56
3.5.5 Conclusion	57
3.6 ACKNOWLEDGEMENTS	58
CHAPTER 4: SUMMARY AND CONCLUSION.....	59
LIST OF REFERENCES.....	62
APPENDIX 1: CONSENT FORMS	71
APPENDIX 2: IPQ	82
APPENDIX 3: OPEN QUESTIONNAIRE	87

LIST OF TABLES

Table 3.1: Participant descriptions.	33
Table 3.2: Task Times and Movement Counts.	40
Table 3.3: Task Characteristics.	42
Table 3.4: Task Components.	43
Table 3.5: Task Error.	44
Table 3.6: Task Behaviours Agreement.	45
Table 3.7: Questionnaire Feedback Comments.	50

LIST OF FIGURES

Figure 1.1: The miWe 1.0 virtual environment.	9
Figure 1.2: A less than ideal circumstance requiring reaching safely.	10
Figure 1.3: The Razer Hydra motion controller (left) and magnetic base unit (right).	12
Figure 3.1: Task Diagrams.	27
Figure 3.2: Task Time Mean Difference.	35
Figure 3.3: Example Position Traces of VR Trials.	36
Figure 3.4: Example traces of joystick excursion.	37
Figure 3.5: Movement Count Mean Difference.	38
Figure 3.6: iGroup Presence Questionnaire.....	46
Figure 3.7: Task-specific scale questions.....	48
Figure 3.8: General scale questions.....	49

ABSTRACT

Reaching for objects is essential in powered wheelchair (PW) mobility. For PW users, learning how to navigate their PW to reach for objects safely, as in daily activities, is crucial to their quality of life. Training for such PW use is limited due to lack of dedicated space, time, or equipment. Addressing these issues, the McGill Immersive Wheelchair (miWe) simulator is a virtual reality (VR) system for teaching PW driving skills that runs on an ordinary computer. However, a practical and low-cost training tool for reaching tasks does not exist for the miWe or any other PW simulator. *Objective:* The purpose of this study was to evaluate a \$150 3D hand motion controller (Razer Hydra, Sixense, USA), as an interface for training reaching tasks within the miWe. This device allows 3D control of a virtual cursor with hand/arm movements. *Method:* Twelve experienced PW users performed three combined PW navigation and reaching tasks both in the real world (RW) and in the miWe: working at a desk, operating an elevator, and opening a door. First, we determined concordance of task performance in VR with that in the RW. Total task time, time spent reaching, number of joystick movements, and number of reaching movements were measured. A video task analysis was also performed. Second, the sense of presence in VR was assessed using the iGroup Presence Questionnaire (IPQ). Third, participants gave feedback in an open questionnaire. *Results:* Tasks performed in VR demonstrated significantly ($p < 0.05$, Wilcoxon Sign-Rank) longer task times and greater number of movements for the elevator and desk tasks but not the door task. Task analysis revealed significantly greater ($p < 0.05$) risk of collisions and reaching errors in VR compared to RW tasks. The majority of navigation and reaching behaviours showed moderate to excellent ($K > 0.4$, Cohen's Kappa) agreement between the two environments. IPQ scores demonstrated a significant ($p < 0.05$) increase in "involvement" while "general sense of presence", "spatial presence", and "realism" remained the same compared to previously collected miWe data. Participants generally perceived the tasks and the reaching component to be useful, but noted difficulties with joystick control and software glitches. *Conclusions:* Task performance showed poorer

kinematic performance in VR than RW overall, but similar strategies. While the reaching component represents a promising addition to the miWe simulator, important limitations must be addressed for this VR simulator to be an effective tool for training PW navigation-reaching tasks.

ABRÉGÉ

La préhension d'objets est essentielle à la mobilité en fauteuil roulant électrique (FRE). Pour les utilisateurs (*de FRE*), apprendre à diriger leur FRE pour attraper des objets de façon sûre dans leurs activités quotidiennes est crucial pour leur qualité de vie. L'entraînement pour une telle utilisation des FRE est limitée à cause du manque d'espace dédié, de temps ou d'équipement. Examinant ces questions, le simulateur de Fauteuil roulant immersif de McGill (Frim) est un système de réalité virtuelle (RV) dont l'objectif est d'enseigner les compétences de conduite d'un FRE et qui fonctionne sur un ordinateur ordinaire. Il n'existe cependant pas d'outil d'entraînement pratique et abordable pour les tâches de préhension, ni pour le Frim ni pour aucun autre simulateur de FRE. *Objectif* : Le but de cette étude est d'évaluer un contrôleur de mouvements manuels 3D à \$150 (Razer Hydra, Sixense, USA) en tant qu'interface d'entraînement pour les tâches de préhension au sein du Frim. Cet appareil permet le contrôle 3D d'un curseur virtuel par des mouvements des mains/bras. *Méthode* : Douze utilisateurs expérimentés de FRE ont réalisé trois tâches associant conduite d'un FRE et préhension, à la fois dans le monde réel (MR) et au sein du Frim : travailler à un bureau, faire fonctionner un ascenseur et ouvrir une porte. D'abord, nous avons déterminé la concordance de l'exécution d'une tâche dans la RV avec celle dans le MR. Ont été mesurés la durée totale de la tâche, le temps passé pour attraper, le nombre de mouvements du manche à balai et le nombre de mouvements de préhension. Une analyse vidéo des tâches a également été réalisée. Ensuite, la sensation de présence dans la RV a été évaluée à l'aide du Questionnaire Présence iGroupe (QPI). Enfin, les participants ont fait part de leurs commentaires dans un questionnaire ouvert. *Résultats* : Les tâches réalisées dans la RV ont présenté des durées totales significativement ($p < 0.05$, test de Wilcoxon) plus longues et un plus grand nombre de mouvements pour les tâches de l'ascenseur et du bureau mais pas pour celle de la porte. L'analyse des tâches a révélé un risque de collisions et d'erreur de préhension significativement ($p < 0.05$) plus grand dans la RV comparé aux tâches dans le MR. La majorité des comportements de conduite et de préhension ont fait preuve d'une concordance modérée à excellente ($K >$

0.4, Kappa de Cohen) entre les deux environnements. Les scores de QPI ont révélés une hausse significative ($p < 0.05$) en « implication » alors que la « sensation générale de présence », la « présence spatiale » et le « réalisme » sont restés les mêmes comparés aux données Frim collectées auparavant. De façon générale, les participants ont perçu les tâches en général et la préhension en particulier comme étant utiles mais ont noté des difficultés de contrôle du manche à balai ainsi que des problèmes de fonctionnement du logiciel. *Conclusions :* L'exécution des tâches a présenté dans l'ensemble une performance cinématique moindre dans la RV que le MR mais des stratégies similaires. Bien que l'aspect préhension représente une addition prometteuse au simulateur Frim, d'importantes limites doivent être résolues afin que ce simulateur de RV devienne un outil efficace d'entraînement pour les tâches de conduite et préhension en FRE.

PREFACE

This thesis contains no materials that have been published elsewhere or written by someone else, except where specifically referenced. The research presented constitutes original material and contributes to the advancement of knowledge in the field of virtual reality based rehabilitation and assistive technologies.

Author's contributions

This thesis is presented in manuscript form, based on the guidelines of Graduate and Postdoctoral Studies, McGill University and contains one manuscript to be submitted for publication in *Disability and Rehabilitation: Assistive Technology*. I, Gordon Tao, was the principal investigator for the manuscript entitled “Powered Wheelchair Simulator Development: Integrating Combined Navigation-Reaching Tasks with a 3D Hand Motion Controller”, with my supervisor, Dr. Philippe Archambault, as co-author.

My contribution included the literature review, study design, software development, data collection, data analysis, and manuscript preparation. Dr. Philippe Archambault provided guidance, suggestions, critical review, and feedback for each stage of the study.

Organization of the thesis

This thesis is organized into 4 chapters. Chapter 1 is a review of the literature which covers major topics relevant to the theoretical and practical background of this thesis. Chapter 2 presents the rationale, objectives, and hypotheses of this thesis. Chapter 3 includes the above-mentioned manuscript in its entirety, which addresses the objectives described in the previous chapter. Chapter 4 summarizes the findings of this thesis and presents the conclusion of this thesis. The list of references combines references in the manuscript with references in the rest of the thesis.

CHAPTER 1: REVIEW OF THE LITERATURE

1.1 INSUFFICIENT TRAINING FOR POWER WHEELCHAIR USERS

With a steadily growing population of persons requiring the use of powered wheelchairs (PWs), there is an increasing need for training environments that provide PW users with enough familiarization for safe and effective operation of their wheelchairs (Kaye et al. 2000; McNeil, 1997).

Wheelchairs, including the powered variety represent a highly effective intervention for many persons with mobility limitations (Frank and De Souza, 2013; Löfqvist et al. 2012; Edwards and McCluskey, 2010; Davies et al. 2003). The Participation and Activity Limitation Survey by Statistics Canada (Ottawa, Canada) defines mobility disability as “difficulty walking half a kilometre or up and down a flight of stairs, about 12 steps without resting, moving from one room to another, carrying an object of 5 kg for 10 m or standing for long periods” (Statistics Canada, 2008). However, this definition is by no means exhaustive. Mobility limitations are often a secondary consequence of a wide variety of health conditions including stroke, spinal cord injury, old age, complications from diabetes, etc.; these limitations result in many barriers that restrict activities of daily living (Blach et al. 2012; Dixon et al. 2008) and reduce quality of life (Webber et al. 2010). For example, Vestling and colleagues (2003) reported that, for patients recovering from stroke, the ability to walk was a major indicator for their future return to work and that returning to work was important for these patients’ subjective well-being and life satisfaction. The enhanced mobility and independence offered by PWs allows their users many more opportunities for participation in the community (Davies et al. 2003; Evans et al. 2007a/b; Giesbrecht et al. 2009; Blach et al. 2012). Moreover, the benefits of PWs are applicable to a wide range of age groups and health conditions (Butler et al. 1983; Chase and Bailey, 1990; Bottos et al. 2001).

However, with the benefits of PWs also come inherent risks both to the user and to bystanders. Approximately 20-25% of PW users experience accidents (Kirby and Ackroyd-Stolarz, 1995; Edwards and McCluskey, 2010); common

accidents include tips, falls, and accidental contact. These accidents are often related to wheelchair-using behaviours and insufficient experience and training (Chen et al. 2011). Indeed, there is a general consensus among both PW users and clinicians that the amount of training provided to new users is inadequate (Evans et al. 2007b; Holliday et al. 2005; Corfman et al. 2004). Traditional training facilities for wheelchairs usually require large open spaces with custom-built environments and professionals on staff. The cost and time required for using these facilities makes access to training limited. This limitation leads to decreased confidence in using one's wheelchair and thereby limits their capacity for social participation (Brandt et al. 2004; Davies et al. 2003). Moreover, a qualitative study by Mortenson and colleagues (2005) on PW users' perception of mobility indicated that "learning the rules of the road" and safety are important and ongoing concerns of PW users. Again, wheelchair users are a steadily growing population. As such, there is a clear need to increase the amount of training of new users and improve access to training resources.

1.2 VIRTUAL REALITY SIMULATORS ARE USEFUL FOR TRAINING

Given the high cost of traditional facilities, virtual reality (VR) simulators offer an attractive means of supplementing the training needs of PW users. This thesis focuses on improving one such simulator. Virtual reality refers to computer-generated simulations of environments that emulate places and objects in the real world (RW) or imagined worlds. The most common example of VR is a videogame. People playing these games experience a variety of environments viewed on a video display with sound effects and music from speakers and interact via a game controller or keyboard and mouse. While this kind of apparatus is fairly simple, other fields have developed highly immersive (the degree to which simulated sensory input encapsulates the user) simulators to train a variety of complex tasks. Airline pilots are regularly trained in a full-cockpit simulator with a virtual world displayed through the cockpit windows (Hays et al. 1992). Medical research has shown that VR simulators for laparoscopic surgery improves the performance of surgical trainees (Grantcharov et al. 2004).

Furthermore, there is growing evidence on the effectiveness of VR training on basic functional skills, e.g. reaching and grasping in post-stroke upper extremity retraining (Levin et al. 2014; Holden, 2005). Overall, these studies have demonstrated that skills practiced in certain VR simulators have the potential to be transferred to real-world tasks. Furthermore, basic research on VR systems has shown positive results in improving skills related to PW use, i.e. visuospatial skills and navigation planning (Teixeira et al. 2012; Wallet et al. 2010; Heyde et al. 2001).

1.2.1 Transferability

The core tenet of VR training is transferability: 1) skills acquired in a virtual environment are applicable to the equivalent environment in the real world and 2) practice of skills in a virtual environment leads to improvement in the performance of those skills in the real world (Cox, 1997; Bossard et al. 2008; Levac and Sveistrup, 2014). From the pedagogical framework of constructivism, learning a skill through experience (experiential learning) involves a basic cyclic process of active experimentation, the resultant concrete experience, reflection upon the experience, and abstract conceptualization of the experience (Kolb, 1984). It is this memory and abstract conceptualization of past experiences that allows people to apply skills in new and future situations, i.e. transfer of skills. Therefore, VR training must facilitate this learning process for a given skill and the learner's abstract conceptualization of the experienced skill ought to be equivalent to those gained by training in the real world.

Bloom's taxonomy (Anderson et al. 2001) categorizes skills into three domains: cognitive, affective, and psychomotor. While these skills are often integrated in practice, they may be treated separately. In the case of cognitive skills, the learning and practice of these skills are usually not dependent on the physical nature of the learning experience; learning the skill of multiplication is categorically independent of whether one does it on a physical or virtual chalkboard, vis-à-vis cognitive skills. One is simply doing multiplication. As such, the abstracted conceptualization of trained cognitive skills in VR is

equivalent to trained skills in RW. Conversely, affective and psychomotor skills usually are physically dependent. For example, learning to throw a dart accurately in RW is dependent on how the learner physically moves in relation to the physical environment and the physical feedback therein. If the sensorimotor experience of throwing a dart in VR is too divergent from the RW experience, then the abstract conceptualization of the skill in VR is not equivalent to the RW skill, and is therefore not readily applicable to throwing the dart in RW.

As an example of all 3 categories, we may consider learning how to handle a medical triage situation. The actual triaging, evaluating and prioritizing patients based on pre-determined criteria, is a cognitive skill involving abstract concepts and can be practiced in a classroom or on a computer. However, in the triage environment, there is an emotional impact of having to keep track of many different things in a chaotic environment and life and death consequences; in this context practicing affective skills such as managing one's own emotions and recognizing the emotional state of others is dependent on an external environment that elicits real emotions. Likewise, learning the psychomotor skills of doing things in the triage environment, e.g. assessing and transporting patients in a triage setting, is dependent on the physical experience of doing so.

Therefore, the key pedagogical concern with using VR as a training tool is how physically and emotionally representative the learning experience in VR is of using a PW in the real world community. The primary focus of this thesis is the cognitive and psychomotor aspects of the learning experience.

1.2.2 Training in the clinical setting

To frame the application of virtual reality to PW training, we may first consider the standard training new PW users receive—the “tried and true” method of training. The Wheelchair Skills Program (WSP) is a standardized training method which clinicians often use that addresses a set of representative wheelchair skills (Dalhousie University, 2012). Accompanying the WSP is the assessment tool for these representative skills: the Wheelchair Skills Test (WST). The training and assessment of powered wheelchair skills are primarily concerned

with learning manoeuvring skills, in addition to proper operation of PW features. Specifically, the skills targeted include basic flat surface manoeuvring, navigating specific inclines, reaching for objects, and dealing with obstacles. The WSP is often implemented, with the clinician as the trainer, in a rehabilitation centre with adequate space for manoeuvres and obstacles built to specifications.

The Power-Mobility Indoor Driving Assessment (PIDA) (Dawson et al. 1994) is another assessment which extends these skills into the in-home environment. PW users are asked to complete tasks in context of daily activities and were given open-ended instructions on how to complete the tasks. For example, in the “Bedroom” scenario, PW users are prompted, “Please approach your dresser as if to open your top drawer or reach something from its surface.” The assessment criterion for this task is having the “ability to position oneself effectively to access the dresser drawers or reach something from the surface.” Another task involving the operation of an elevator requires participants to look around for obstacles (e.g. humans) without prompting. In this assessment, users need to integrate basic manoeuvring skills, as demonstrated in the WST, into a contextualized and self-directed task. Additionally, both the WST and the PIDA assess the ability of the user to operate all of the features of their PW, e.g. turning the wheelchair on/off, charging the batteries, etc.

Finally, the Power-mobility Community Driving Assessment (PCDA) is concerned with evaluating driving performance in outdoor and community environments (Letts et al. 2007). The emphasis here concerns the additional skills involved in driving a PW outdoors compared to indoors; the varied and constantly changing environment one encounters in the community necessitates greater cognitive and navigation skills than those covered by in the WST. As such, the PCDA assesses performance and knowledge in situations such as street crossings, emergency situations, accessing transit, public places, and varied surfaces. Indeed, PW users may frequently be required to integrate multiple skills from the WSP in unfamiliar and non-ideal circumstances; the PCDA fills this gap. A study by Walker and colleagues (2010) emphasized the importance of practicing PW driving skills in the community, in addition to in-facility training, for more

challenging tasks. However, a safe and thoroughly complete implementation of training and assessment of these situations is often not possible due to access limitations and logistics.

In summary, it is clear that learning to use a PW involves the obvious psychomotor skills (hand-eye coordination for joystick control, distance judgement for reaching tasks, etc.) but also higher cognitive skills (obstacle avoidance, task planning, route finding, problem solving, etc.) and knowledge of PW functionality. Furthermore, PW users need to have confidence and situational awareness in using their PW in the community where hazardous environments and unforeseen barriers may occur.

1.2.3 Application of VR to powered wheelchair training

In light of the goals and limitations in the above training paradigms, VR simulators offer several advantages over training in a real-world scenario. One key advantage is that a VR simulator can encompass a wider range of scenarios and a wider range of difficulties than in a real-world training environment such as a rehabilitation centre. In an evaluation of motorised mobility scooter use, Townsend and Watson (2013) note the importance of cognitive skills such as “coordination... memory, concentration, insight, divided attention, and judgement”. Moreover, they emphasize the importance of adaptability to varied environments. A VR simulator may be designed to develop all of these skills in low-to-high difficulty and integrated scenarios.

VR systems can be a safe way to practice complex and dangerous tasks (Reid, 2002). For example, preparing and practicing for Montréal’s notoriously treacherous and ever-present potholes, varied in shape and size and lurking where you least expect them. Indeed, testing out risky situations and behaviours can be an important part of learning the limitations of one’s PW. In a study by Mortenson and colleagues (2005), 17 of 19 power mobility participants acknowledged that some accidents are unavoidable. Practice in varied virtual settings may also contribute to a user being able to recognize scenarios where accidents are more likely to happen. Considering the goals and scenarios outlined

by the PCDA, virtual reality simulators can be a solution for practicing key skills for outdoor community mobility.

Moreover, these systems allow for easy recording of skill and performance for evaluation and, more importantly, augmented feedback for the user, i.e. trial and task specific feedback that may otherwise not be available. An early study indicated that, in a table tennis motor task, augmented feedback from a virtual training system resulted in better performance than with normal coaching (Todorov, 1997). More recently, Levin and colleagues (2010) showed that, in a upper limb stroke rehabilitation context, augmented feedback from a virtual environment in the form of knowledge of results (speed and precision) and knowledge of performance (movement pattern) elicited motor function beyond normal expectations, demonstrating the motivational potential of VR environments. Other key advantages, now that many simulators can run on a normal computer, include cost and portability. The manual for the WSP suggests that training and practice requires hundreds of trials over many sessions; a VR simulator can help meet these practice needs. To compare, adding a dozen hours of training sessions at a rehabilitation centre would amount to so many working hours and hundreds of dollars at least; the start-up costs for implementing a miWe VR system would be one to two thousand dollars at most and would have minimal operation and maintenance costs.

Again, real-world training facilities are expensive, are limited in accessibility, and are limited in the extent of training that can be provided (Holliday et al. 2005). Conversely, you may imagine yourself having just ordered your PW. While you wait for it to arrive, you may already begin training on a VR simulator. You may start with the most basic tasks and work your way up to the more complex tasks. In one instant you may be practicing driving along a narrow uneven sidewalk and the next you may be practicing manoeuvring through a crowded mall. Since the simulator is low cost and highly portable, requiring only a computer and controller, you can practice any task you like whenever you have time, and in the convenience of your own home. At the very least VR simulators

would be an additional tool clinicians may use to for training and assessment in the clinical setting.

1.2.4 Existing power wheelchair simulators

There have been several VR simulators designed for PWs that have shown some positive training outcomes (Abellard, 2010). One of the first simulators for powered wheelchairs was presented by Hasdai and colleagues (1998); they demonstrated that children inexperienced with PW driving significantly improved their driving skills in the RW after practice in a simulator that involved piloting a cursor through a 2-dimensional (2D) maze. Further research has demonstrated efficacious VR training in participants with traumatic brain injury (Spaeth, 2008) and other neurological impairments (Harrison, 2002). However, many of these simulators have simplistic virtual environments and only offer a 2D perspective (Erren-Wolters et al, 2007). The simulators that do utilize 3D virtual environments tend to have limited graphical fidelity.

As with any type of VR simulator, realism is an obvious factor to consider in the development of PW simulators, i.e. the experience of using the simulator must match the experience of using a PW in the real world. This is often accomplished by using a highly immersive simulator, where the image of the virtual environment occupies a large portion or the entirety of the user's field of view. The simulator developed by Sonar and colleagues (2005) combined a head mounted display for visual immersion and a hydraulic platform for kinesthetic and vestibular feedback. More commonly, visual immersion is accomplished by projecting the virtual environment onto a large shaped surface (Abellard, 2010).

However, accomplishing this level of immersion has its drawbacks in that the use of raised platforms, large projectors, or head mounted displays is costly and requires a significant amount of space (platforms and projectors can require an entire room); such equipment may not be suited for widespread clinical use. Other PW simulators aim to strike a balance between providing the most realistic (and presumably effective) training experience and low-cost portable systems. The WheelSim (LifeTool, Linz, Austria) is a commercial simulator that was

originally released in 1998 that utilized 3D graphics and joystick control on a personal computer. However, an evaluation by Alshaer and colleagues (2013) considered the simulation unrealistic in terms of the virtual environment and the joystick controls. Another simulator utilized by Linden and others (2013) focused on training school aged children. This project emphasized engagement with children and only dealt with a basic slalom-type task.

The McGill Immersive Wheelchair (miWe) simulator v1.0, developed by Archambault and colleagues (2011), is a PW VR simulator created with the primary goal of being inexpensive and portable enough to be implemented as a training tool in any clinic or at home. The current version is designed to train navigation and obstacle avoidance skills. One of the virtual environments is modelled after tasks trained in the Wheelchair Skills Program. There is also an indoor community centre where users must complete extended navigation tasks. Other scenarios under development include a crowded mall, street crossing, public washroom, grocery store, and boarding an adapted transport.



Figure 1.1: The miWe 1.0 virtual environment.

The simulator provides the user with a first-person perspective view of a detailed 3D environment (Figure 1.1). Users control a simulated wheelchair using a realistic USB joystick to perform a variety of navigation tasks. However, the control interface may be adapted in the future to work with other types of interfaces such as head control or sip & puff. To ensure the most realistic driving experience, the simulated PW is programmed according to recorded data from real PWs. Characteristics including acceleration, speed, inertia, and turning rate can all be configured to match the each individual user's own PW. Thus, the miWe offers a unique combination of cost effectiveness, portability, and realistic

wheelchair-environment physics, making it an important tool for meeting the growing need for PW training.

1.3 REACHING AND MOBILITY

However, a major drawback of the miWe simulator, and other PW simulators, is that it lacks a realistic interface for tasks that involve reaching. Reaching for objects, in addition to manoeuvrability within confined spaces, is a key factor in PW mobility, i.e. the ability to overcome the physical and social obstacles of daily activities, and crucial for PW users' independence and quality of life (Holliday et al. 2005). PW users typically spend much of their waking hours in their wheelchair (Ward et al. 2010; Sonenblum et al. 2008). The ability to reach is necessary in a wide variety of common tasks: preparing food, working at an office, shopping etc. Many such tasks, if performed incorrectly, may result in tips and falls, representing a safety risk that can be reduced by training. Everyday activities often involve complex navigation and manoeuvre-to-reach type tasks, e.g. pulling open a door and getting through it before it closes. For these tasks, positioning one's PW properly for safe and effective reaching is often further complicated when users have upper extremity and/or trunk functional impairments such as weakness or limited range of motion. Indeed, the PIDA assessment, discussed previously, includes such navigate-to-reach type tasks in context of several daily activities. Research regarding the life experience of wheelchair users indicate that confined spaces, and unanticipated barriers and circumstances are a constant issue (Torkia, 2014; Blach 2012; Evans, 2007a/b; Mortenson, 2005); these issues inevitably affect reaching tasks.

One may imagine needing to position oneself to reach



Figure 1.2: A less than ideal circumstance requiring reaching safely.

something in the tight corridors of an office space. Certainly PW users will encounter many frustrating situations in the outside world where objects are not located for them to reach conveniently (Figure 1.2). Therefore, we propose that including a reaching component in the miWe simulator will enhance the training experience for PW users and consequently increase safety and confidence in using their wheelchair.

1.4 REACHING IN VR: TECHNOLOGY OVERVIEW

Including a reaching interface in a VR environment requires some kind of motion tracking system that translates a user's physical reaching movements into an equivalent movement of a virtual hand. The most common tools for motion tracking in VR research are optical-based systems that capture the position and movement of markers placed on the body, for example Optotrak (NDI, Canada) and Vicon (Vicon, USA) systems. These systems are often used for precise tracking with very high accuracy, or over a large space with full body tracking (Schmidt et al. 2009; Windolf et al. 2008). Another type of motion tracking technology utilizes sensors that interact with a magnetic field generated by a base unit, for example the 3D Guidance trakSTAR (Ascension Technology Corp, Boston NY). However, these research-level tools are costly (tens of thousands of dollars), large, and require complicated and specialized hardware. Moreover, the level of precision and accuracy afforded by these systems far surpass what is needed for a reaching interface for training. While these systems have been used extensively in VR applications for upper-extremity rehabilitation (Ma et al. 2012; Zhou and Hu, 2008; Subramanian, 2007), these systems are not a practical option for implementing a reaching component in the miWe simulator.

Recent advancements in consumer-level motion-tracking technology provide a low-cost (\$100-\$200) and portable substitute for high-end motion tracking systems. The Nintendo Wiimote (Nintendo Japan) hand controller is one such device that has already been widely used in rehabilitation research (Butler and Keith, 2010; Nitz et al. 2010; Deutsch et al. 2008), particularly in upper extremity motor rehabilitation in conditions such as stroke (Saposnik et al. 2010;

Leder et al. 2008). The Wiimote is a hybrid device that includes motion sensors (accelerometer and gyroscope) and an optical tracking unit that operates on the same principle as the Optotrak and Vicon systems, except on a much smaller scale. Another device is the Microsoft Kinect (Microsoft, USA). Unlike Optotrak/Vicon, the Kinect is an optical tracking system that doesn't require the use of markers; instead, its camera detects the volumetric silhouette of objects in front of it. Algorithms are used to transform the silhouette into a rough human skeleton which is used for motion control. Research utilizing the Kinect for rehabilitation is also beginning to emerge (Pastor et al. 2012; Chang et al. 2011). However, these optical devices are designed to be used in front of a television with a clear line-of-sight and ample room for movement. Therefore, these devices are not ideal for the desk and computer configuration used with the miWe simulator.

The Razer Hydra (Sixense Entertainment, USA) is a 3D hand motion controller using magnetic field-based motion tracking technology, like the aforementioned trakSTAR. The Hydra controller is a small and portable device that fits into one hand, similar in shape to a remote control (Figure 1.3). This controller contains a magnetic sensor that interacts with a weak magnetic field produced by a base unit, providing accurate and precise tracking of the controller's movement and orientation



Figure 1.3: The Razer Hydra motion controller (left) and magnetic base unit (right).

through space (precision of 1 mm and 1°, according to listed specifications). This precise tracking allows for one-to-one motion translation of physical hand movements into virtual hand movements. Unlike the Wiimote or Kinect, the Hydra does not require line-of-sight and is designed to operate in the spatial range of a desk. Furthermore, it is easy to set up and low-

cost (\$150). Therefore, the Razer Hydra is most suitable for implementing a reaching component in the miWe simulator.

1.5 COMPARING VR AND REAL WORLD

This project will validate the use of the Razer Hydra for reaching tasks in the miWe simulator. We must emphasize that this project is not about the efficacy of training, rather we must first determine the fundamental suitability of the Hydra-miWe interface for training reaching tasks. It is widely accepted that the amount of practice is an important factor in learning a new task (Schmidt and Lee, 1988; Newell and Rosenbloom, 1981). As discussed in the above section on transferability, it is also crucial in VR training for the *performance* of the task in the virtual environment to be similar to how the task is performed in the RW, if we are to expect learned skills in the virtual world to be transferable and applicable to the real world (Holden, 2005). One of the most common methods of comparing virtual and real-world physical tasks has been a comparison of movement, i.e. kinematics.

1.5.1 Task Performance

Previous studies involving PW simulators focused on quantitative measures for characterizing driving behaviour in terms of skill, error, and strategy. Task completion time and joystick movements are commonly used as a measure of overall driving skill (Linden et al. 2013; Archambault et al. 2011; Harrison et al. 2000). Archambault and colleagues (2012) previously compared virtual vs real-world driving behaviour in the miWe simulator. Sixteen participants in the VR group were asked to complete a series of tasks modelled from the Wheelchair Skills Test in the miWe virtual environment; another thirteen completed the tasks in the real world. This study showed similar counts of joystick movements and similar task completion times for certain tasks; more difficult tasks tended to take longer to complete in the virtual environment. Other quantitative measures used by various studies include number of collisions or

errors, path length, and average speed (Mahajan et al. 2013; Spaeth et al. 2008; Harrison et al. 2002).

Comparison of reaching tasks between virtual and real-world environments have largely been conducted with respect to neurological conditions such as stroke in the context of an intervention (Levin et al. 2014; Holden et al. 2005). Again, task completion time is a common kinematic measure used for comparison (Ma et al. 2012; Magdalon et al. 2011). Other kinematic measures include velocity profiles, trajectories, and joint angles (Wang et al. 2011; Subramanian et al. 2011; Subramanian et al. 2007). For example, Viau and colleagues (2004) compared movements during a reaching task (reach for and transport a ball) between a virtual environment and reality. They demonstrated, in healthy adults, similar reaching trajectories and trajectory curvatures, similar peak and time-to-peak wrist velocity, and similar patterns of interjoint coordination. However, they also showed that these same participants used less wrist extension for grasping and greater elbow extension when placing the ball. Moreover, these differences were also observed in participants with hemiparesis.

Another method of comparing performance between virtual and real-world scenarios is through video task analysis. Task analysis, broadly, is a detailed breakdown of a task (e.g. laying down bricks, teaching a class, driving, writing a thesis, etc.) in terms of physical, mental, social, and other contextual descriptors of the task's component activities (Kirwan and Ainsworth, 1992). One example, conducted by Clark and colleagues (1990), was a characterization of activities of daily living of older adults in a home setting. By deconstructing these activities in their natural context, Clark and colleagues showed common task components that allow for these activities of daily living to be viewed from a hierarchical perspective. In context of performing motor tasks in a virtual environment, task analysis may be considered as an observational method of categorizing task performance and strategy, e.g. "the participant used his left hand".

Video task analysis also offers a convenient way to detect gross differences in kinematic performance where precise kinematic measurement is not practical. Archambault and colleagues (2012) used video task analysis to compare

driving patterns of users between the virtual environment of the miWe simulator and reality. They demonstrated similar driving trajectory patterns in WST tasks such as going through a hinged door: “positions wheelchair at an angle to push door open, goes through, turns around to close the door”. Their video analysis also showed more frequent adjustments and more frequent collisions for some tasks in the virtual environment.

1.5.2 Sense of Presence

A crucial factor for an effective virtual training simulator is the sense of presence, i.e. the temporary suspension of disbelief such that the user feels as if they are “in” the virtual environment (Mantovani and Castelnuovo, 2003). Developing a sense of presence is largely dependent on the quality and fidelity of sensory input, attention, the type of tasks performed, and overall level of engagement (Tichon, 2007; Bystron et al. 2009). As before, this is often pursued by attempting to generate the most realistic sensory input: immersive visual interfaces, haptic feedback, kinesthetic and vestibular feedback, etc.

Another approach is based on the fundamentally interactive nature of VR. That is having a high degree of interactivity, or being able to perform what one would perform in the real world, can elicit a significant sense of presence even when sensory input is of limited fidelity (IJsselsteijn, 2002; Seegert, 2009). Unfortunately, the exact relationship between presence and performance remains unclear (Youngblut and Huie, 2003; Nash et al. 2000). It is likely that presence only indirectly influences performance (Bystrom et al. 1999). However, it is widely accepted that a positive sense of presence is necessary for genuine responses and performance (Powers and Emmelkamp, 2008; Bystrom et al. 1999). Mantovani and Castelnuovo (2003) described the role of presence in virtual training as an important aspect of the process of learning in VR and the transfer of skills. They suggested that a strong sense of presence not only promotes authentic behaviour in VR, but also prompts thoughts and emotions about their behaviour that makes the learning experience relevant and recallable. Therefore, to be an

effective training tool, the Hydra-miWe reaching component must engage the user and contribute to a strong sense of presence.

The iGroup Presence Questionnaire (IPQ) is a popular standardized questionnaire for general sense of presence in a virtual environment. The IPQ comprises of fourteen items in four subcategories (Nichols et al. 2000):

1. Spatial Presence (5 items) – the sense of being physically present in the virtual environment,
2. Involvement (4 items) – measuring the attention devoted to the virtual environment and involvement experienced,
3. Experienced Realism (4 items) – measuring the subjective experience of realism in the virtual environment.
4. A general item on the “sense of being there”

All items are scored on a seven point scale (0-6), with a higher score indicated a greater sense of presence. The IPQ has good psychometric properties and has been replicated across multiple samples (Schubert et al. 2001), with an internal consistency over two studies of 0.85 and 0.87. The IPQ built on previous standard measures and was developed in part using desktop VR environments like the miWe. Total score can be treated as an overall measure of sense of presence, or the subscales can be treated separately.

Previous assessment of presence in the miWe simulator demonstrated an overall score of 3 or greater for Spatial Presence, Involvement, and General Impressions, but below 3 for Experienced Realism (Archambault et al, 2011). Moreover, these scores were on average greater in comparison to a 3D game.

1.5.3 Population

This thesis project does not focus on the actual training of PW users. Rather, the emphasis is on comparing performance in VR to reality. Therefore, a stable example of performance in the real world is required. The benchmark performance in the real world will be established by experienced PW users. It is assumed that experienced PW users are least likely to change their performance in the real world due to training effects. They are also most likely to perform tasks in

the desired manner: safely and efficiently. Experienced PW users have previously participated in this capacity in the development of PW simulators (Archambault et al. 2011; Harrison et al. 2000).

Experienced PW users can provide expert opinions and feedback (i.e. qualitative data) on differences or similarities of the virtual environment that may not be necessarily captured quantitatively. For example, Harrison and colleagues (2000) compared driving performances between VR and reality in a PW manoeuvrability task and in a route finding task. Experienced users reported that they found the tasks more difficult to accomplish in the virtual environment than in the real world.

Finally, experienced PW users are the best qualified to ascertain the overall utility of the added reaching feature of the simulator with respect to training and to the relevance of specific simulated reaching tasks to activities of daily living (Torkia et al, 2014; Blach et al, 2012; Evans et al, 2007a; Evans et al, 2007b; Mortenson et al, 2005).

CHAPTER 2: RATIONALE, OBJECTIVES, AND HYPOTHESES

2.1 RATIONALE

Powered wheelchairs represent a powerful intervention for persons with severe mobility limitations; they enable people to better carry out activities of daily living and provide a greater opportunity for participation in the community. However, both PW users and clinicians agree that many people receiving their first PW do not receive sufficient training. This not only leads to an ongoing safety concern, but also to a lack of self-confidence in using their PW, which can be a barrier to community participation. Moreover, limited access to training facilities coupled with a growing population of PW users indicates an increasing need to improve available powered wheelchair training programs and facilities.

A virtual reality simulator for PW training is one potential solution. Over the last two decades, virtual reality has been effectively implemented as a tool for training skills from basic upper-limb motor tasks to abstract and complex skills such as piloting a plane. Furthermore, VR environments can be advantageous over traditional training resources in terms of cost, safety, and providing augmented feedback. The caveat is that the virtual environment and virtual tasks must be realistic and generate a high sense of presence; the resultant motor performances must be authentic in comparison to reality and the acquired skills must be transferable to the real world. Finding the best ways to accomplish this is an ongoing goal of current VR research.

The obvious approach to creating a VR training environment for powered wheelchairs is to derive from and expand upon current training programs. The McGill Immersive Wheelchair Simulator is one such simulator that trains driving skills derived from the Wheelchair Skills Program and provides virtual environments that challenge users to integrate these skills in an outdoor and in-the-community setting. However, one limitation of this simulator, and in all other PW simulators, is the inability to meaningfully simulate manual interactions with virtual objects, i.e. reaching for objects. Reaching is an integral aspect of mobility and activities of daily living. Therefore, having a reaching component in the

simulator would expand on the types and complexity of tasks that can be trained in the miWe. From a VR standpoint, integrating multiple modes of interaction should also contribute to a more realistic experience and greater sense of presence, thereby making the miWe a more effective training system. We chose to use the Razer Hydra as the interface for reaching in the miWe virtual environment.

2.2 OBJECTIVES

The purpose of this thesis project was to integrate a reaching component into the miWe simulator and to evaluate the appropriateness of this component as a tool for training integrated navigation and reaching tasks for PW users. Therefore, we posed three questions to be answered with the participation of experienced PW users.

Questions

- 1) For PW users performing combined navigation-reaching tasks, using a 3D hand motion controller in the McGill Immersive Wheelchair Simulator, to what extent are kinematic parameters and task strategies concordant between the simulator and real life?
- 2) Does including this reaching component in the simulator improve sense of presence over the simulator without the reaching tasks?
- 3) To what degree do participants feel the combined navigation-reaching tasks, in context of the simulator, are appropriate for powered wheelchair training?

2.3 HYPOTHESES

We expect to find no significant difference in kinematic parameters and in performance behaviours between the simulator and real world tasks. Moreover, we expect the inclusion of the reaching component in the simulator to result in an increased sense of presence, as measured by the IPQ score, compared to previous data using the miWe for navigation only (Archambault et al. 2012). Such results would demonstrate the immediate benefits of adding hand-reaching tasks to the

simulator. Expanding the miWe simulator's capabilities to include reaching tasks will contribute to a broader range of training scenarios for users. We anticipate participants will respond positively to the implementation of the navigation-reaching component. This will enhance the utility of the simulator, leading to a potential for improving PW users' safety and improving their confidence in using their PW. These advantages would be most impactful to new users as they are first assigned their PWs and as they first begin driving them.

CHAPTER 3: MANUSCRIPT

POWERED WHEELCHAIR SIMULATOR DEVELOPMENT: IMPLEMENTING COMBINED NAVIGATION-REACHING TASKS WITH A 3D HAND MOTION CONTROLLER

Gordon Tao, BSc

Philippe S. Archambault, OT, PhD

School of Physical and Occupational Therapy, McGill University;
Interdisciplinary Research Center in Rehabilitation (CRIR), Montreal, Canada.

To be submitted to *Disability and Rehabilitation: Assistive Technology*

Corresponding author:

Philippe Archambault

philippe.archambault@mcgill.ca

School of Physical & Occupational Therapy, McGill University

www.mcgill.ca/spot (+1) 514 398-7323

CRIR - Centre de recherche interdisciplinaire en réadaptation du Montréal
métropolitain

Hôpital Juif de Réadaptation

www.crir.ca Lab: (+1) 450 688-9550 x4832

3.1 ABSTRACT

Virtual reality (VR) simulators are a promising method of supplementing the training that powered wheelchair (PW) users receive. The McGill Immersive Wheelchair (miWe) simulator is designed to train PW navigation skills and runs on an ordinary computer. However, there is no interface for reaching, a crucial aspect of mobility, in any existing PW simulator. *Objective:* This study evaluated a low-cost magnetic-based hand motion controller as an interface for reaching tasks within the miWe. *Method:* Twelve experienced PW users performed three navigation-reaching tasks in the real world (RW) and in VR: working at a desk, using an elevator, and opening a door. We determined concordance of task performance in VR with that in the RW. A video task analysis was performed to analyze task strategies. The sense of presence in VR was assessed using the iGroup Presence Questionnaire (IPQ). *Results:* VR performance demonstrated longer ($p < 0.05$) task times and greater number of movements for the elevator and desk tasks but not the door task. Task analysis revealed greater ($p < 0.05$) risk of collisions and reaching errors in VR. The majority of navigation and reaching behaviours showed moderate to excellent ($K > 0.4$, Cohen's Kappa) agreement between the two environments. Compared to previously collected miWe data, IPQ scores demonstrated an increase in "involvement" ($p < 0.05$). *Conclusions:* Task performance showed poorer kinematic performance in VR than RW but similar strategies. Therefore, the reaching component represents a promising addition to the miWe training simulator, though some limitations must be addressed in future development.

Keywords: Virtual Reality, Powered Wheelchair, Training, Reaching, Navigation, Rehabilitation

3.2 INTRODUCTION

Reaching for objects, along with manoeuvrability within confined spaces, is a key factor in powered wheelchair (PW) mobility, i.e. the ability to overcome the physical and social obstacles of daily activities (Holliday et al. 2005). The ability to reach is necessary in a wide variety of common tasks: preparing food, working at an office, etc. Considering that PW users typically spend all their waking hours in their wheelchair (Ward et al. 2010; Sonenblum et al. 2008), learning how to best navigate their PW in order to reach for objects is crucial to their independence and quality of life. This advanced task-related training is often not possible in rehabilitation centers as access to training for PWs is already limited (Kaye et al. 2000; McNeil, 1997).

Virtual reality (VR) simulators offer a highly feasible alternative for rehabilitation training either at home or in a clinical setting. Several simulators for powered wheelchairs are already in development (Linden et al. 2013; Archambault et al. 2011; Abellard, 2010). Critical to the effectiveness of VR training is the transfer of skills to real-world scenarios (Levin et al. 2014; Holden, 2005; Mantovani and Castelnovo, 2003). To simulate reaching tasks for training, motion capture technology may be used to recreate the user's manual movements in the VR environment, in real-time. In VR research, however, this usually requires large and expensive 3D cameras that are impractical for an at-home simulator (Ma et al. 2012; Zhou and Hu, 2008; Subramanian, 2007).

Therefore, a practical training tool for reaching tasks does not exist for PW simulators. Recent advancements in consumer-level motion-capture technology provide a low-cost and portable substitute for high-end motion capture systems. The focus of this study was to validate a 3D hand motion controller (Razer Hydra, Sixense, USA), as a training tool for manual tasks in PW use. The Razer Hydra is a device that fits into one hand, similar in shape to a TV remote. There are two trigger buttons for the index and middle fingers and an analogue stick and button cluster accessible by the thumb. The motion capture aspect of this device allows the user to physically control a virtual hand or cursor in 3D space

with hand and arm movements. This 3D hand motion controller was evaluated as an integrated tool in the miWe simulator.

An important consideration in VR research is the user's sense of presence, i.e. the temporary suspension of disbelief such that the user feels as if they are "in" the VR environment (Mantovani and Castelnuovo, 2003). Accordingly, presence is suspected to make tasks in the VR environment feel more natural and relevant to the user and therefore enhances task training and translation into task performance in the RW environment. Usually, maximizing a sense of presence is accomplished with visual immersion in the virtual world via head mounted display or large projection screens (Abellard, 2010). However, a greater degree of interactivity or the number of things that can be authentically *performed* in the virtual environment can also contribute a greater sense of presence (IJsselsteijn, 2002; Seegert, 2009). Therefore, the addition of a 3D hand motion controller is expected to contribute to a greater sense of presence by providing a means of interacting with the virtual environment using one's hands.

The Hydra motion controller was integrated into the McGill Immersive Wheelchair (miWe) simulator, a VR training simulator for powered wheelchair users. The miWe is a first-person perspective environment that runs on an ordinary computer. It can be used at home and is designed to teach PW users navigation and obstacle avoidance skills in the outside community. Manual tasks, such as opening doors, in the miWe were originally accomplished by keystroke. This project enabled users to physically perform such manual tasks in combination with manoeuvring their wheelchair in the simulator.

The purposes of this study were:

- 1) to compare, in a group of powered wheelchair users, the performance of combined navigation-reaching tasks in a powered wheelchair simulator using a 3D hand motion controller to those same activities performed in real life,
- 2) to determine to what extent the hand motion controller increases the sense of presence of powered wheelchair users compared to the simulator without the reaching interface, and

3) to elucidate the way in which participants feel the combined navigation-reaching tasks, in context of the simulator, are appropriate for powered wheelchair training.

3.3 METHODS

3.3.1 Population and Sample

This study required the participation of experienced PW users, as they are most likely to have stable behaviour and know how best to perform tasks. These users were well suited for the comparison of the virtual world tasks and their real world equivalents. They are familiar with scenarios encountered during activities of daily living and could provide expert opinions and feedback on the overall utility of the added reaching feature to the simulator.

Participants were recruited from the Lucie Bruneau Rehabilitation Center (Canada). PW users were eligible if they had a minimum of 2 years experience with their PW. Participants needed to have a standard indoor/outdoor PW controlled by joystick. Other inclusion criteria consisted of: able to fully understand the tasks (MoCA), one able arm and hand for controlling the wheelchair, able to grasp at 40cm forward and laterally, and normal or corrected vision for viewing a monitor at 50cm. All participants provided their informed consent, as approved by local ethic committee guidelines.

3.3.2 Procedures

Real-world and Virtual Environments

Participants were required to perform 3 tasks both in the real-world and in the miWe simulator. These tasks were designed to reflect a variety of hand-arm movements with different levels of difficulty and are illustrated in Figure 3.1. The real-world scenario took place at the Lucie-Bruneau rehabilitation centre in a PW mobility training room. The training room was an open space with props needed for the experimental tasks, including a table and doorway. The virtual environments developed for the miWe included objects (doorway, desk, etc.) that were dimensional recreations of the objects used in the training room; reaching

and driving movements performed by the participant were translated 1:1 into the virtual world. The virtual PW was modeled to reflect a generalized powered wheelchair based on weight, acceleration, size, and directionality.

Manual interaction in the simulator with objects was contextual and initiated by proximity; the virtual hand would automatically “press a button” or “grasp an object” when the participant reached close enough to the object.

The real-world and miWe simulator scenarios took place in the same facility. After participants completed one scenario, they proceeded to the next scenario after a short break. The starting scenario was randomized, with 50% of participants performing tasks in VR first. Furthermore, we directed each participant to adjust their maximum PW speed to a comfortable indoor speed for each task. While this adjustment may be different between VR and RW, the perception of speed in VR categorically contributes to how participants choose to perform tasks. For each of the three tasks in each scenario, participants performed the task 5 times in succession.

Desk

For this task, participants began directly in front and parallel with the length of the desk. On the opposite side of the desk from where the participant began were two chairs with enough space between to fit the wheelchair. On the left side of the desk was a desktop drawer and on the right side was a roll of tape. Participants were tasked with manoeuvring around the table, parking between the two chairs, opening the drawer, placing the object in the drawer, and finally closing the drawer.

Elevator

For this task, participants began 2 m in front of the door. They were tasked with manoeuvring into position to press the elevator’s call button, entering the elevator when the “door opens” (6 s delay), and pressing the floor button. For the real-world scenario, an elevator mock-up was used in the training room.

Door

For this task, participants began 2 m from and oriented towards the door. Participants were tasked to approach the door, open the door, and proceed through

the doorway. The task ended when the wheelchair crossed through the doorway. In this task, the door opened outward from the PW user. In the virtual environment, the hand would automatically grasp the door on proximity. However the participant needed to rotate the handle 45 ° then make a pushing gesture to open the door, which would automatically swing all the way open.

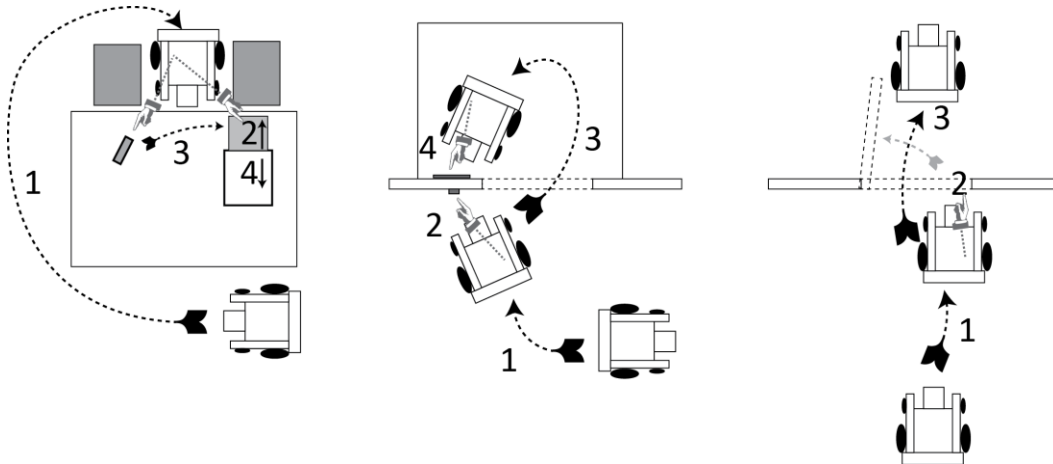


Figure 3.1: Task Diagrams.

Illustrations of task progression for the “Desk” (left), “Elevator” (middle), and “Door” (right).

For the RW part of the session, participants entered the training environment in their own PW. Participants were familiarized with the tasks until they felt comfortable with them (max 10 min) before proceeding with data collection. The order of tasks in the RW scenario was generally fixed to minimize time spent moving props around, in consideration of the already long (approximately 3 hours) session time: *Elevator* task, *Desk* task, *Door* task. Since these tasks were fairly ordinary for these experienced PW users, we reasoned that the order would have minimal effects on performance. In some cases, the task order was adjusted to accommodate technical considerations.

For the simulator part of the session, participants were seated in front of the computer monitor in their own wheelchair. The simulator joystick was attached in place of the normal wheelchair joystick to ensure comfortable and realistic control of the wheelchair. The joystick used to interface with the simulator was similar to joysticks utilized by many PW models (Penny & Giles joystick, Traxsys, UK). The Hydra motion controllers (Sixense, USA) were

strapped to the back of each hand. These are capable of one-to-one position and orientation tracking in 3D space. Each controller contains a magnetic sensor that interacts with a weak magnetic field produced by a base unit, providing accurate and precise tracking of the controller's movement and orientation through space (precision of 1 mm and 1°, according to specifications). The primary advantage of this system over other motion controllers is that it does not require line-of-sight between controller and sensor. Participants were given an opportunity to familiarize themselves with the simulator and to practice navigating and interacting with objects in each virtual task (max 15 min).

In VR, participants generally performed the *Door* task first, followed by the *Desk* then *Elevator* tasks. We reasoned that, while participants were given time to become familiar with the simulator, some learning effects were still likely to occur. Therefore, the *Door* task, as the most straight-forward task and least likely to see varied strategy, was presented first. However, the ultimate order depended on the participant; sometimes a participant had difficulty completing a given task at first—this task was revisited at the end after the other tasks were recorded.

3.3.3 Data Collection

Data collection for tasks performed in the RW involved a ceiling-mounted video camera and a joystick data logger. For joystick position data, we used a standard PW joystick modified to be connected to a data logging system (Archambault et al. 2011) that we mounted on the participant's wheelchair. The data logging system sampled at 200 Hz and consisted of a tablet PC placed inside a backpack. The ceiling-mounted video camera was a wide-lens Logitech HD Pro Webcam C920 (Morges, Switzerland) with an average sampling rate of 30 Hz at 1080p resolution and encoded in H.264/MPEG-4.

Data for tasks performed in the miWe simulator was recorded by the simulator from the joystick input and the motion controllers, with an average sampling rate of 50 Hz, corresponding to the simulator's video frame rate.

The iGroup Presence Questionnaire (IPQ) was used to determine the users' sense of presence while using the miWe simulator. The IPQ comprises of fourteen items in four subcategories (Nichols et al. 2000):

1. Spatial Presence (5 items) – the sense of being physically present in the virtual environment,
2. Involvement (4 items) – measuring the attention devoted to the virtual environment and involvement experienced,
3. Experienced Realism (4 items) – measuring the subjective experience of realism in the virtual environment.
4. A general item on the “sense of being there”

All items are scored on a seven point scale (0 - 6), with a higher score indicating a greater sense of presence. The IPQ has good psychometric properties and has been replicated across multiple samples (Schubert et al. 2001). Total score can be treated as an overall measure of sense of presence, or the subscales can be treated separately. The IPQ was administered immediately after completing the session.

Qualitative data was collected from a task-specific and general questionnaire that prompted participants to provide suggestions, criticisms, and overall feedback on the simulator. The questionnaire was similar to the feedback form used in a previous study involving the miWe (Archambault et al. 2012), asking for feedback about usability, relevance, limitations, improvements, etc. Emphasis was placed on feedback regarding the reaching component of the task and the Razer Hydra motion controller. The feedback form was administered immediately after the IPQ.

3.3.4 Analysis

Video and joystick data from the real-world scenario were time synchronized by the manual marking of the onset of first joystick movement—the task start.

Task completion time was determined by task-specific criteria: closing the drawer, pressing the floor button of the elevator, and crossing through the doorway. Completion time was further broken down to include time spent reaching; time of reaching movements was defined by the onset of a reaching movement towards a reaching objective to the end of returning the arm to rest or the end of task completion criteria.

In both the real-world and virtual scenarios, joystick excursion was calculated from its centre position via the vector norm of its x and y displacements. Joystick movements were defined as an excursion away from the neutral position (threshold of 10 %). Since the wheelchair brakes were automatically engaged when the joystick was in neutral position, this definition allowed us to measure number of movements interposed by instances of braking. While this method did not account for smaller sub-movements, it provided a clear picture of go-stop driving patterns.

Reaching movements were counted from the video data for the RW task and from the hand position data collected from the simulator for VR. A reaching movement was defined as “an effortful movement towards an object”; thus, pressing a button counted as 2 movements (reach to press and return to rest) while reaching to grasp with lateral drifting (searching behaviour) still counted as one movement (without return to rest).

Physical measures were compared across participants as a self-controlled paired group. Data pairs (RW, VR) were the average of the five trials per task and per environment. Wilcoxon sign-rank tests were used to compare non-normally distributed continuous and count data.

A video task analysis was performed to compare performance and strategy characteristics (collisions, errors, parking location and orientation, which hand and when for reaching, etc). Errors were compared using relative risk assessment.

Concordance between RW and VR tasks was analyzed for each characteristic behaviour/strategy identified in each task. For a given task characteristic (e.g. which hand they used to reach), each participant’s dominant behaviour in RW was identified, and then compared to their corresponding

dominant behaviour in VR; the dominant behaviour in VR could either be concordant or discordant with that of the RW. To illustrate, we may consider the characteristic strategy, “uses left or right hand to grasp the door handle”, during the *Door* task. The participant performed the task 5 times each in the VR and RW. If the participant used the right hand 5/5 times in RW and 3/5 times in VR, the dominant behaviour in both environments would be “right hand”. Therefore, the characteristic, “hand used”, would be rated as concordant for this particular task and participant. If, however, the participant used the right hand 3/5 times in RW and 2/5 times in VR (i.e. used the left hand 3/5 times in VR), the dominant behaviour in RW would be “right hand” and the dominant behaviour in VR would be “left hand”. Therefore, the characteristic would be rated as discordant.

Each task characteristic for each participant was rated with a binary score: concordant/discordant (1/0). Moreover, characteristics were described with two options where possible: “left or right hand” or “they demonstrated behaviour/did not demonstrate behaviour”. The utilization of “dominant behaviour” in this context was selected to describe the expert participants’ preferred strategy/behaviour and most likely reflects their “best practice” for task performance in RW. We wanted to see how closely VR performance matched these behaviours. Furthermore, this method also allowed for the fact that, in the real world, PW users do not always perform tasks in the same manner. A VR simulator that elicits authentic behaviour should also reflect this.

Concordance of task characteristics across participants was determined from total count of concordant cases using Cohen’s Kappa coefficient:

$$K = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)},$$

where $\Pr(a)$ is the proportion of counted concordant events and $\Pr(e)$ is the proportion of concordant events due to “random guessing” behaviour, e.g. the $\Pr(e)$ of “used hand” would be 0.5.

IPQ scores were compared to previous data gathered on the miWe simulators without the reaching component with an independent t-test.

Questionnaire data were summarized with common trends.

3.4 RESULTS

Four women and eight men aged between 36 and 60 years (50.1 ± 9.1 ; mean $\pm$ 1 SD) participated in this study (Table 3.1). The participants had between 2 and 30 years (16.1 ± 9.7) experience using their powered wheelchairs and an overall MOCA score of 20.1 ± 4.5 . The right-handed to left-handed ratio was 1:1.

All participants completed all tasks for both the real-world (RW) and virtual reality (VR) scenarios. However, two participants needed to complete the session over two separate days, with one scenario (VR/RW) completed on each day.

Measures of task completion time, reaching time, joystick movement count, and reaching movement count were averaged for each task for each participant. Distributions for these measures, across participants, were generally found to be non-normal (Shapiro-Wilk, $p < 0.05$); distributions were either asymmetric, multimodal, or had outliers. Therefore, the Wilcoxon signed-rank test was appropriate for comparing paired data, given the sample size.

Table 3.1: Participant descriptions.

Twelve participants with mean age 50.1 ± 9.1 yrs, 2:1 male/female, mean experience 16.1 ± 9.7 yrs, 1:1 left/right handedness, and mean MoCA 20.1 ± 4.5 .

Participant	Age	Sex	Experience	Handedness	PWC	MoCA
1	36	M	24	R	Quickie 747	15
2	60	F	14	L	Quickie 747	19
3	51	F	23	L	Orthofab Oasis 2	13
4	55	F	10	L	Orthofab Oasis 2	25
5	51	M	20	L	Quickie 646	20
6	56	M	30	L	Invacare TDX-SP	18
7	56	F	2	R	Invacare Arrow	25
8	37	M	25	R	Invacare Arrow	24
9	59	M	4	R	Orthofab Oasis	26
10	59	M	26	L	Invacare	21
11	38	M	10	R	Quickie 646	14
12	43	M	5	R	Orthofab Oasis	21

Age (years), Sex (Male, Female), Experience (years), Handedness (Right, Left), MoCA = Montréal Cognitive Assessment Test (max = 30).

3.4.1 Task Times

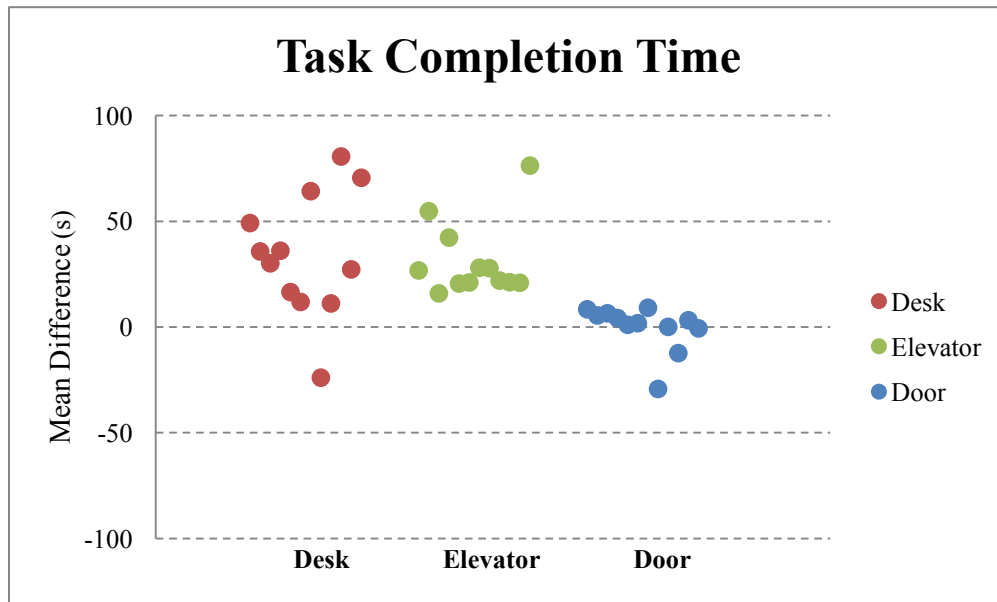
A summary of task completion and reaching times is provided in Table 3.2. The *Elevator* task took the longest total time with a median time of 24.9 s (IQR 21.4—31.7 s; interquartile range) in RW and 57.6 s (IQR 42.6—69.2 s) in VR. The median time for the *Desk* task was 19.5 s (IQR 15.3—24.9 s) in RW and 52.6 s (IQR 39.4—77.4 s) in VR. The *Door* task took the least time overall with a

median task time of 10.6 s (IQR 7.5—14.4 s) in RW and 13.4 s (IQR 42.6—69.2 s) in VR.

Of these three tasks, only the *Door* task demonstrated similar task completion times with no significant difference between the two environments ($p = 0.3$). For the *Desk* and *Elevator* tasks, the VR task completion times were both significantly ($p < 0.01$) longer, with the *Desk* task showing the greatest difference; the *Desk* VR scenario took a median 33.0 s (IQR 15.4—53 s) longer to complete than the RW scenario. A plot of task completion time differences is shown in Figure 3.2a.

Within each task in the RW, participants spent time reaching for objects a median of 6.1s (IQR 4.8—9.0 s) in the *Desk* task, 5.2 s (IQR 4.1—6.7 s) in the *Elevator* task, and 3.8 s (IQR 3.4—5.6 s) in the *Door* task. By comparison, participants spent significantly more time in the VR scenario for all three tasks ($p = 0.02$ for *Desk*, $p < 0.01$ for *Elevator*, $p = 0.03$ for *Door*). The greatest difference in reaching time was in the *Desk* task where participants took a median 14.2 s (IQR 4.0—19.7 s) longer for reaching in VR than in RW. A plot of reaching time differences is shown in Figure 3.2b.

a)



b)

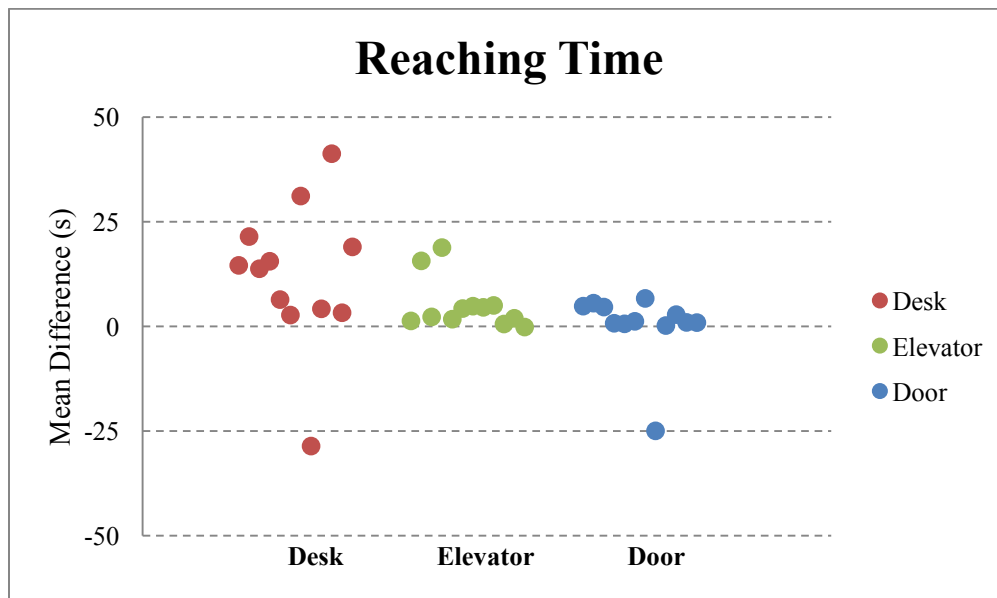


Figure 3.2: Task Time Mean Difference.

(a) shows differences in total task time and (b) shows differences in time spent reaching. Values > 0 indicate greater time in VR compared to RW. Each point represents the mean difference between environments for one participant.

3.4.2 Discrete Movements

Figure 3.3 shows an example of the *Elevator* task and the *Door* task performed by one participant in VR. Figure 3.4a shows example traces representing joystick excursion during the *Elevator* task in RW and in VR. The complexity of the navigation component of this task is demonstrated by the number of joystick movements. Moreover, the VR trace shows noticeably more joystick movements than in the RW counterpart. Figure 3.4b shows another pair of RW/VR traces of joystick excursion for a *Door* task trial from the same participant; in this example, there are noticeably fewer joystick movements overall and the RW and VR traces appear more similar than in the *Elevator* example.

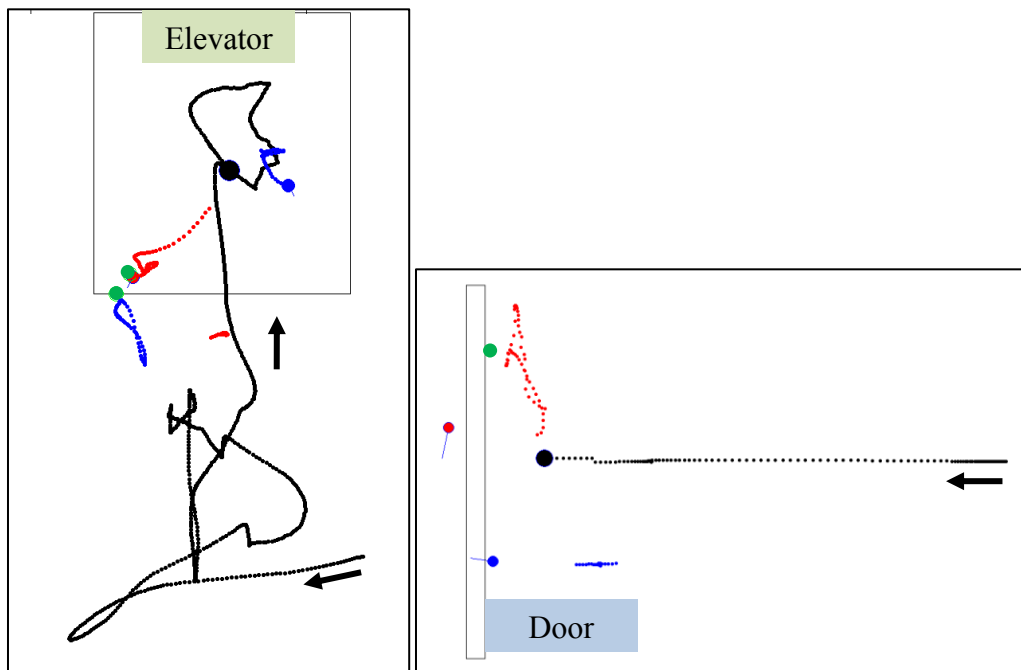


Figure 3.3: Example Position Traces of VR Trials.

Examples are from participant 5. The *Elevator* example (left) shows the path of the PW (black) starting in the bottom right and the *Door* example (right) shows the path of PW starting from the right. The red and blue traces represent reaching movements of the right and left hands respectively and the green circles represent reaching targets.

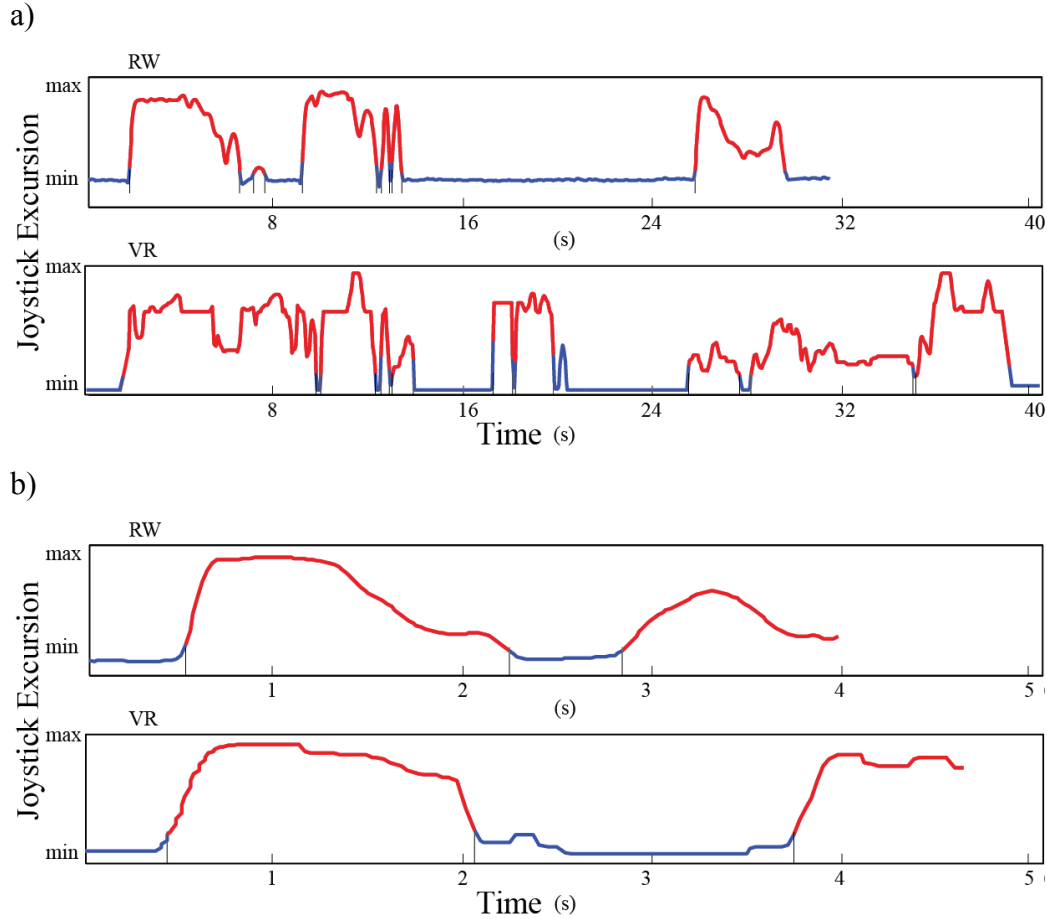
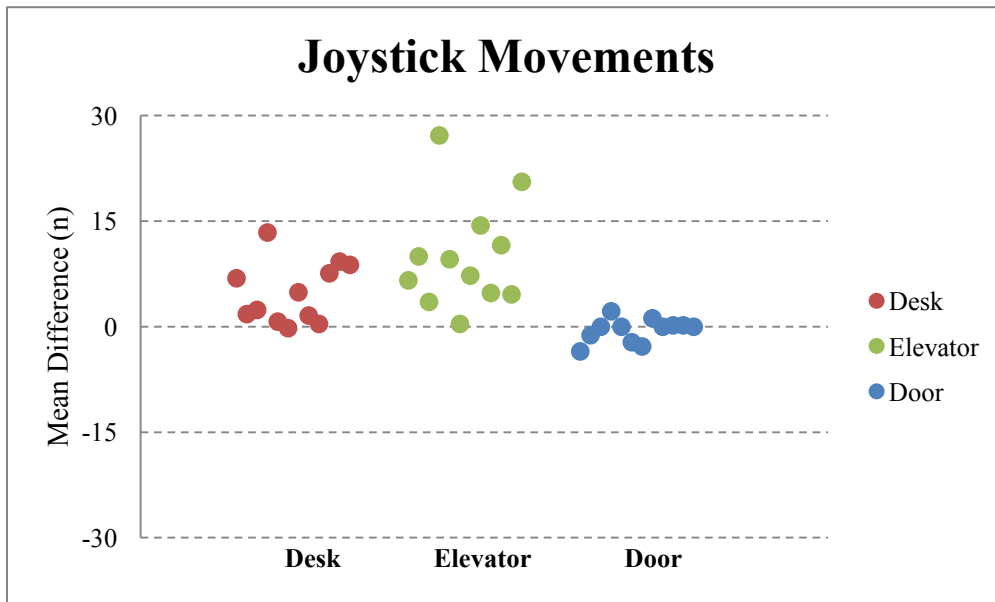


Figure 3.4: Example traces of joystick excursion.

Joystick excursion (from centre) in the *Elevator* (a) example from Participant 5 shows 6 joystick movements (red) over 30 s in RW and 9 movements over 37 s in VR. The *Door* example from Participant 5 shows 2 movements over 3.6 s in RW and 2 movements over 4.8 s in VR.

Within each task in the RW, participants completed tasks with a median number of joystick movements of 2.7 (IQR 1.8—4.5) in the *Desk* task, 4.4 (IQR 3.4—6.0) in the *Elevator* task, and 3.6 (IQR 2.4—5.2) in the *Door* task. By comparison, participants utilized significantly more joystick movements in the VR scenario for the *Desk* task ($p < 0.01$) and *Elevator* task ($p < 0.01$). The greatest difference was in the *Elevator* task where the VR scenario required a median of 8.4 (IQR 4.8—12.3) more joystick movements than the RW scenario. However, joystick movement count was concordant between RW and VR in the *Door* task, with no significant difference between counts ($p = 0.45$). A plot of joystick movement differences is shown in Figure 3.5a.

a)



b)

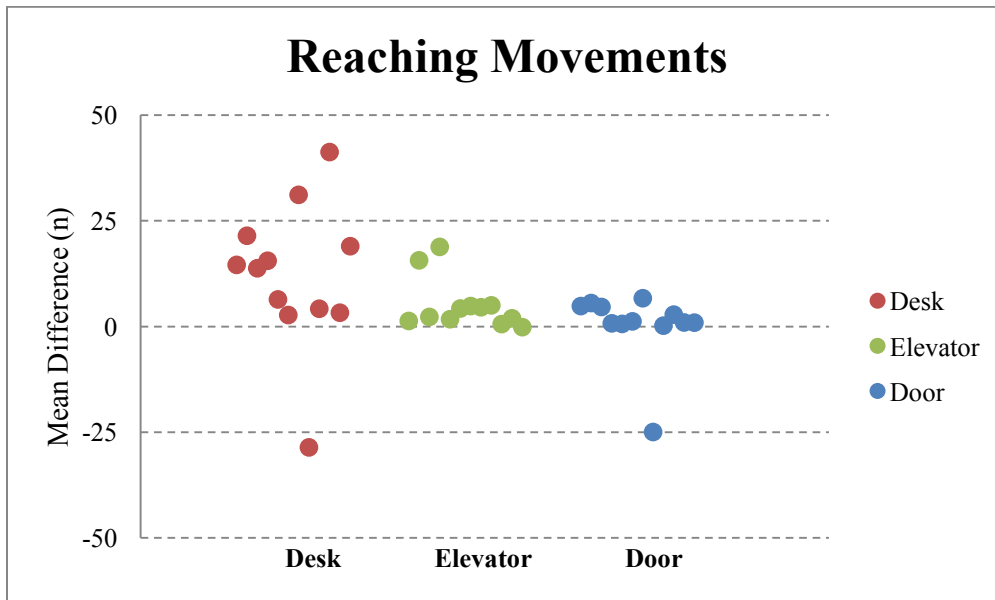


Figure 3.5: Movement Count Mean Difference.

(a) shows differences in total joystick movements and (b) shows differences in total reaching movements. Values > 0 indicate greater time in VR compared to RW. Each point represents the mean difference between environments for one participant.

Similarly, the number of reaching movements utilized was concordant between RW and VR only for the *Door* task ($p = 0.74$). A significantly greater

number of reaching movements were made in the VR scenario for the *Desk* task ($p < 0.01$) and *Elevator* task ($p = 0.04$). The greatest difference was in the *Desk* task where the VR scenario required a median of 1.9 (IQR 1.0—2.7) more reaching movements than the RW scenario. For comparison, participants required a median count in RW of 6.3 (IQR 6.0—6.7) in the *Desk* task, 3.8 (IQR 3.4—4.1) in the *Elevator* task, and 4.1 (IQR 3.8—4.7) in the *Door* task. A plot of reaching movement differences is shown in Figure 3.4b.

A summary of joystick movement counts and reaching movement counts are provided in Table 3.2.

Table 3.2: Task Times and Movement Counts.

Summary statistics of the measure distributions and their difference (Δ) distributions (N=12) are provided. VR vs RW was compared using Wilcoxon Sign-Rank test. A p-value < 0.01 indicates Δ is significantly > 0 .

Task Completion Time (s)									
	Desk			Elevator			Door		
	RW	VR	Δ	RW	VR	Δ	RW	VR	Δ
Median	19.5	52.6	33.0	24.9	57.6	24.4	10.6	13.7	2.6
IQR	15.3	39.4	15.4	21.4	42.6	21.1	7.5	10.4	-0.1
	24.9	77.4	53.0	31.7	69.2	31.7	14.4	21.1	5.8
p-value			<0.01			<0.01			0.30
Reaching Time (s)									
	RW	VR	Δ	RW	VR	Δ	RW	VR	Δ
Median	6.1	22.7	14.2	5.2	8.9	3.3	3.8	7.1	1.1
IQR	4.8	10.9	4.0	4.1	7.7	1.7	3.4	4.6	0.8
	9.0	27.9	19.7	6.7	14.6	4.9	5.6	10.4	4.7
p-value			0.02			<0.01			0.03
Joystick Movements (count)									
	RW	VR	Δ	RW	VR	Δ	RW	VR	Δ
Median	2.7	8.9	3.7	4.4	13.7	8.4	3.6	3.3	0.0
IQR	1.8	3.4	1.4	3.4	10.3	4.8	2.4	2.4	-1.5
	4.5	10.9	7.9	6.0	20.4	12.3	5.2	4.3	0.2
p-value			<0.01			<0.01			0.45
Reaching Movements (count)									
	RW	VR	Δ	RW	VR	Δ	RW	VR	Δ
Median	6.3	8.47	1.9	3.8	5.1	1.3	4.1	4.5	0.5
IQR	6.0	8.1	1.0	3.4	4.6	0.3	3.8	4.0	-0.6
	6.7	9.1	2.7	4.1	5.9	2.0	4.7	5.1	1.0
p-value			<0.01			0.04			0.74

RW (Real World), VR (Virtual Reality), Δ (difference between VR and RW), IQR (interquartile range), p-value (Wilcoxon Sign-Rank Test).

3.4.3 Task Analysis

Two important task errors were observed in the performance of each task (Table 3.5): collisions (driving error) and errors in judgment of maximum reaching distance (reaching error). A collision was defined as any contact of the PW with an obstacle. An error in reaching distance occurred when the participant misjudged the distance required to reach a target object (e.g. a button) and needed to adjust their parking position closer. Trials were divided into trials where one or more driving errors occurred and trials where no collisions occurred (same for reaching distance errors). For each task and across all participants, there was a significantly greater chance (relative risk, $p < 0.05$) of driving and reaching errors occurring during a trial performed in VR than in RW.

Each of the three tasks was broken down into component tasks based on video analysis. For example, in the *Elevator* task, navigating to the call button and deciding on parking position for reaching are two distinct tasks. For each component, characteristic strategies and behaviours were identified. For example: using the left or right hand for reaching components or completing navigation components without any major pauses. All of these behaviours, except for parking position, were binary; either they did, or did not. Table 3.3 describes all the characteristics identified and Table 3.4 sorts these characteristics into each component of each task.

Table 3.3: Task Characteristics.

Task characteristics are described in detail and given a summary code. Codes with “G” are general characteristics observable in all tasks.

Code	Driving Characteristic	Code	Reaching Characteristic
DG1	<i>Fluid drive-to-park:</i> participants completed navigation without pausing	RG1	<i>Start reaching before park:</i> participants began reaching before their PW completely stopped
DG2	<i>Parking Position:</i> 2-4 positions depending on context	RG2	<i>L/R hand:</i> which hand was used to reach the target
DG3	<i>Collision:</i> any contact of the wheelchair with an obstacle	RG3	<i>Adjust parking close for reach:</i> misjudged reaching distance, i.e. reaching error
DE11	<i>Turn first/reverse first:</i> how participants began navigating to the first button	RDe1	<i>Pickup order:</i> the object was picked up before, after, or at the same time as opening the drawer
DE12	<i>Waiting for door:</i> participants waited for the door without repositioning their PW	RDe2	<i>Heavy leaning:</i> participants needed clearly uncomfortable trunk compensation to reach target
DE13	<i>Forward/reverse in:</i> entering the elevator	RDe3	<i>Close drawer hand:</i> participants closed the drawer with either the same or opposite hand that placed the object inside the drawer
DE14	<i>Horizontal Adjust:</i> a characteristic “S” manoeuvre sideways	RDo1	<i>Fluid turn + push:</i> the door was opened in a single, non-segmented movement
DDr1	<i>Advance straight:</i> participants drove in a straight line to the door	RDo2	<i>Hand still raised:</i> while driving through the doorway

Table 3.4: Task Components.

Tasks are broken down into component tasks and progress chronologically. Task characteristics are organized into each component. Some characteristics appear in multiple components of the same task.

Desk	Elevator	Door
<i>Navigating around desk</i> DG1, DG3, RG1	<i>Navigate to button 1</i> DG1, DG3, DE11, RG1	<i>Advancing towards door</i> DG1, DG3, DDr1, RG1
<i>Parking between chairs</i> DG2, DG3, RG3	<i>Parking at button 1</i> DG2, DG3, RG3	<i>Parking in front of door</i> DG2, DG3, RG3
<i>Reaching for object</i> RG2, RDe1, RDe2	<i>Pressing button 1</i> RG2	<i>Reaching for door handle</i> RG2
<i>Opening drawer</i> RG2, RDe2	<i>Navigate to button 2</i> DG1, DG2, DG3, DE12, DE13, DE14, RG1	<i>Opening door</i> RDo1
<i>Placing object in and closing drawer</i> RDe2, RDe3	<i>Parking at button 2</i> DG2, DG3, RG3 <i>Pressing button 2</i> RG2	<i>Driving through doorway</i> RDo2

According to guidelines proposed by Fleiss (1981), performance in the *Desk* task showed fair ($0.4 < K < 0.75$) to excellent ($K > 0.75$) agreement for most reaching behaviours except for the “close drawer hand” component. However, driving behaviours showed poor agreement. Of note, the “fluid drive-to-park” characteristic showed a negative Kappa score ($K = -0.17$), indicating that participants had a tendency towards the opposite behaviour in VR. Performance in the *Elevator* task showed generally fair agreement between RW and VR for driving and reaching behaviours. Only the “fluid drive-to-park” and “waiting for door” characteristics showed poor agreement. Finally, performance in the *Door*

task showed generally fair agreement for driving and reaching behaviours except for the “advance straight” and “fluid turn and push” characteristics. All agreement statistics are listed in Table 3.6.

Table 3.5: Task Error.

Summary of driving errors (DG3) and reaching errors (RG3) for each task. Rate of occurrence (%) is listed and relative risk (RR) is used to compare VR relative to RW.

		%	RR	95% CI
Desk				
Driving Error	VR	100	3.72	(3.00, 4.61)
	RW	27		
Reach Error	VR	13	2.93	(1.39, 61.7)
	RW	5		
Elevator				
Driving Error	VR	93	4.31	(3.36, 5.52)
	RW	22		
Reach Error	VR	33	5.86	(3.59, 9.56)
	RW	5		
Door				
Driving Error	VR	60	1.89	(1.52, 2.35)
	RW	32		
Reach Error	VR	15	1.50	(0.96, 2.34)
	RW	10		

RR = relative risk and CI = confidence interval of RR

Table 3.6: Task Behaviours Agreement.

Summary of concordance, as measured by Cohen's Kappa coefficient (K), for each characteristic in each task across participants.

		<i>K</i>
Desk		
Driving Behaviour	Fluid drive-to-park	-0.17
	Parking Position	0.33
Reaching Behaviour	Start reaching before park	0.83
	Pickup order	0.50
	Close drawer hand	0.20
	L/R Hand	0.80
	Heavy leaning	0.67
Elevator		
Driving Behaviour	Turn First/Reverse First	0.83
	Fluid drive-to-park	0.22
	Parking Position	0.45
	Waiting for Door	0.17
	Forward/Reverse In	0.67
	Horizontal adjust	0.67
Reaching Behaviour	Start reaching before park	0.67
	L/R Hand	0.60
Door		
Driving Behaviour	Advance straight	0.17
	Fluid drive-to-park	0.67
	Parking Position	0.67
Reaching Behaviour	Start reaching before park	0.50
	L/R Hand	0.80
	Fluid turn + push	0.33
	Hand still raised	0.67

3.4.4 Presence

Presence was measured for the VR simulator using the IPQ and scores are summarized with mean and standard deviation in Figure 3.5. Overall, “general sense of presence”, “spatial presence”, and “realism” averaged slightly below 3. Only “involvement” averaged above 3. In comparison with previous data collected in the miWe (Archambault et al. 2012), without a reaching component, our results showed a significantly greater (independent t-test, $p < 0.05$) sense of “involvement”. However, scores in the remaining three categories were not significantly different.

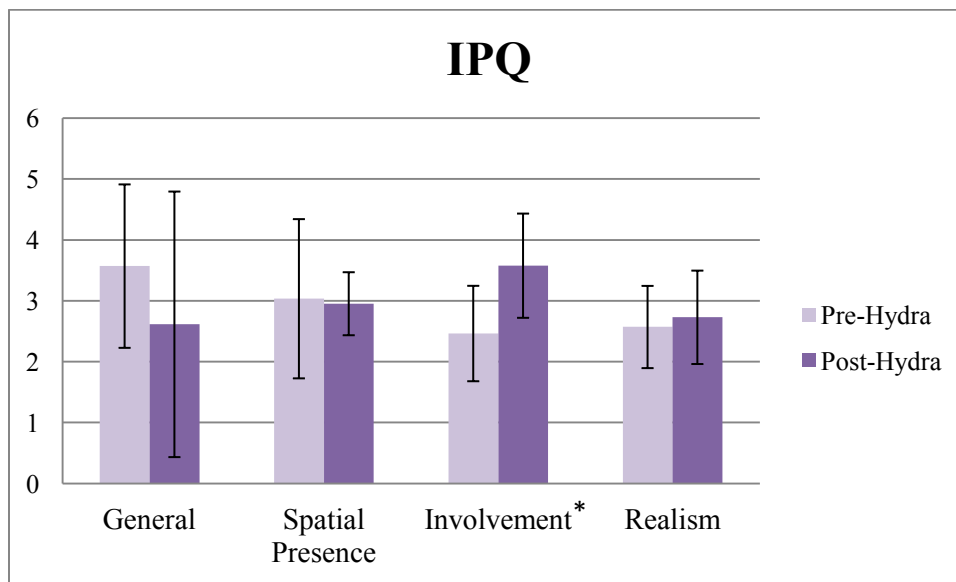


Figure 3.6: iGroup Presence Questionnaire

IPQ scores are summarized across 4 domains compare previously gathered miWe data without the 3D hand motion controller (Pre-Hydra) and our results (Post-Hydra). Error bars represent standard deviation and (*) is significant ($p < 0.05$).

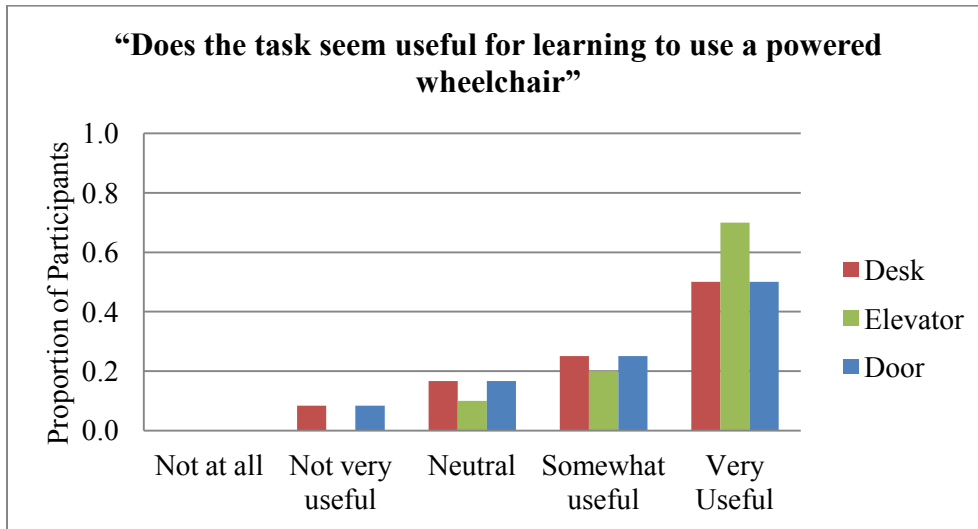
3.4.5 Questionnaire and Feedback

Participants answered additional task specific (Figure 3.6) and general (Figure 3.7) questions on a 5-point Likert scale (Not at all, Not very, Neutral, Somewhat, Very) and were prompted to make task specific and general suggestions and comments (Table 3.4) about the VR simulator.

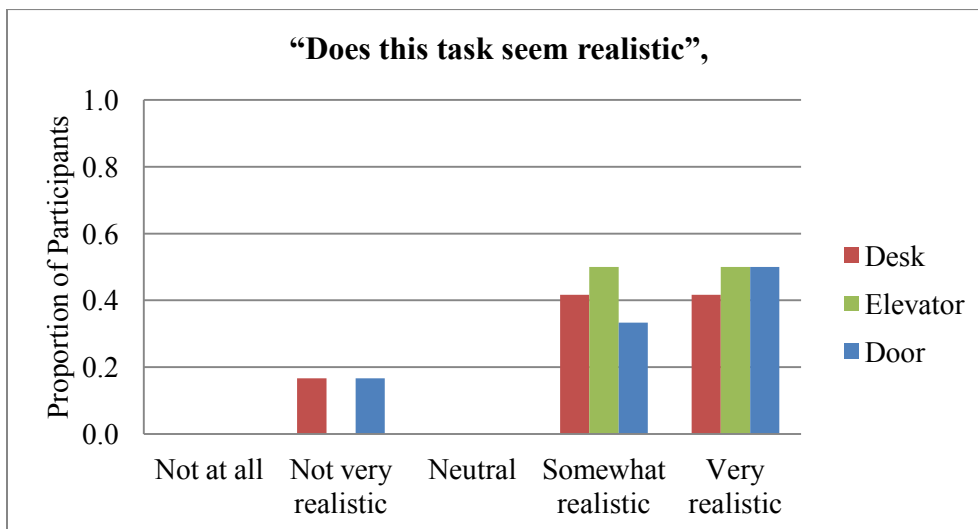
Overall, when asked, “Does the task seem useful for learning to use a powered wheelchair” in context of the VR simulator, 9/12 participants or more rated all of the tasks as somewhat or very useful (4/5 and 5/5 on the Likert scale,

respectively). When asked, “Does this task seem realistic”, nearly all (10/12 or more) participants rated the *Desk*, *Elevator*, and *Door* task as somewhat to very realistic. However, only 6/12 to 7/12 participants rated the difficulty of the simulator tasks as somewhat to very appropriate. Likewise, 5/12 to 6/12 participants rated the tasks as somewhat to very motivating.

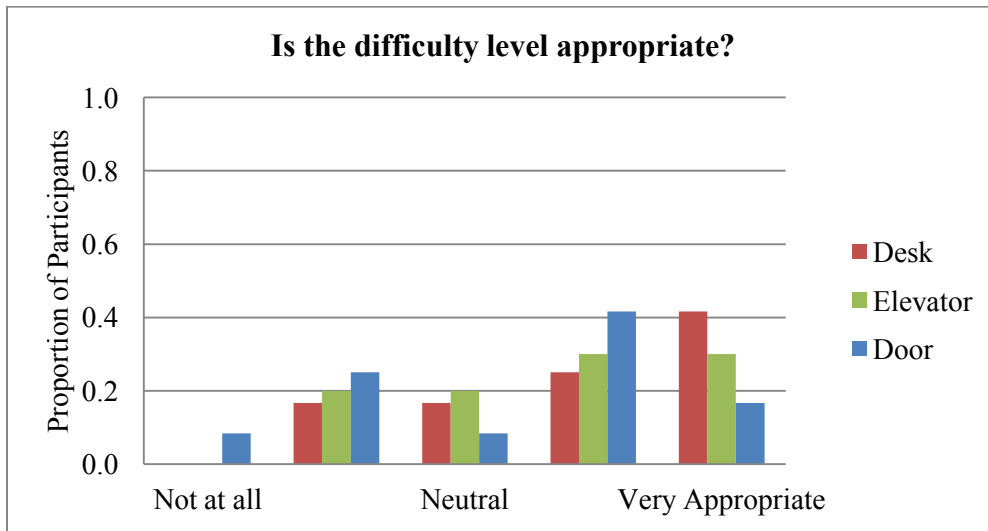
a)



b)



c)



d)

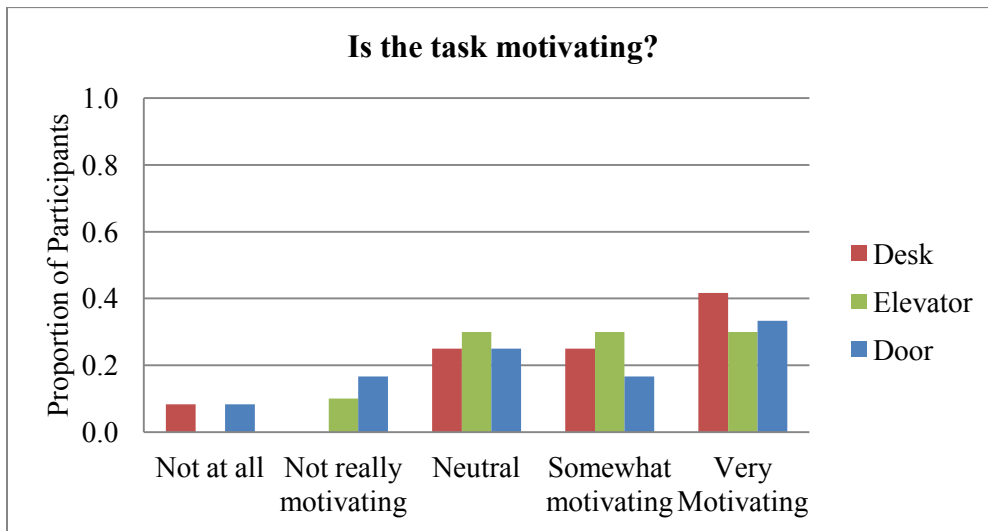
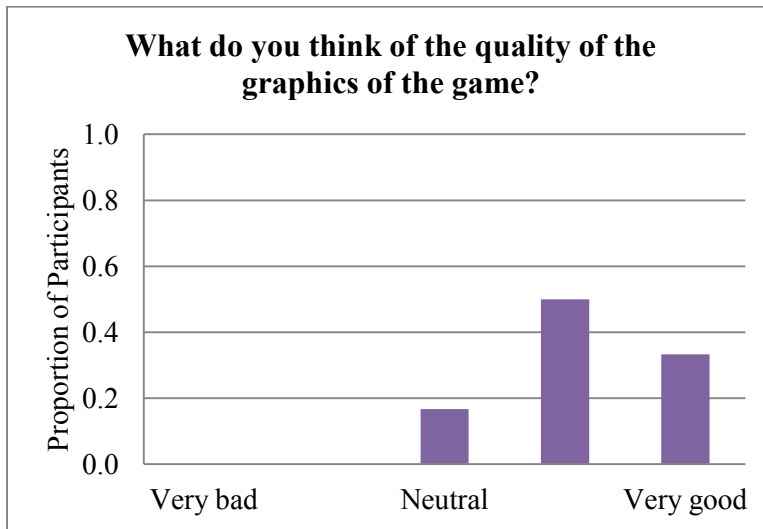


Figure 3.7: Task-specific scale questions.

Proportion of responses for each task to each Likert scale item.

General questions about the VR simulator included “What do you think of the quality of the graphics of the game” and “Does using the hand-motion controllers enhance the realism of the game”. When rating the graphics quality, 10/12 participants rated it as somewhat to very good. Finally, 10/12 participants rated the added realism due to the Hydra as somewhat to very much (Fig. 3.8).

a)



b)

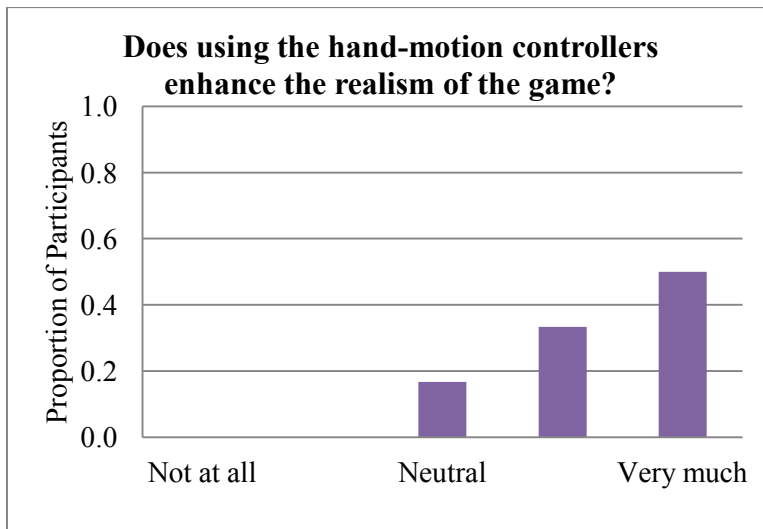


Figure 3.8: General scale questions.

Proportion of responses to each Likert scale item for generalized questions.

Participants' comments regarding specific tasks and the simulator in general were various and included both positive and negative feedback. One participant commented, "Interesting. I like the word 'success' in the end, it's motivating!" Another participant commented "I was a little stressed. I do not like playing with joysticks in a virtual environment." Participants were also prompted

to suggest other relevant tasks. The only task that was suggested more than once was “getting coffee”. A list of common comments is summarized in Table 3.7.

Table 3.7: Questionnaire Feedback Comments.

Summary of the most frequent comments. Comments were generalized to give an overall impression of how participants responded. Categories represent topical prompts to which participants responded.

Category	Generalized Comment	Count
Criticism of the tasks	Difficulty with joystick precision and accuracy	5
	Lacking of vision due to fixed camera	3
	Elevator was too small	3
Reactions to the reaching controller	Enjoyed using the reaching controller	5
	Noted "glitches" during reaching tasks	3
	"It adds realism to the game"	2
	Difficulty due to lack of depth perception	2
Suggestions	Changes to the task that would add complexity	5
	Changes to the task that would lower complexity	5
	Specified other indoor tasks	6
	Specified other outdoor tasks	1

3.5 DISCUSSION

3.5.1 Task Performance

The first objective of this study was to compare task performance between RW and VR scenarios. We found that, in two of three tasks (*Desk* and *Elevator*), task completion time, time spent reaching, number of joystick movements, and number of reaching movements were all significantly greater when the task was performed in VR compared to RW. Only the *Door* task showed concordant performance measures (except for reaching time).

Joystick movements were represented by continuous deviation from the joystick centre position and therefore reflect distinct PW manoeuvres. As such, concordant joystick movements in the *Door* task indicate that participants followed the same manoeuvring sequence in VR and PW; discordant joystick movements for the *Desk* and *Elevator* tasks indicate that participants navigated to objectives differently.

There have been few studies that directly compare PW task performance between VR and RW. Similar to our results, a study by Harrison and colleagues (2000) reported greater task completion times and a greater number of discrete manoeuvres in VR compared to RW when comparing several manoeuvring tasks and one route-finding task. However, the previous study involving the miWe simulator (Archambault et al. 2012) showed no significant difference in task completion times in 4/7 Wheelchair Skills Test (Dalhousie University, 2012) type tasks and no significant difference in the number of joystick movements in 6/7 of these tasks. The authors noted that the tasks with significantly greater times and movements were the most difficult ones. Specifically, in their “Door (Push)” task, participants lined up with the door, “pushed” the door open, drove through, turned around, and closed the door. In comparison, our *Door* task was arguably the simplest (drive forward to door, open door, and drive through) of our three tasks, requiring no turning and minimal manoeuvring through tight spaces. Therefore, it is unsurprising that the *Door* task was the one task that did show concordant performance measures in total task time and joystick control.

Our video task analysis showed a higher risk of collisions in VR compared to RW. Of note, collisions occurred in 100% of *Desk* trials and 93% of *Elevator* trials in VR. In a similar comparison, Harrison and colleagues (2000) counted a total of 4 collisions over all their RW trials and 140 over all VR trials, in their manoeuvring and route-finding tasks. The authors noted that collision rates were greatest in tasks that required turning. Furthermore, Archambault and colleagues (2012) noted frequent collisions and adjustments in VR compared to RW for their most complex manoeuvring tasks. This is consistent with our results where the greatest relative risk of collisions in VR were with regard to the *Desk* and *Elevator* tasks, which required navigating and turning in tight spaces. Therefore, corrective and repeat movements for collisions likely contributed to greater task times. The poor agreement of the driving behaviours “advance straight” (*Door* task) and “fluid drive-to-park” further suggests that navigation was overall more efficient in RW than in VR.

The poorer navigation performance may be explained by a number of simulator limitations. A consistent limitation of the miWe simulator is the limited and fixed field of view (FOV) of the simulation; the virtual camera is fixed in the forward position and participants cannot easily “look around” their wheelchair to focus on obstacles. Moreover, the miWe system uses a 2D, monoscopic display instead of a 3D stereoscopic display, meaning participants lack depth perception for judging distances to obstacles. Since maximum PW speed was adjusted to the participants’ comfort for each scenario and task, a cautious selection of maximum PW speed (a potential result of depth perception limitations) would have also contributed to longer navigation times. Finally, some participants responded on the questionnaire that the joystick control of the PW was unrealistic, e.g. turn radius, or needed improvement in terms of precision and accuracy. Together, these limitations make obstacle avoidance, especially in tight spaces, more challenging in VR than in RW and likely make a major contribution to the observed discordance in navigation performance. While it is possible that a more challenging experience in VR for navigation may contribute to greater training efficacy simply by requiring users to exercise their fine motor control more,

regardless of realism, the contextualized motor planning skills may train inefficient driving patterns; for example, a significantly greater PW turn radius in VR would make manoeuvring in tight spaces more difficult, but training with this turn radius may cause users to misjudge the manoeuvring ability in their own PW.

For cognitive skills such as path finding and overall task planning, however, participants tended to adopt concordant (moderate to excellent agreement) strategies when making navigation choices in VR and RW: they generally parked in the same position relative to the reaching target and they approached the buttons (outside and inside) on the elevator in the same relative orientation. Also, the majority of observed reaching behaviours and strategies were concordant (moderate to excellent agreement) for each task in VR and RW: participants tended to use the same hand for reaching a given object and had similar start-of-reach timing relative to parking. This suggests that, while participants may have driven less efficiently in VR compared to RW, they still performed both route finding and task planning (for navigation and reaching components) in similar ways.

Reaching movements were represented by distinct hand and arm movements to a target. Like the joystick results, participants showed concordant reaching sequences in the *Door* task and discordant reaching sequences in the *Desk* and *Elevator* tasks.

Of note, Figures 3.2b and 3.5b show outlier points from one participant with much shorter reaching time and fewer reaching movements in VR than RW in the *Desk* and *Door* tasks. This participant (P8) met all of the cognitive requirements for inclusion, however P8 had cerebral palsy. Our participants exhibited a range of upper limb motor deficits, and this was the most extreme case. We chose to include P8 since our only physical criterion was the ability to complete the tasks and our framework was a generalized PW user population. Moreover, the inclusion of this participant also demonstrated some hard limitations on 3D motion tracking and insights for future design.

The outlier data may be explained by the VR object interaction interface (i.e. operating drawer, grabbing an object on a desk, and opening the door) which

operated in an “on rails” fashion, e.g. once the VR hand was moved within proximity to the VR door handle, the hand was “locked-on” to the handle and the participant’s hand movements would only control rotation of the handle. This setup was more forgiving in terms of fine motor function than the RW counterpart and explains why P8 took much less effort to complete the *Desk* and *Door* tasks in VR. However, the *Elevator* task, which only required button pressing, presented a more consistent representation of the object interaction part of the task between VR and RW in context of involuntary/spastic movements.

Overall, the interactions with objects in the door and drawer tasks were those where the reaching components of VR departed the most from RW (no physical object to grasp) in terms of user interface.

To our knowledge, this study is the first to compare reaching performance between VR and RW in context of using a PW. However, there is already a fair amount of research on motor performance in VR with respect to upper-limb rehabilitation (Levin et al. 2014). Of note, Viau and colleagues (2004) compared motor performance and movement patterns between VR (2D display) and RW during a reach, grasp, and release task performed by healthy and post-stroke participants. These authors reported similar overall movement strategies between the two environments, but different movement with respect to degree of elbow and wrist extension. However, other studies have demonstrated mixed results (Liebermann et al. 2012; Ma et al. 2012; Wang et al. 2011; Lott et al. 2003). Some of the differences in performance in VR (both 2D and 3D) have been attributed to the presence or absence of haptic feedback (Magdalon et al. 2011) and display platforms (Subramanian and Levin, 2011).

Therefore, the lack of haptic feedback and depth perception are likely contributing factors to the greater number of reaching movements (*Door* and *Elevator* tasks) and reaching time (all tasks) observed in our study; one participant commented in the questionnaire that they had difficulty knowing if they had pressed the button in the *Elevator* task. Additionally, the reaching tasks in our study differ from other studies in that the starting position of the user relative to the reaching objective was variable and dependent on the participant’s judgement;

they decided where to park. As such, participants were required to accurately judge that the reaching objective was indeed within reach. Our results showed that, for all tasks, participants were more likely to misjudge this reaching distance. While the lack of depth perception undoubtedly contributed to this error, other studies have shown that, even with stereoscopic displays for VR, users tend to underestimate distances (Armbrüster et al. 2008; Knapp and Loomis, 2004).

3.5.2 Presence

We hypothesized that the inclusion of the navigate-to-reach component and the Razer Hydra 3D hand motion controller interface would increase the sense of presence in the miWe simulator. In the previous miWe study, where manual tasks were performed by keystroke, average scores were above 3 for general sense of presence and spatial presence, but below 3 for involvement and realism (Archambault et al. 2012). In our study, only involvement showed a significant increase. This likely reflects a positive effect from the added level of interactivity provided by the Hydra controllers and the increased complexity, both physically and cognitively, of a combined navigation-reaching task. However, it is unclear why no changes were observed in the other sub-categories, especially the general sense of presence.

In our implementation, the miWe simulator was presented on a relatively small laptop monitor. The Hydra controllers were strapped to the participants' hands and their hands were well within their FOV during reaching. Moreover, the presentation of hands in the simulator were of disconnected "floating" hands. These factors together with the fixed simulator FOV were readily noticeable by participants and could have contributed to a decrease in realism, spatial presence, and general sense of presence that countered any gains due to the Hydra controller. A potential solution for these issues may be the utilization of low cost consumer-level HMDs, e.g. the upcoming Oculus Rift (Oculus VR, Irvine, USA), featuring a 1080p resolution stereoscopic display, a physical 90° by 110° FOV, and head motion tracking capabilities. This would provide greater visual

immersion, allow for users to look around the virtual environment using head movements, and obstruct the user's view of their real hands.

3.5.3 Participant Feedback

Participants responded positively with respect to training utility, realism, and graphical quality. The appropriateness of task difficulty and overall motivation were judged less positively, but were generally neutral or better. These results suggest that the overall design of the tasks were representative of tasks in the RW. Participants' comments also reflected frustration with the above-discussed limitations of the simulator. A previous study comparing PW driving in VR vs RW showed similar reactions from participants (Harrison et al. 2000). Participants of our study indicated that VR tasks felt more difficult to accomplish than the corresponding RW tasks, particularly because the joystick control was hard to use and quite different from what they were used to. However, several participants also commented that the reaching tasks were fun and engaging, indicating the potential for improving the motivational aspect of the simulator. Overall, the feedback comments were ambivalent, with some participants responding very positively and others having severe difficulty with the simulator. One factor to consider in these responses is the novelty of the PW simulator, particularly with respect to the reaching component; since the study was cross-sectional, the novelty of the situation may have led to greater initial enthusiasm for those who already enjoyed VR experiences (e.g. videogames) and insufficient familiarization for those who were already anxious about VR environments.

3.5.4 Limitations

This study introduced a new interface, new tasks, and new virtual environments to the miWe simulator; these are distinct features of the simulator, but are also difficult to treat independently. As such, it is unclear to what degree each of these features contributed positively and negatively to participants' sense of presence. Moreover, the implementation of each of these features was not ideal and could be improved. The point at which implementation of these features may

be considered “good enough” is an important consideration for any training simulator and another topic for future research.

In the case of participants who completed the session over two days, our sample size is insufficient to show whether or how much the separation of scenarios affected our results and represents a limitation of this study. However, these participants are experienced PW users and we do not think their RW performance was unduly affected.

3.5.5 Conclusion

In summary, this study on the Razer Hydra 3D motion controller, as an interface for combined navigation-reaching tasks in the miWe simulator, demonstrated some evidence supporting our hypotheses, but also important limitations that must be addressed in future development. First, participants demonstrated concordant (between VR and RW) task behaviours and strategies, and concordant kinematic performance on the least difficult task. However, participants demonstrated poorer kinematic performance in the two other, more difficult, tasks and greater overall rates of navigation and reaching errors. We attributed these differences primarily to limitations in depth perception, lack of camera control, joystick control, and haptic feedback. Second, the virtual environment generated an, as expected, greater sense of involvement, but not a greater general sense of presence. Finally, feedback from participants indicated that the combined navigation-reaching tasks were appropriate, useful for PW training, and engaging. However, the also noted difficulties with the implementation of some features.

With these results taken together, we believe that, in more complex tasks, fundamental differences between the implementation of the virtual simulation (e.g. PW steering characteristics, depth perception, multiple interfaces) and the real world are more likely to be compounded, resulting in divergent task performances. However, it is this very capacity for complex tasks that marks a key advantage of VR simulators. It allows us to expand upon, in VR, what can be learned and practiced safely in a traditional training facility to include a variety of

stakeholder-relevant tasks, environments, and scenarios. In context of this study, we may consider any situation, at home or in the community, in which PW users would need to interact using their hands. Therefore, future development will need focus on minimizing the experiential differences from the real world due to the implementation of simulator interfaces and virtual environments and will need to consult with PW users and clinicians on which at-home and in-community situations are most important. Some of these developments in the miWe are already underway and reported by Archambault and colleagues (2014). Finally, future development need also consider training requirements for PW users who have more severe upper-limb mobility limitations. Since people are often prescribed a PW because they are unable to use a manual wheelchair, reaching may not be as relevant for these users. As such, other adapted interfaces, or more generalized interfaces should be included in future development.

3.6 ACKNOWLEDGEMENTS

The authors would like to thank all the participants who took part in this study. Helen Zhu and Elise Busilacchi assisted in data collection and processing. Christian Beaudoin, Frederic Bobohn, and Frederic Vicaire contributed to software development and Igor Sorokin built the props.

Gordon Tao was the recipient of a scholarship from the School of Physical and Occupational Therapy of McGill University. This project was funded in part by Le Projet Stratégique Innovant of CRIR.

CHAPTER 4: SUMMARY AND CONCLUSION

This thesis demonstrated the immediate utility of integrating a reaching component into the miWe simulator using the Razer Hydra 3D hand motion controller. The added reaching interface allows PW users to practice realistic combined navigation-reaching tasks that are representative of their activities of daily living. The results showed that experienced PW users generally approached these tasks in the virtual environment with behaviours and strategies concordant with their approach to the corresponding tasks in the real world. However, the study also indicated several limitations with the simulation and the way in which the reaching component was integrated, including lack of depth of field, a fixed camera view, unrealistic joystick control, and a lack of haptic feedback. The consequences of these limitations were reflected in the overall greater task completion times, greater number of movements required, and higher rate of driving and reaching errors. Together, these differences in the virtual experience likely contributed to the overall lack of improvement in sense of presence, as indicated by the IPQ scores compared to a previous miWe study (Archambault et al. 2012). However, the higher sense of “involvement” pointed to the beneficial contribution of the added hand motion controller. Finally, participant feedback suggested that the contribution of this project was useful and appropriate. For this reason, further development and refinement of the reaching interface for the miWe and the corresponding virtual tasks would be of benefit to future VR-based PW training.

To our knowledge, our project was the first to integrate 3D motion tracking for reaching in the context of a PW simulator. Though there is already a considerable amount of research involving reaching in VR (Levin et al. 2014; Holden, 2005), our project offers a unique perspective on reaching tasks in context of activities of daily living. While most research involves reaching from a fixed and pre-determined position, our project demonstrated how participants behaved, in VR, during navigate-to-reach tasks wherein the context and requirements of the reaching task was dependent on prior planning and navigation performance. This contributes to a better understanding of how VR may be used to simulate a wider range of realistic, integrated, and in-community based tasks in other VR applications for rehabilitation. Furthermore, this project demonstrated the utility of using the Razer Hydra for such applications. For example, the CRIR’s Rehabilitation

Living Lab Project, which involves broad rehabilitation research in context of a community shopping mall, has recreated part of this mall in a virtual environment for projects related to functional tasks and measurement of cognitive and motor abilities. The findings in our project may be of benefit in future development of this project in terms of integrating a reaching interface and task design.

Finally, this thesis contributes to the broader field of virtual reality research. First, it provides an applied example of a consumer-level magnetic based motion tracking interface. Numerous low-cost motion tracking technologies have been released and have continued to develop, e.g. Kinect 2 (Microsoft, USA) and Leap Motion Controller (Leap Motion, USA). Indeed, the Razer Hydra technology is being further developed in the form of the STEM System (Sixense Entertainment, USA), a 5-sensor wireless magnetic motion tracking system. Our study may help future VR projects decide which type of low-cost tracking system is best suited to a given application. Second, our results contribute insights into presence as a complex and multi-dimensional construct. In context of the presence model described by Mantovani and Castelnuovo (2003), our implementation of the reaching task made a trade-off between interactivity/control and suspension of disbelief: we allowed for complex navigation/reaching interactions, but the equipment meant participants readily perceived their own moving hands and controllers alongside the virtual hands. Moreover, our simulator included motivational factors but also demonstrated undue difficulties for participants. Therefore, this study may help the future design of VR environments and interfaces that effectively integrates all of these factors to synergistically generate a very strong sense of presence.

Ultimately, our findings suggest a host of various future directions for our project. Of immediate technical concerns, we may further take advantage of the rapid advancement of consumer-level VR technologies. First, utilizing a low-cost head mounted display such as the Oculus, along with more streamlined motion tracking systems like the STEM System, would likely further enhance the miWe's capacity to produce a strong sense of presence. Second, the miWe software currently lacks an easy method of modifying the physical parameters and driving characteristics of the simulated PW. A list of preset parameters modeled after popular PWs or simply an interface to intuitively adjust the parameters would help address the joystick control issues. Finally,

the virtual environments of the miWe may be improved, given the input of experienced PW users. Even with future developments, the translation of users' intended movements into the virtual environment may not be perfect (users' movements in VR may not be exactly what they expect). For example, even though the elevator in our simulator was dimensionally identical to the RW prop, participants felt it was too small to manoeuvre in. For training purposes, it is more important that the perceptual experience of VR is equivalent to RW than having the programmed environment being dimensionally exact. Therefore, we may adjust the virtual environments to account for such perceptual differences, e.g. making the VR elevator bigger so that it "feels the same".

The use of the miWe simulator may also be used beyond the scope of training PW users. It may also give caregivers and friends an opportunity to explore a key aspect (driving a PW) of PW users' life world in the first-person. Such an experience, especially in the case of someone waiting for their first PW, would give insight into what to expect for all parties concerned. Furthermore, the simulator may also give designers, architects, and urban planners a chance to see the world from the PW point of view and to even test out designs from an assistive technology standpoint.

For PW users themselves, VR simulators also offer participatory and leisure opportunities. Granted, there are already many virtual worlds to explore in the form of videogames using a keyboard and mouse. However, some people may prefer to experience such environments in a way that's representative of their RW experience, i.e. using a PW. Furthermore, some PW require other adapted control interfaces, e.g. head array and sip and puff. Therefore, future development of the miWe may benefit the design of virtual worlds that expand the ways in which PW users can participate.

LIST OF REFERENCES

- Abellard, P., Randria, I., Abellard, A., Ben Khelifa, M., & Ramanantsizehena, P. (2010). Electric Wheelchair Navigation Simulators: why, when, how? In A. Di Paola & G. Cicirelli (Eds.), *Mechatronic Systems Applications*: InTech.
- Alshaer, A., Hoermann, S., & Regenbrecht, H. (2013). *Influence of peripheral and stereoscopic vision on driving performance in a power wheelchair simulator system*. Paper presented at the Virtual Rehabilitation (ICVR), 2013 International Conference on.
- Armbrüster, C., Wolter, M., Kuhlen, T., Spijkers, W., & Fimm, B. (2008). Depth perception in virtual reality: distance estimations in peri-and extrapersonal space. *CyberPsychology & Behavior*, 11(1), 9-15.
- Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., . . . Wittrock, M. C. (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, abridged edition. *White Plains, NY: Longman*.
- Archambault, P. S., Chong, J. N. F., Sorrento, G., Routhier, F., & Boissy, P. (2011, 27-29 June 2011). *Comparison of powered wheelchair driving performance in a real and in a simulated environment*. Paper presented at the Virtual Rehabilitation (ICVR), 2011 International Conference on.
- Archambault, P. S., Tremblay, S., Cachecho, S., Routhier, F., & Boissy, P. (2012). Driving performance in a power wheelchair simulator. [Evaluation Studies Research Support, Non-U.S. Gov't]. *Disabil Rehabil Assist Technol*, 7(3), 226-233. doi: 10.3109/17483107.2011.625072
- Archambault, P. S., Norouzi, N. G., Kairy, D., Solomon, J. M., & Levin, M. F. (2014). Towards Establishing Clinical Guidelines for an Arm Rehabilitation Virtual Reality System *Replace, Repair, Restore, Relieve—Bridging Clinical and Engineering Solutions in Neurorehabilitation* (pp. 263-270): Springer.
- Blach Rossen, C., Sørensen, B., Würtz Jochumsen, B., & Wind, G. (2012). Everyday life for users of electric wheelchairs-a qualitative interview study. *Disability and Rehabilitation: Assistive Technology*, 7(5), 399-407.

- Bossard, C., Kermarrec, G., Buche, C., & Tisseau, J. (2008). Transfer of learning in virtual environments: a new challenge?. *Virtual Reality*, 12(3), 151-161.
- Bottos, M., Bolcati, C., Sciuto, L., Ruggeri, C., & Feliciangeli, A. (2001). Powered wheelchairs and independence in young children with tetraplegia. *Developmental Medicine & Child Neurology*, 43(11), 769-777.
- Brandt, A., Iwarsson, S., & Stahle, A. (2004). Older people's use of powered wheelchairs for activity and participation. *Journal of Rehabilitation Medicine*, 36(2), 70-77.
- Butler, C., Okamoto, G. A., & McKay, T. M. (1983). Powered mobility for very young disabled children. *Developmental Medicine & Child Neurology*, 25(4), 472-474.
- Butler, D. P., & Willett, K. (2010). Wii-habilitation: Is there a role in trauma? *Injury*, 41(9), 883-885.
- Bystrom, K.-E., Barfield, W., & Hendrix, C. (1999). A conceptual model of the sense of presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, 8(2), 241-244.
- Chang, Y.-J., Chen, S.-F., & Huang, J.-D. (2011). A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. *Research in developmental disabilities*, 32(6), 2566-2570.
- Chase, J., & Bailey, D. M. (1990). Evaluating the potential for powered mobility. *The American journal of occupational therapy: official publication of the American Occupational Therapy Association*, 44(12), 1125-1129.
- Chen, W.-Y., Jang, Y., Wang, J.-D., Huang, W.-N., Chang, C.-C., Mao, H.-F., & Wang, Y.-H. (2011). Wheelchair-Related Accidents: Relationship With Wheelchair-Using Behavior in Active Community Wheelchair Users. *Archives of Physical Medicine and Rehabilitation*, 92(6), 892-898. doi: 10.1016/j.apmr.2011.01.008
- Clark, M. C., Czaja, S. J., & Weber, R. A. (1990). Older adults and daily living task profiles. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 32(5), 537-549.
- Corfman, T. A., Cooper, R. A., Fitzgerald, S. G., & Cooper, R. (2003). Tips and falls during electric-powered wheelchair driving: effects of seatbelt use, legrests, and driving speed. *Archives of Physical Medicine and Rehabilitation*, 84(12), 1797-1802.

- Cox, B. D. (1997). The rediscovery of the active learner in adaptive contexts: A developmental-historical analysis.. *Educational psychologist*, 32(1), 41-55.
- CRIR-livinglabvivant. (2014). A Rehabilitation Living Lab Retrieved August 11, 2014, from http://crir-livinglabvivant.com/synopsis_projects-en.html
- Dawson, D., Chan, R., & Kaiserman, E. (1994). Development of the power-mobility indoor driving assessment for residents of long-term care facilities: A preliminary report. *Canadian Journal of Occupational Therapy*, 61(5), 269-276.
- Deutsch, J. E., Borbely, M., Filler, J., Huhn, K., & Guarrera-Bowlby, P. (2008). Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. *Phys Ther*, 88(10), 1196-1207.
- Dixon, D., Johnston, M., Rowley, D., & Pollard, B. (2008). Using the ICF and psychological models of behavior to predict mobility limitations. *Rehabilitation Psychology*, 53(2), 191.
- Edwards, K., McCluskey, A. (2010). A survey of adult power wheelchair and scooter users. *Disability and Rehabilitation: Assistive Technology*, 5(6), 411-419.
- Erren-Wolters, C. V., van Dijk, H., de Kort, A. C., IJzerman, M. J., & Jannink, M. J. (2007). Virtual reality for mobility devices: training applications and clinical results: a review. *International Journal of Rehabilitation Research*, 30(2), 91-96.
- Evans, S., Frank, A. O., Neophytou, C., & De Souza, L. (2007a). Older adults' use of, and satisfaction with, electric powered indoor/outdoor wheelchairs. *Age and ageing*, 36(4), 431-435.
- Evans, S., Neophytou, C., De Souza, L., & Frank, A. O. (2007b). Young people's experiences using electric powered indoor-outdoor wheelchairs (EPIOCs): Potential for enhancing users' development? *Disability & Rehabilitation*, 29(16), 1281-1294.
- Frank, A. O., & De Souza, L. H. (2013). Recipients of Electric-Powered Indoor/Outdoor Wheelchairs Provided by a National Health Service: A Cross-Sectional Study. *Archives of Physical Medicine and Rehabilitation*, 94(12), 2403-2409.
- Giesbrecht, E. M., Ripat, J. D., Quanbury, A. O., & Cooper, J. E. (2009). Participation in community-based activities of daily living: comparison of a pushrim-activated, power-assisted wheelchair and a power wheelchair. [Comparative Study

- Randomized Controlled Trial Research Support, Non-U.S. Gov't]. *Disabil Rehabil Assist Technol*, 4(3), 198-207. doi: 10.1080/17483100802543205
- Grantcharov, T. P., Kristiansen, V., Bendix, J., Bardram, L., Rosenberg, J., & Funch-Jensen, P. (2004). Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *British Journal of Surgery*, 91(2), 146-150.
- Harrison, A., Derwent, G., Enticknap, A., Rose, F. D., & Attree, E. A. (2002). The role of virtual reality technology in the assessment and training of inexperienced powered wheelchair users. *Disability and Rehabilitation*, 24(11-12), 599-606. doi: doi:10.1080/09638280110111360
- Harrison¹, A., Derwent, G., Enticknap¹, A., Rose, F., & Attree, E. (2000). Application of virtual reality technology to the assessment and training of powered wheelchair users. *ICDVRAT 2000*.
- Hasdai A, J. A., LW P. (1998). Use of a Computer SIMulator for Training Children With Disabilities in the Operation of a Powered Wheelchair. *American Journal of Occupational Therapy*, 52(3), 215-220. doi: 10.5014/ajot.52.3.215
- Hays, R. T., Jacobs, J. W., Prince, C., & Salas, E. (1992). Flight simulator training effectiveness: A meta-analysis. *Military Psychology*, 4(2), 63-74.
- Heyde, M., Riecke, B. E., Cunningham, D. W., & Bühlhoff, H. H. (2001). No visual dominance for remembered turns—Psychophysical experiments on the integration of visual and vestibular cues in virtual reality. *Journal of Vision*, 1(3), 188-188.
- Holden, M. K. (2005). Virtual environments for motor rehabilitation: review. *CyberPsychology & Behavior*, 8(3), 187-211.
- Holliday, P., Mihailidis, A., Rolfson, R., & Fernie, G. (2005). Understanding and measuring powered wheelchair mobility and manoeuvrability. Part I. Reach in confined spaces. *Disability & Rehabilitation*, 27(16), 939-949.
- IJsselsteijn, W. (2002). Elements of a multi-level theory of presence: Phenomenology, mental processing and neural correlates. *Proceedings of PRESENCE*, 2002, 245-259.
- J, M. (1997). Household economic studies, current population reports *Americans with Disabilities* (pp. 70-73). Washington, DC, USA: US Census Bureau.
- Kaye, H. S., Kang, T., & LaPlante, M. P. (2000). Mobility Device Use in the United

- States. Disability Statistics Report 14.
- Kirby, R. L., & Ackroyd-Stolarz, S. A. (1995). Wheelchair safety-adverse reports to the United States Food and Drug Administration. *American journal of physical medicine & rehabilitation*, 74(4), 308-312.
- Kirwan, B., & Ainsworth, L. K. (1992). *A guide to task analysis: the task analysis working group*: CRC press.
- Knapp, J. M., & Loomis, J. M. (2004). Limited field of view of head-mounted displays is not the cause of distance underestimation in virtual environments. *Presence: Teleoperators and Virtual Environments*, 13(5), 572-577.
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development* (Vol. 1): Prentice-Hall Englewood Cliffs, NJ.
- Leder, R. S., Azcarate, G., Savage, R., Savage, S., Sucar, L. E., Reinkensmeyer, D., . . . Molina, A. (2008). *Nintendo Wii remote for computer simulated arm and wrist therapy in stroke survivors with upper extremity hemiparesis*. Paper presented at the Virtual Rehabilitation, 2008.
- Letts, L., Dawson, D., Bretholz, I., Kaiserman-Goldenstein, E., Gleason, J., McLellan, E., . . . Roth, C. (2007). Reliability and validity of the power-mobility community driving assessment. *Assistive Technology*, 19(3), 154-163.
- Levac, D. E., & Sveistrup, H. (2014). Motor Learning and Virtual Reality. In *Virtual Reality for Physical and Motor Rehabilitation* (pp. 25-46). Springer New York.
- Levin, M., Sveistrup, H., & Subramanian, S. K. (2010). Feedback and virtual environments for motor learning and rehabilitation. *Schedae*, 1, 19-36.
- Levin, M. F., Deutsch, J. E., Kafri, M., & Liebermann, D. G. (2014). Validity of Virtual Reality Environments for Sensorimotor Rehabilitation *Virtual Reality for Physical and Motor Rehabilitation* (pp. 95-118): Springer.
- Liebermann, D. G., Berman, S., Weiss, P. L., & Levin, M. F. (2012). Kinematics of reaching movements in a 2-D virtual environment in adults with and without stroke. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, 20(6), 778-787.
- Linden, M. A., Whyatt, C., Craig, C., & Kerr, C. (2013). Efficacy of a powered

- wheelchair simulator for school aged children: A randomized controlled trial. *Rehabilitation Psychology*, 58(4), 405.
- Löfqvist, C., Pettersson, C., Iwarsson, S., & Brandt, A. (2012). Mobility and mobility-related participation outcomes of powered wheelchair and scooter interventions after 4-months and 1-year use. *Disability and Rehabilitation: Assistive Technology*, 7(3), 211-218.
- Lott, A., Bisson, E., Lajoie, Y., McComas, J., & Sveistrup, H. (2003). The effect of two types of virtual reality on voluntary center of pressure displacement. *CyberPsychology & Behavior*, 6(5), 477-485.
- Ma, H.-I., Hwang, W.-J., Wang, C.-Y., Fang, J.-J., Leong, I.-F., & Wang, T.-Y. (2012). Trunk–arm coordination in reaching for moving targets in people with Parkinson’s disease: Comparison between virtual and physical reality. *Human movement science*, 31(5), 1340-1352.
- Magdalon, E. C., Michaelsen, S. M., Quevedo, A. A., & Levin, M. F. (2011). Comparison of grasping movements made by healthy subjects in a 3-dimensional immersive virtual versus physical environment. *Acta psychologica*, 138(1), 126-134.
- Mahajan, H. P., Dicianno, B. E., Cooper, R. A., & Ding, D. (2013). Assessment of wheelchair driving performance in a virtual reality-based simulator. *The journal of spinal cord medicine*, 36(4), 322-332.
- Mortenson, W. B., Miller, W. C., Boily, J., Steele, B., Odell, L., Crawford, E. M., & Desharnais, G. (2005). Perceptions of power mobility use and safety within residential facilities. *Canadian Journal of Occupational Therapy*, 72(3), 142-152.
- Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. *Cognitive skills and their acquisition*, 1.
- Nichols, S., Haldane, C., & Wilson, J. R. (2000). Measurement of presence and its consequences in virtual environments. *International Journal of Human-Computer Studies*, 52(3), 471-491.
- Nitz, J., Kuys, S., Isles, R., & Fu, S. (2010). Is the Wii Fit™ a new-generation tool for improving balance, health and well-being? A pilot study. *Climacteric*, 13(5), 487-491.

- Pastor, I., Hayes, H. A., & Bamberg, S. J. (2012). *A feasibility study of an upper limb rehabilitation system using kinect and computer games*. Paper presented at the Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE.
- Powers, M. B., & Emmelkamp, P. M. (2008). Virtual reality exposure therapy for anxiety disorders: A meta-analysis. *Journal of Anxiety Disorders*, 22(3), 561-569.
- Reid, D. T. (2002). Benefits of a virtual play rehabilitation environment for children with cerebral palsy on perceptions of self-efficacy: a pilot study. *Developmental Neurorehabilitation*, 5(3), 141-148.
- Saposnik, G., Teasell, R., Mamdani, M., Hall, J., McIlroy, W., Cheung, D., . . . Bayley, M. (2010). Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation a pilot randomized clinical trial and proof of principle. *Stroke*, 41(7), 1477-1484.
- Schmidt, J., Berg, D. R., Ploeg, H.-L., & Ploeg, L. (2009). Precision, repeatability and accuracy of Optotrak® optical motion tracking systems. *International Journal of Experimental and Computational Biomechanics*, 1(1), 114-127.
- Schmidt, R. A., & Lee, T. (1988). *Motor Control and Learning*, 5E: Human kinetics.
- Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence*, 10(3), 266-281.
- Seegert, A. (2009). Doing there vs. being there: performing presence in interactive fiction. *Journal of Gaming & Virtual Worlds*, 1(1), 23-37.
- Sonar, A. V., Burdick, K. D., Begin, R. R., Resch, E. M., Thompson, E. M., Thacher, E., . . . Carroll, J. J. (2005, 29 July-1 Aug. 2005). *Development of a virtual reality-based power wheel chair simulator*. Paper presented at the Mechatronics and Automation, 2005 IEEE International Conference.
- Sonenblum, S. E., Sprigle, S., Harris, F. H., & Maurer, C. L. (2008). Characterization of power wheelchair use in the home and community. *Archives of Physical Medicine and Rehabilitation*, 89(3), 486-491.
- Spaeth, D. M., Mahajan, H., Karmarkar, A., Collins, D., Cooper, R. A., & Boninger, M. L. (2008). Development of a wheelchair virtual driving environment: trials with subjects with traumatic brain injury. *Archives of Physical Medicine and*

- Rehabilitation*, 89(5), 996-1003.
- Subramanian, S., Knaut, L. A., Beaudoin, C., McFadyen, B. J., Feldman, A. G., & Levin, M. F. (2007). Virtual reality environments for post-stroke arm rehabilitation. *J Neuroeng Rehabil*, 4, 20. doi: 10.1186/1743-0003-4-20
- Subramanian, S. K., & Levin, M. F. (2011). Viewing medium affects arm motor performance in 3D virtual environments. *J Neuroeng Rehabil*, 8, 36.
- Subramanian, S. K., Lourenco, C. B., Sveistrup, H., & Levin, M. F. (2011, 27-29 June 2011). *Arm motor rehabilitation in chronic stroke: Effects of two training environments*. Paper presented at the Virtual Rehabilitation (ICVR), 2011 International Conference on.
- Teixeira, L., Vilar, E., Duarte, E., Rebelo, F., & da Silva, F. M. (2012). Comparing two types of navigational interfaces for Virtual Reality. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 41, 2195-2200.
- Tichon, J. G. (2007). Using presence to improve a virtual training environment. *CyberPsychology & Behavior*, 10(6), 781-788.
- Todorov, E., Shadmehr, R., & Bizzi, E. (1997). Augmented feedback presented in a virtual environment accelerates learning of a difficult motor task. *Journal of motor behavior*, 29(2), 147-158.
- Torkia, C., Reid, D., Korner-Bitensky, N., Kairy, D., Rushton, P. W., Demers, L., & Archambault, P. S. (2014). Power wheelchair driving challenges in the community: a users' perspective. *Disabil Rehabil Assist Technol*. doi: 10.3109/17483107.2014.898159
- Townsend, K., & Watson, A. (2013). Competent use of a motorised mobility scooter – assessment, training and ongoing monitoring: A vital role for occupational therapy practice. *Australian Occupational Therapy Journal*, 60(6), 454-457. doi: 10.1111/1440-1630.12095
- University, D. (2012). Wheelchair Skills Program Retrieved August 11, 2014, from <http://www.wheelchairskillsprogram.ca/eng/index.php>
- Vestling, M., Ramel, E., & Iwarsson, S. (2013). Thoughts and experiences from returning to work after stroke. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 45(2), 201-211.

- Viau, A., Feldman, A. G., McFadyen, B. J., & Levin, M. F. (2004). Reaching in reality and virtual reality: a comparison of movement kinematics in healthy subjects and in adults with hemiparesis. *J Neuroeng Rehabil*, 1(1), 11. doi: 10.1186/1743-0003-1-11
- Walker, K. A., Morgan, K. A., Morris, C. L., DeGroot, K. K., Hollingsworth, H. H., & Gray, D. B. (2010). Development of a Community Mobility Skills Course for People Who Use Mobility Devices. *American Journal of Occupational Therapy*, 64(4).
- Wallet, G., Sauzéon, H., Rodrigues, J., Larrue, F., & N’Kaoua, B. (2010). Virtual/real transfer of spatial learning: Impact of activity according to the retention delay. *Stud Health Technol Inform*, 154, 145-149.
- Wang, C.-Y., Hwang, W.-J., Fang, J.-J., Sheu, C.-F., Leong, I.-F., & Ma, H.-I. (2011). Comparison of virtual reality versus physical reality on movement characteristics of persons with Parkinson's disease: effects of moving targets. *Archives of Physical Medicine and Rehabilitation*, 92(8), 1238-1245.
- Ward, A. L., Sanjak, M., Duffy, K., Bravver, E., Williams, N., Nichols, M., & Brooks, B. R. (2010). Power wheelchair prescription, utilization, satisfaction, and cost for patients with amyotrophic lateral sclerosis: preliminary data for evidence-based guidelines. *Archives of Physical Medicine and Rehabilitation*, 91(2), 268-272.
- Webber, S. C., Porter, M. M., & Menec, V. H. (2010). Mobility in older adults: a comprehensive framework. *The Gerontologist*, gnq013.
- Windolf, M., Götzén, N., & Morlock, M. (2008). Systematic accuracy and precision analysis of video motion capturing systems—exemplified on the Vicon-460 system. *Journal of biomechanics*, 41(12), 2776-2780.
- Zhou, H., & Hu, H. (2008). Human motion tracking for rehabilitation—A survey. *Biomedical Signal Processing and Control*, 3(1), 1-18. doi: 10.1016/j.bspc.2007.09.001

APPENDIX 1: CONSENT FORMS



INFORMED CONSENT TO PARTICIPATE IN A STUDY ENTITLED:

The miWe powered wheelchair simulator with a reaching component.

Researchers

Gordon Tao, BSc

Master's Student

School of Physical & Occupational Therapy

McGill University

Philippe Archambault, PhD, erg.

Assistant Professor,

School of Physical & Occupational Therapy

McGill University

Funding Organization: Natural Sciences and Engineering Research Council (NSERC)

We are asking you to participate in a research project which involves trials in a powered wheelchair driving simulator. Before you accept, please take the necessary time to read and understand the information contained below.

This consent form explains the objectives of the study, the procedures as well as the advantages and possible risks and discomforts you may experience. The names of people you may want to contact are also indicated. You may come across words that are difficult to understand. We welcome you to ask questions to the researcher and the research staff involved in the study so that they may explain any word or concept that you find unclear.

Objective of the research study

The study is based on a powered wheelchair simulator used for training navigation skills. The study is designed to determine how individuals are able to drive in a powered wheelchair in combination with reaching for objects. The simulator works on a regular personal computer and can be eventually used at home for the evaluation and training of powered wheelchair driving skills. This study aims to validate a method of incorporating reaching tasks using a 3D hand motion controller. These tasks will be performed while the participant is seated in his/her wheelchair.



The simulator's hand motion controller and its control base.



Example of the simulator being used by one of our researchers.

Nature of your participation

You will be asked to participate in one research session lasting a total of 3 hours. You will be required to perform a series of driving/reaching tasks in the simulator while seated in your own powered wheelchair: driving up to a table and reaching for a bottle, operating an elevator, and opening and driving through a doorway. For the simulator, the motion controller will be comfortably strapped to your forearm. The controller is approximately the same size as a remote control.

You will then be asked to complete the same tasks in your own powered wheelchair, in a room setup for this purpose. In order to record hand movements in the room, you will be recorded on video. To aid in tracking your hand, a coloured sticker may be placed on your hand. Please note that for the driving tasks with your wheelchair, your joystick will be replaced by one of the same model, but modified in order to record the data needed for the study. This joystick will be connected to a computer, which will be placed in a backpack that will be attached to your wheelchair. After you have completed all the trials, your joystick will be reinstalled. To complete the study, you will have to answer some questionnaires about the simulator.

Sites of experimental session:

Jewish Rehabilitation Hospital; 3205 Place Alton Goldbloom, Laval, Qc, Canada, H7V 1R2.

Phone: (450) 688-9550.

Lucie-Bruneau Rehabilitation Center: 2275, avenue Laurier Est Montréal (Québec) H2H 2N8.

Phone. : (514) 527-4527

Constance Lethbridge Rehabilitation Center: 7005, boul. de Maisonneuve Ouest Montréal (Québec) H4B 1T3. Phone: (514) 487-1770

Your Safety

Certain individuals may be ill at ease when using a virtual reality environment, and experience symptoms such as headaches or nausea. Such symptoms, while unpleasant, have no long term consequences. If such symptoms were to occur, we will pause the experiment or stop it if required.

Changing the joystick on your wheelchair will not affect the programming or the performance of your wheelchair. The researcher who will change your joystick is experienced with the procedure. The questionnaires do not present any risk. However, if you do not want to answer some of the questions, for any reason, simply mention this to the person who will be conducting the interview.

While performing driving tasks that will allow us to assess the driving of your wheelchair and your skills, we will try to avoid significant impacts or collisions. For your safety, you may fasten the seatbelt on your chair.

Attachment of the motion controller to your arm may cause some irritation. If this happens, lotion will be provided to help relieve the irritation.

Your Participation

There are no direct advantages for my participation in this study. You will, however, contribute to scientific knowledge, in particular with respect to physical rehabilitation.

Compensatory Indemnity

You will receive a compensatory indemnity of 40\$ for your participation in this study.

Confidentiality of information

Video cameras will be connected only during the study and you will only be recorded while performing tasks. Information from the research study will be held in the strictest confidence and will not be used except for research purposes. Your file and any data will be coded in a way that will ensure anonymity. Any published results will be presented with complete anonymity, e.g. face blurring for videos. Any personal data (e.g., address, telephone number) will be kept in a separate file folder, accessible only to the researcher responsible for the project. However, for control purposes, your research record could be accessed by a person authorized by the Research Ethics Board (REB) of the CRIR facilities or by the Ethics Unit of the Department of Health and Social Services of Quebec, adhering to a policy of strict confidentiality.

This information will be retained for five years after the end of the project in a locked filing cabinet in the laboratory of the researcher and both the written and video data will be destroyed at the end of this period.

Issues concerning this study

You may ask any questions regarding this study and they will be answered. These questions may be addressed to Gordon Tao (gordon.tao@mail.mcgill.ca) at (438) 402-1176; or to Philippe Archambault (philippe.archambault@mcgill.ca), the project supervisor who can be reached at either of those two numbers: 450 688-9550 x4832 (lab) or 514 398-7323 (office).

Responsibility clause

In accepting to participate in this study, you will not relinquish any of your rights and you will not relieve the researchers nor their sponsors or the institutions involved from any of their legal or professional obligations.

Resource person

If you have any questions concerning your rights or your participation in this research project, you can contact Me Anik Nolet, Coordinator of Research Ethics for the CRIR Establishments at 514-527-4527 # 2643 or by email at the following address:

anolet.crir@ssss.gouv.qc.ca.

Voluntary participation and withdrawal from the study

Your participation in the above described study is free and voluntary. You may withdraw from the study at any time without prejudice. Refusal to participate in the study will not result in any penalty or loss of benefits.

Consent

The project, the nature and the degree of my participation and the possible inconveniences and risks of the project as listed in this consent form have been explained to me. I have had the opportunity to ask all my questions concerning the different aspects of the study and have received responses to my satisfaction.

I, the undersigned, voluntarily accept to participate in this study. I can withdraw from the study at any time without any prejudice. I understand that if I withdrawal, any collected data will beretained unless I indicate otherwise. I certify that I have had adequate time to make my decision.

A signed copy of this consent form will be given to me.

Name of participant

Signature

Signed in (city) , on (date)

Responsibility of the study investigators

I, the undersigned, _____, certify that

- (a) I have explained to the participant the terms of the present consent form,
- (b) I have responded to all the questions posed to me
- (c) I have clearly indicated that the participant is free to leave the study described above at any time, and
- (d) that I will give the participant a signed and dated copy of this form

Signature

Date

Gordon Tao
Université McGill
Contact : (438) 402-1176
gordon.tao@mail.mcgill.ca



FORMULAIRE DE CONSENTEMENT POUR LA PARTICIPATION À L'ÉTUDE INTITULÉE :

Le simulateur de fauteuil motorisé 'miWe' avec un mouvement d'atteinte.

Chercheur :

Gordon Tao, BSc.

L'étudiant-chercheur (MSc)

École de physiothérapie et d'Ergothérapie

Université McGill

Philippe Archambault, PhD, erg.

Professeur adjoint,

École de physiothérapie et d'Ergothérapie

Université McGill

Source de fonds : **Conseil de Recherche en Sciences Naturelles et en Génie (CRSNG)**

Nous vous demandons de participer à un projet de recherche qui implique l'essai d'un simulateur de conduite en fauteuil roulant motorisé. Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements qui suivent.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin. Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui ne serait pas clair.

Objectifs de la recherche

Cette étude est basée sur un simulateur de conduite en fauteuil motorisé, utilisé pour l'entraînement des habiletés de conduite. L'étude a pour but de déterminer comment les personnes conduisent dans un simulateur, en combinaison avec des mouvements



d'atteinte vers des objets. Le simulateur fonctionne sur un ordinateur personnel et pourrait être éventuellement utilisé à la maison. L'objectif de l'étude est de valider une méthode permettant d'incorporer des tâches d'atteinte, en utilisant un contrôleur de mouvement 3D.

Nature de la participation

On vous demande de participer à une seule session qui durera au maximum 3 heures. Vous aurez à effectuer dans le simulateur une série de tâches de conduite incorporant des mouvements d'atteinte du bras: déplacement vers une table pour prendre une bouteille; utiliser un ascenseur; ouvrir une porte et traverser l'ouverture. Pour ces tâches, un contrôleur 3D sera fixé à votre avant-bras à l'aide de courroies élastiques. Le contrôleur a à peu près la taille d'une télécommande.

Vous aurez ensuite à effectuer les mêmes tâches dans un circuit prévu à cette fin et en utilisant votre fauteuil roulant motorisé. Afin de pouvoir enregistrer les mouvements de votre main dans cette salle, vous serez filmé par caméra vidéo. Pour nous aider à bien suivre les mouvements de votre main, un morceau de ruban adhésif coloré sera fixé au dos de votre main. Prenez note que pour la conduite avec votre fauteuil, votre manette (joystick) sera changée pour une manette équivalente mais qui nous permet de recueillir l'information dont nous avons besoin. Cette manette sera reliée à un ordinateur, placé dans un sac à dos que l'on installera au dossier de votre fauteuil. Après ces essais de conduite, votre manette sera réinstallée. Finalement, vous aurez à répondre à des questionnaires sur vos habitudes en fauteuil roulant motorisé.

Sites pour la session expérimentale

Hôpital juif de réadaptation; 3205 Place Alton Goldbloom, Laval, Qc, Canada, H7V 1R2.
Tél : (450) 688-9550.

Centre de réadaptation Lucie-Bruneau: 2275, avenue Laurier Est Montréal (Québec) H2H 2N8.

Tél. : (514) 527-4527

Centre de réadaptation Constance Lethbridge : 7005, boul. de Maisonneuve Ouest
Montréal (Québec) H4B 1T3. Tél : (514) 487-1770

Risques et inconvénients découlant de la participation

Certaines personnes peuvent ressentir un malaise lorsqu'elles interagissent avec un environnement de réalité virtuelle, comme des maux de tête ou une sensation de nausée. Ces malaises, bien que déplaisants, n'entraînent pas de conséquences à long terme. Si de tels symptômes devaient survenir, nous prendrons une pause ou pourrions mettre un terme à l'expérience.

Le changement de manette sur votre fauteuil ne modifie en rien la programmation ou les performances de votre fauteuil.

Les questionnaires ne comportent aucun risque pour vous. Si vous souhaitez ne pas répondre à certaines questions, pour quelque raison que se soit, vous n'aurez qu'à le mentionner à la personne qui vous interviewera.

Lors de la réalisation de tâches de conduite qui nous permettra d'évaluer la conduite de votre fauteuil roulant et vos habiletés, nous tenterons d'éviter tout choc ou collision important. Pour votre sécurité, vous pourrez utiliser la ceinture de sécurité de votre fauteuil.

Avantages pouvant découler de votre participation

Vous ne retirerez personnellement pas d'avantage à participer à cette étude. Toutefois, vous aurez contribué à l'avancement de la science, particulièrement au niveau de la réadaptation.

Indemnité compensatoire

Une compensation financière de 40\$ vous sera remise pour votre participation à cette étude.

Confidentialité de l'information

Les caméras vidéo n'enregistreront que votre participation pendant les tâches expérimentales; sinon, elles seront débranchées. L'information recueillie dans le cadre de l'expérience sera strictement confidentielle et ne sera utilisée qu'aux fins de la communication scientifique, professionnelle et d'enseignement. Il est entendu que toutes les données seront codées de façon à assurer votre anonymat. Il est aussi entendu que tous les résultats publiés seront présentés de façon à assurer l'anonymat; en particulier, votre visage sera caché lors de présentation d'enregistrements vidéo. Tout renseignement personnel (ex. : adresse, numéro de téléphone) sera gardé dans un dossier séparé, accessible seulement par le chercheur responsable du projet. Cependant, à des fins de contrôle du projet de recherche, votre dossier de recherche pourrait être consulté par un personne mandatée par le CÉR des établissements du CRIR ou par l'Unité d'éthique du ministère de la Santé et des Services sociaux du Québec, qui adhèrent à une politique de stricte confidentialité. Cette information sera conservée cinq ans suivant la fin du projet dans un classeur verrouillé au laboratoire du chercheur, puis les données écrites et vidéo seront détruites à la fin de cette période.

Questions concernant l'étude

Si vous avez des questions sur ce projet de recherche ou sur les implications de votre participation, veuillez communiquer avec Gordon Tao (gordon.tao@mail.mcgill.ca) au (438) 402-1176; ou avec Philippe Archambault (philippe.archambault@mcgill.ca), superviseur pour ce projet, à un des numéros suivants : 450 688-9550 x4832 (laboratoire) ou le 514 398-7323 (bureau).

Clause de responsabilité

En acceptant de participer à cette étude, vous ne renoncez à aucun droit ni ne libérez les chercheurs, leurs commanditaires ou les institutions impliquées de leurs obligations légales et professionnelles.

Personne-ressource

Pour toute question concernant vos droits ou votre participation à ce projet de recherche, vous pouvez contacter Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au 514-527-4527, post 2643 ou par courriel à l'adresse suivante : anolet.crir@ssss.gouv.qc.ca.

Participation volontaire et retrait de l'étude

Votre participation à l'étude décrite ci-dessus est tout à fait libre et volontaire. Il est également entendu que vous pourrez, à tout moment, mettre un terme à votre présentation sans que cela n'entraîne aucune conséquence.

Consentement

Ce projet, la nature et le degré de ma participation et les possibles inconvénients et risques de ce projet tels que décrits dans ce formulaire de consentement m'ont été expliqués. J'ai eu l'opportunité de poser toutes mes questions concernant les différents aspects de cette étude et ai reçu des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer de cette étude en tout temps, sans préjudice. Je certifie que j'ai eu le temps nécessaire pour prendre ma décision.

Une copie signée de ce formulaire de consentement me sera remise.

Nom du participant

Signature

Fait à , le

Responsabilité du chercheur

JE, SOUSSIGNE(E), _____, CERTIFIE QUE :

(A) J'AI EXPLIQUE AU PARTICIPANT LES TERMES DE CE PRESENT FORMULAIRE DE CONSENTEMENT;

(B) J'AI REPONDU A TOUTES LES QUESTIONS QUI M'ONT ETE POSEES ;

(C) J'AI CLAIREMENT INDIQUE AU PARTICIPANT QU'IL PEUT SE RETIRER DE L'ETUDE EN TOUT TEMPS; ET

(D) QUE JE LUI DONNERAI UNE COPIE SIGNEE ET DATEE DE CE FORMULAIRE.

Signature du chercheur

Date

Gordon Tao
Université McGill
Contact : (438) 402-1176
gordon.tao@mail.mcgill.ca

APPENDIX 2: IPQ

IGROUP PRESENCE QUESTIONNAIRE

Date: _____ Sex: _____ Participant Code: _____

Now you'll see some statements about the experience you just had. Please indicate whether or not each statement applies to your experience. If a question is not relevant to the virtual environment you used, just skip it. You can use the whole range of answers. There are no right or wrong answers, only your opinion counts.

You will notice that some questions are very similar to each other. This is necessary *for statistical reasons*. And please remember: Answer all these questions only referring to this *one* experience.

In the computer generated world I had a sense of “being there”

not at all -3 -2 -1 0 +1 +2 +3 very much

Somehow I felt that the virtual world surrounded me.

fully disagree -3 -2 -1 0 +1 +2 +3 fully agree

I felt like I was just perceiving pictures.

fully disagree -3 -2 -1 0 +1 +2 +3 fully agree

I did not feel present in the virtual space.

did not feel -3 -2 -1 0 +1 +2 +3 felt present

I had a sense of acting in the virtual space, rather than operating something from outside

fully disagree -3 -2 -1 0 +1 +2 +3 fully agree

I felt present in the virtual space

fully disagree -3 -2 -1 0 +1 +2 +3 fully agree

How aware were you of the real world surroundings while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

extremely aware -3 -2 -1 0 +1 +2 not aware at all
+3
moderately aware

I was not aware of my real environment.

fully disagree -3 -2 -1 0 +1 +2 +3 fully agree

I still paid attention to the real environment.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree
----------------	----	----	----	---	----	----	----	-------------

I was completely captivated by the virtual world.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree
----------------	----	----	----	---	----	----	----	-------------

How real did the virtual world seem to you?

completely real	-3	-2	-1	0	+1	+2	+3	not real at all
-----------------	----	----	----	---	----	----	----	-----------------

How much did your experience in the virtual environment seem consistent with your real world experience?

not consistent	-3	-2	-1	0	+1	+2	+3	very consistent
				moderately consistent				

How real did the virtual world seem to you?

about as real as an imagined world	-3	-2	-1	0	+1	+2	+3	indistinguishable from the real world
---------------------------------------	----	----	----	---	----	----	----	---

The virtual world seemed more realistic than the real world.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree
----------------	----	----	----	---	----	----	----	-------------

QUESTIONNAIRE (IPQ)

Date : _____ Sexe : _____ Code de participant : _____

Voici plusieurs propositions qui peuvent s'appliquer à l'expérience que vous venez d'avoir. Indiquez, s'il vous plaît, si chacune de ces propositions s'applique ou non à votre expérience. Si une question ne s'applique pas à l'environnement virtuel dont vous venez juste d'utiliser, simplement passez à la prochaine question. Vous pouvez utiliser n'importe quelle graduation. Il n'y a pas de bonnes ou de mauvaises réponses, seule votre opinion est importante.

Vous remarquerez que certaines questions se ressemblent. Ceci est nécessaire pour des raisons statistiques. Rappelez-vous que vous devez répondre à ces questions en vous référant seulement à l'expérience que vous venez juste d'avoir.

A quel point étiez-vous conscient du monde réel environnant alors que vous étiez en train de naviguer dans le monde virtuel ? (par exemple : sons, température de la pièce, présence d'autres gens, etc.) ?

Extrêmement conscient Pas conscient du tout

-3 -2 -1 0 +1 +2 +3

Modérément
conscient

Comment le monde virtuel vous a-t-il semblé?

Complètement réel Pas du tout réel

-3 -2 -1 0 +1 +2 +3

J'ai eu la sensation d'agir dans l'espace virtuel plutôt que d'agir sur un quelconque mécanisme à l'extérieur de celui-ci.

Pas du tout d'accord Complètement d'accord

-3 -2 -1 0 +1 +2 +3

A quel point votre expérience dans l'environnement virtuel vous a-t-elle semblée cohérente avec votre expérience dans le monde réel ?

Pas cohérente

Très cohérente

-3 -2 -1 0 +1 +2 +3

Modérément
cohérente

A quel point le monde virtuel vous a-t-il semblé réel ?

A peu près aussi réel qu'un monde
imaginé

Indisc du monde réel

-3 -2 -1 0 +1 +2 +3

Je ne me suis pas senti(e) présent(e) dans l'espace virtuel.

Pas senti présent

Senti présent

-3 -2 -1 0 +1 +2 +3

Je n'étais pas conscient(e) de mon environnement réel.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

Dans le monde généré par l'ordinateur, j'ai eu le sentiment "d'y être".

Pas du tout

Beaucoup

-3 -2 -1 0 +1 +2 +3

D'une certaine façon, j'ai eu l'impression que le monde virtuel m'entourait.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

Je me suis senti(e) présent(e) dans l'espace virtuel.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

Je faisais toujours attention à l'environnement réel.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

Le monde virtuel semblait plus réaliste que le monde réel.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

J'avais l'impression que j'étais juste en train de percevoir des images.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

J'étais complètement captivé(e) par le monde virtuel.

Pas du tout d'accord

Tout à fait d'accord

-3 -2 -1 0 +1 +2 +3

APPENDIX 3: OPEN QUESTIONNAIRE

Open Questionnaire for Virtual Reality Simulator (miWe with Hydra)

Participant Code: _____

Questions for Door Task

1. Functionality

- Does the task seem useful for learning to use a powered wheelchair?

0- Not at all 1- Not very useful 2- Neutral 3- Somewhat useful 4-
Very useful

- Does this task seem realistic?

0- Not at all 1- Not very realistic 2- Neutral 3- Somewhat realistic 4-
Very realistic

2. In your opinion, what skills are being trained by doing this task?

3. Is the difficulty level appropriate?

0- Not at all 1- Not really appropriate 2- Neutral 3- Somewhat 4-
Very appropriate

4. Is the task motivating?

0- Not at all 1- Not really 2- Neutral 3- Somewhat motivating 4-
Very motivating

5. Do you think this task should be modified? If so, how?

6. Other comments

Questions for Desk/Drawer Task

7. Functionality

- Does the task seem useful for learning to use a powered wheelchair?

0- Not at all 1- Not very useful 2- Neutral 3- Somewhat useful 4-
Very useful

- Does this task seem realistic?

0- Not at all 1- Not very realistic 2- Neutral 3- Somewhat realistic 4-
Very realistic

8. In your opinion, what skills are being trained by doing this task?

9. Is the difficulty level appropriate?

0- Not at all 1- Not really appropriate 2- Neutral 3- Somewhat 4-
Very appropriate

10. Is the task motivating?

0- Not at all 1- Not really 2- Neutral 3- Somewhat motivating 4-
Very motivating

11. Do you think this task should be modified? If so, how?

12. Other comments

Questions for Elevator Task

13. Functionality

- Does the task seem useful for learning to use a powered wheelchair?

0- Not at all 1- Not very useful 2- Neutral 3- Somewhat useful 4- Very useful

- Does this task seem realistic?

0- Not at all 1- Not very realistic 2- Neutral 3- Somewhat realistic 4- Very realistic

14. In your opinion, what skills are being trained by doing this task?

15. Is the difficulty level appropriate?

0- Not at all 1- Not really appropriate 2- Neutral 3- Somewhat 4- Very appropriate

16. Is the task motivating?

0- Not at all 1- Not really 2- Neutral 3- Somewhat motivating 4- Very motivating

17. Do you think this task should be modified? If so, how?

18. Other comments

General questions

1. What do you think of the quality of the graphics of the game?

0- Very bad 1- Somewhat bad 2- Neutral 3- Somewhat good 4-
Very good

2. Does using the hand-motion controllers enhance the realism of the game?

0- Not at all 1- Not really 2- Neutral 3- Somewhat 4-
Very much

**3. How did you feel using the hand motion controllers. What did you like,
what didn't you like?**

4. Are there specific reach-related tasks that should be added to the game?

Questions ouvertes pour simulateur (miWe avec Hydra)

Code de participant: _____

Questions pour la tâche : ouvrir la porte

19. Utilité

- Cette tâche semble-t-elle utile pour l'apprentissage de l'utilisation d'un fauteuil motorisé?

0- Pas du tout 1- Un peu 2- Moyennement 3- Plutôt utile 4- Très utile

- Cette tâche semble-t-elle réaliste?

0- Pas du tout 1- Un peu 2- Moyennement 3- Plutôt réaliste 4- Très réaliste

20. Selon vous, quelles aptitudes de conduit sont entraînées en faisant cette tâche?

21. Est-ce que le niveau de difficulté semble approprié?

0- Pas du tout 1- Un peu 2- Moyennement 3- Plutôt approprié 4- Très approprié

22. Est-ce que la tâche vous semble motivante?

0- Pas du tout 1- Un peu 2- Moyennement 3- Plutôt motivante 4- Très motivante

23. Pensez-vous que cette tâche devrait être modifiée? Si oui, comment?

24. Autres commentaires

Questions pour la tâche: bureau/tirroir

1. Utilité

- Cette tâche semble-t-elle utile pour l'apprentissage de l'utilisation d'un fauteuil motorisé?

0- Pas du tout utile 1- Un peu 2- Moyennement 3- Plutôt utile 4- Très utile

- Cette tâche semble-t-elle réaliste?

0- Pas du tout réaliste 1- Un peu 2- Moyennement 3- Plutôt réaliste 4- Très réaliste

2. Selon vous, quelles aptitudes de conduit sont entraînées en faisant cette tâche?

3. Est-ce que le niveau de difficulté semble approprié?

0- Pas du tout approprié 1- Un peu 2- Moyennement 3- Plutôt approprié 4- Très approprié

4. Est-ce que la tâche vous semble motivante?

0- Pas du tout motivante 1- Un peu 2- Moyennement 3- Plutôt motivante 4- Très motivante

5. Pensez-vous que cette tâche devrait être modifiée? Si oui, comment?

6. Autres commentaires

Questions pour la tâche: l'ascenseur

1. Utilité

- Cette tâche semble-t-elle utile pour l'apprentissage de l'utilisation d'un fauteuil motorisé?

0- Pas du tout utile 1- Un peu 2- Moyennement 3- Plutôt utile 4- Très utile

- Cette tâche semble-t-elle réaliste?

0- Pas du tout réaliste 1- Un peu 2- Moyennement 3- Plutôt réaliste 4- Très réaliste

2. Selon vous, quelles aptitudes de conduit sont entraînées en faisant cette tâche?

3. Est-ce que le niveau de difficulté semble approprié?

0- Pas du tout approprié 1- Un peu 2- Moyennement 3- Plutôt approprié 4- Très approprié

4. Est-ce que la tâche vous semble motivante?

0- Pas du tout motivante 1- Un peu 2- Moyennement 3- Plutôt motivante 4- Très motivante

5. Pensez-vous que cette tâche devrait être modifiée? Si oui, comment?

6. Autres commentaires

Questions générales

5. Comment jugez-vous la qualité générale des graphiques?

0- Très mauvaise 1- Plutôt mauvaise 2- Moyenne 3- Plutôt bonne
4- Très bonne

6. Est-ce que l'utilisation des contrôleurs 3D (pour les mains) ajoute au réalisme du jeu?

0- Pas du tout 1- Plutôt non 2- Moyennement 3- Plutôt oui 4-
Beaucoup

**7. Comment vous sentiez-vous en utilisant les contrôleurs 3D (pour les mains)?
Qu'aviez-vous aimé ou que n'aviez-vous pas aimé?**

8. Y'a-t-il des tâches spécifiquement reliées aux mouvements d'atteinte qui devraient être ajoutées?
