

UNIVERSITY  
*of*  
OTAGO



*Te Whare Wānanga o Otāgo*  
NEW ZEALAND

Virtual Reality Interface Factors in a Power Wheelchair  
Simulator

Abdulaziz Alshaer

A thesis submitted for the degree of  
Doctor of Philosophy  
at the University of Otago, Dunedin,  
New Zealand  
November 2017

# ABSTRACT

Power wheelchairs (PWCs) can improve users' quality of life by enabling them to participate in the activities of daily living, decreasing their dependence on human assistance. PWC users are faced with restricted environments, with limited space to manoeuvre, and are therefore vulnerable to collisions and injuries. To use a PWC effectively and safely, individuals must undertake training and assessment of their competency. There is significant potential for the use of virtual reality in the training and assessment of PWC users.

To date, there is no standard tool available for PWC assessment and training. Rather, clinics use their own observation measurer and assessment is often largely based on guesswork. Several simulators have been developed to help the training of PWC users, yet the study of virtual assessment is an under-researched area. In fact, most simulators offer only very limited functionality and rely solely on client-centric information. For the development of a useful simulator, it is important to identify and evaluate interface factors affecting perception, behaviour, experience, and driving performance from both the user's and clinician's perspectives.

In this thesis, issues with current PWC simulators were identified and investigated, with the intention of providing a suitable research platform for the advancement of bringing PWC simulator into clinical use. The aspects investigated include the interaction device, perception and behaviour, and virtual assessment. Three systems were developed to test each of these areas by incorporating theories and techniques from computer science and human-computer interaction.

The first experiment answered the question, "which input devices are necessary and appropriate, and which virtual input device

representations can and should be implemented for PWC simulation?” A proprietary PWC joystick was compared to a standard gaming joystick, and driving performance and experience were measured. Four experimental conditions (comprising two virtual input modalities and their two real-world counterparts) were studied. The findings suggest that performance is enhanced when the PWC joystick is represented and that the gaming joystick is adequate for PWC simulation.

The second study investigated the question, “how do immersion factors influence behaviour, perception and sense of presence when navigating a PWC simulator?” The evaluated immersion factors include display type (head mounted display vs. monitor), field of view (changeable vs. static), and avatar presence (present vs. absent). User perception (explicit judgement of doorframe passability) and embedded behaviour (implicit measure of gap passability) were measured, based on the user’s decisions during the experiment. The results show that all three factors affect the user’s sense of presence. The display type affected both perceptual and behavioural measures, whereas field of view only affected behavioural measures.

The final experiment explored the question, “how accurately can clinicians assess driving tasks in the virtual environment compared to the real world?” This study evaluated the effect of three observational techniques (viewpoints) on clinician assessment of PWC driving tasks. In addition, perceived ease of use, confidence level, and sense of presence were also examined. Observational techniques include walk, orbit, and standard viewpoints. The findings of this study suggest that clinicians could make accurate judgments and experience a high confidence level when they were able to walk or orbit the viewpoint. The results from all experiments provide general design guidelines for future virtual reality applications, in particular, PWC simulator design.

## ACKNOWLEDGMENTS

In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis.

I am infinitely thankful to my supervisors Prof. Holger Regenbrecht and Prof. David O'Hare for their patience, understanding, constant support, and guidance throughout the course of my PhD.

Especial thanks go to my mother for her love, support, and patiently waiting all those years for me to finish. Thanks to my brothers and sister who were always standing by my side and giving me all the support I needed. Special thanks go to Mohammad Alghamdi, my soulmate, who is taking the same journey. I thank all my friends in New Zealand, especially the Diwanih Group.

I would like to thank the Saudi Ministry of Education and the University of Umm-Alqura for giving me the opportunity to continue my studies abroad in one of the best universities in the world. Thanks for their support and financial cover for my entire course. Thanks also go to the University of Otago Information Science department for their help and support.

Thank you to all members of the HCI group for their constructive criticism and feedback. I would like to thank Jonny and Chris for their input and knowledge on programming and generally positive attitude. I would like to specifically acknowledge Chris Edwards for his help with the construction of the joystick hardware.

Last but not least, I thank my wife Zainab Alghamdi for her love, understanding, and support, which helped me to overcome setbacks quickly. Thanks to my son Mazen for his patience and understanding. His smiles have always brought happiness to my life. I would like to welcome our newborn baby boy, Omar.

# TABLE OF CONTENTS

|   |            |
|---|------------|
| <b>Abstract</b> .....                                   | <b>i</b>   |
| <b>Acknowledgments</b> .....                            | <b>iii</b> |
| <b>Table of Contents</b> .....                          | <b>iv</b>  |
| <b>List of Figures</b> .....                            | <b>vii</b> |
| <b>List of Tables</b> .....                             | <b>x</b>   |
| <b>Chapter 1: Introduction</b> .....                    | <b>11</b>  |
| <b>1.1 Importance of this Thesis</b> .....              | <b>15</b>  |
| <b>1.2 Main Contributions</b> .....                     | <b>16</b>  |
| <b>1.3 Structure</b> .....                              | <b>17</b>  |
| <b>Chapter 2: Background &amp; Related Work</b> .....   | <b>19</b>  |
| <b>2.1 Power Wheelchairs</b> .....                      | <b>20</b>  |
| 2.1.1 Input devices.....                                | 20         |
| 2.1.2 Methods and Propulsion.....                       | 22         |
| <b>2.2 PWC Driving Assessment and Training</b> .....    | <b>23</b>  |
| <b>2.3 Virtual Environments</b> .....                   | <b>25</b>  |
| 2.3.1 Display types.....                                | 26         |
| 2.3.2 Sense of presence and immersion.....              | 28         |
| 2.3.3 Tracking.....                                     | 30         |
| 2.3.4 Software.....                                     | 31         |
| 2.3.5 Interaction techniques in VEs.....                | 33         |
| <b>2.4 PWC Simulators</b> .....                         | <b>35</b>  |
| <b>2.4.1 Summary</b> .....                              | <b>41</b>  |
| <b>Chapter 3: Interaction &amp; Visualization</b> ..... | <b>44</b>  |
| <b>3.1 Introduction</b> .....                           | <b>46</b>  |
| <b>3.2 System</b> .....                                 | <b>48</b>  |
| 3.2.1 Technical Apparatus.....                          | 48         |
| 3.2.2 Environment and driving task.....                 | 50         |
| 3.2.3 Collision detection.....                          | 51         |
| <b>3.3 Method</b> .....                                 | <b>52</b>  |
| 3.3.1 Participants.....                                 | 52         |
| 3.3.2 Measures.....                                     | 53         |
| 3.3.3 Experimental Design.....                          | 54         |
| 3.3.4 Counterbalancing.....                             | 55         |
| 3.3.5 Participant's Task.....                           | 56         |
| 3.3.6 Procedure.....                                    | 56         |
| <b>3.4 Results</b> .....                                | <b>57</b>  |
| 3.4.1 Path Boundary Violations.....                     | 57         |
| 3.4.2 Wall Collisions.....                              | 58         |
| 3.4.3 Completion Time.....                              | 59         |
| 3.4.4 Overall Driving Performance.....                  | 59         |
| 3.4.5 Experience and awareness.....                     | 60         |
| <b>3.5 Discussion</b> .....                             | <b>61</b>  |
| <b>3.6 Conclusion</b> .....                             | <b>62</b>  |

|  |            |
|--|------------|
| <b>Chapter 4: Perception &amp; Behaviour.....</b>    | <b>64</b>  |
| <b>4.1 Introduction .....</b>                        | <b>66</b>  |
| <b>4.2 System .....</b>                              | <b>69</b>  |
| 4.2.1 Technical Apparatus .....                      | 69         |
| 4.2.2 Environment and driving tasks.....             | 70         |
| 4.2.3 Data recording.....                            | 72         |
| <b>4.3 Method .....</b>                              | <b>73</b>  |
| 4.3.1 Participants.....                              | 73         |
| 4.3.2 Measures.....                                  | 74         |
| 4.3.3 Experimental Design .....                      | 76         |
| 4.3.4 Counterbalancing.....                          | 77         |
| 4.3.5 Participant's Task.....                        | 78         |
| 4.3.6 Procedure .....                                | 78         |
| <b>4.4 Results.....</b>                              | <b>80</b>  |
| 4.4.1 Correct detection (Hit).....                   | 80         |
| 4.4.2 False alarm (FA) .....                         | 83         |
| 4.4.3 Diagnosticity Measures .....                   | 84         |
| 4.4.4 Sense of presence and simulator sickness ..... | 87         |
| 4.4.5 Experience.....                                | 91         |
| 4.4.6 Preference .....                               | 92         |
| <b>4.5 Discussion .....</b>                          | <b>93</b>  |
| 4.5.1 Correct Detection and False Alarms .....       | 93         |
| 4.5.2 PPP and NPP.....                               | 95         |
| 4.5.3 Sense of presence and preference .....         | 95         |
| <b>4.6 Conclusion.....</b>                           | <b>96</b>  |
| <b>Chapter 5: Virtual Assessment.....</b>            | <b>98</b>  |
| <b>5.1 Introduction .....</b>                        | <b>99</b>  |
| <b>5.2 System .....</b>                              | <b>101</b> |
| 5.2.1 Task Recording.....                            | 102        |
| 5.2.2 Technical Apparatus .....                      | 108        |
| 5.2.3 Environment .....                              | 110        |
| <b>5.3 Method .....</b>                              | <b>112</b> |
| 5.3.1 Participants.....                              | 112        |
| 5.3.2 Measures.....                                  | 113        |
| 5.3.3 Experimental Design .....                      | 115        |
| 5.3.4 Counterbalancing.....                          | 115        |
| 5.3.5 Participant's Task.....                        | 116        |
| 5.3.6 Procedure .....                                | 116        |
| <b>5.4 Results.....</b>                              | <b>118</b> |
| 5.4.1 Assessment scores.....                         | 118        |
| 5.4.2 Perceived ease of use .....                    | 119        |
| 5.4.3 Confidence level.....                          | 121        |
| 5.4.4 Correct answers.....                           | 122        |
| 5.4.5 Sense of presence and simulator sickness ..... | 123        |
| 5.4.6 Suitability and user experience.....           | 125        |
| <b>5.5 Discussion .....</b>                          | <b>126</b> |
| 5.5.1 Assessment and correct answers.....            | 127        |
| 5.5.2 Perceived ease and confidence level .....      | 128        |
| 5.5.3 Sense of presence.....                         | 129        |
| 5.5.4 Suitability and user experience.....           | 130        |
| <b>5.6 Conclusion.....</b>                           | <b>130</b> |
| <b>Chapter 6: Discussion &amp; Conclusion.....</b>   | <b>132</b> |

|   |            |
|---|------------|
| <b>6.1 Discussion</b> .....   | <b>132</b> |
| 6.1.1 Contributions .....   | 136        |
| 6.1.2 Future work.....  | 137        |
| <b>6.2 Conclusion</b> .....   | <b>144</b> |
| <b>References</b> .....   | <b>146</b> |
| <b>Appendices</b> .....   | <b>168</b> |
| <b>Appendix A: Documents for interaction and visualisation experiment (Chapter 3)</b> ..... | <b>169</b> |
| <b>Appendix B: Documents for perception and behaviour experiment (Chapter 4)</b><br>.....   | <b>172</b> |
| <b>Appendix C: Documents for virtual assessment experiment (Chapter 5)</b> .....            | <b>183</b> |

# LIST OF FIGURES

|   |    |
|---|----|
| Figure 1: Q-logic Controller for PWC .....  | 21 |
| Figure 2: PWC propulsion methods (Axelson et al., 2002).....  | 22 |
| Figure 3: Display types in VE (D. Bowman, Kruijff, Jr, & Poupyrev, 2004)..  | 27 |
| Figure 4: At the top, full immersive display for VE (from left to right, CAVE (6 sides), HMD, and boom display). At the bottom, partial immersive display (desktop monitor, panoramic displays and 3-5 sides CAVE ) (Kjeldskov, 2001) ..... | 27 |
| Figure 5: Optical tracking methods (Bowman et al., 2004) .....  | 31 |
| Figure 6: Virtual scene created in Unity 3D.....  | 32 |
| Figure 7: Simulator by Spaeth et al. (2008).....  | 35 |
| Figure 8: VRTS simulator (left), VEMS (middle), and Rodriguez' simulator (right) .....  | 36 |
| Figure 9: Simulator on the left and projection visualisation on the right (Alshaer et al., 2013).....   | 37 |
| Figure 10: ViEW simulator (Morère et al., 2014).....  | 38 |
| Figure 11: VRSIM-1, rollers platform (left) and VE (right), developed by (Mahajan et al., 2013).....  | 39 |
| Figure 12: The hemispherical display and mobile platform (Hafid & Inoue, 2005).....   | 41 |
| Figure 13: (Left picture) virtual PWC. (Right picture) real PWC and gaming joysticks (top), virtual PWC and gaming joysticks (bottom). .....  | 49 |
| Figure 14: On the left, experiment setup: Alienware laptop and joysticks. On the right, Arduino board connected to the PWC joystick.....  | 50 |
| Figure 15: (On the top) outside view of the house environment used in the simulator (on the bottom) inside view of the house and the path .....   | 51 |
| Figure 16: A participant completing the experiment .....  | 53 |
| Figure 17: Ideal path through the environment.....  | 55 |
| Figure 18: Screenshot of the electronic consent .....   | 57 |
| Figure 19: Participants' answers to experience and awareness questions. Box plot represents the median, interquartile (blue box), minimum, and maximum. ....  | 60 |
| Figure 20: Left, real world and right virtual environment, (Geuss et al., 2010) .....   | 68 |



|   |     |
|---|-----|
| Figure 21: Experiment components, including monitor, joystick, HMD, laptop, and HMD tracker placed at the top of the screen .....   | 70  |
| Figure 22: The indoor VE consisting of stop sign, walls, doorframe, and set of two poles. ....  | 71  |
| Figure 23: PWC simulator (hallway) .....  | 71  |
| Figure 24: Doorframes/gaps width differences .....  | 72  |
| Figure 25: Simulator outputs.....   | 72  |
| Figure 26: Monitor condition (on the left) and HMD condition (on the right)   | 73  |
| Figure 27: Balanced set of comparable paths .....   | 77  |
| Figure 28: Training version used for demonstration, no gaps or doorframes added .....   | 79  |
| Figure 29: Top: interaction between FOV and Display factors. Middle: interaction between FOV and Avatar factors for Monitor condition. Bottom: interaction between FOV and Avatar factors for HMD condition. ....                               | 82  |
| Figure 30: Interaction between FOV and avatar .....   | 84  |
| Figure 31: Interaction between FOV and self-avatar factors.....   | 86  |
| Figure 32: Top: Interaction between Display and Self-Avatar factors. Middle: interaction between Display and FOV factors for none-Avatar condition. Bottom: interaction between Display and FOV factors for Self-Avatar condition. ....         | 89  |
| Figure 33: Boxplot of all 4 comparative questions: Q1: self-avatar ease of judgement, Q2: self-avatar comfort, Q3: FOV ease of judgement, Q4: FOV comfort. Box plot represents the median, interquartile (blue box), minimum, and maximum. .... | 92  |
| Figure 34: Participants' preferences for each condition within each group ..  | 93  |
| Figure 35: Illustration of the selected driving task based on WST. Driving backwards (top left), Driving forwards (top right), sideways manoeuvre (bottom left), and turn 180° (bottom right).....  | 104 |
| Figure 36: HTC controller placed on the wood frame to track the PWC movement.....   | 106 |
| Figure 37: HTC base stations mounted on the walls and HTC controller placed on the PWC (This is not the actual PWC used for recording) ...  | 106 |
| Figure 38: "Invisible" Unity3D game object to track the controller movement .....   | 107 |

|  |     |
|--|-----|
| Figure 39: Examples of the tracking of the PWC movements for each task. In those pictures, the expert clinician instructing the PWC user, the expert PWC user, and the researcher running the simulator to record the driving tasks..... | 108 |
| Figure 40: Top picture, the two screens. Bottom pictures, (on the left) the experimenter view to change the viewpoints and play the driving tasks, (on the right) a screenshot of the orbiting view .....                                | 109 |
| Figure 41: HTC Vive headset .....  | 109 |
| Figure 42: Panorama picture of the Jewish Hospital Rehabilitation lab where the experiment took place. ....  | 110 |
| Figure 43: The yellow sphere is where clinicians can orbit around the virtual PWC with the ability to zoom in and out at any given time. ....  | 111 |
| Figure 44: Walk condition (on the left) and orbit condition (on the right) ..  | 112 |
| Figure 45: Experimenter menu to select the condition and the driving task based on a pre-randomised order.....   | 118 |
| Figure 46: Interaction between viewpoints and tasks for perceived ease. ..   | 120 |
| Figure 47: Interactions between viewpoints and tasks for confidence level. ....  | 121 |
| Figure 48: Number of correct answers. Box plot represents the median, interquartile (blue box), minimum, and maximum. ....   | 122 |
| Figure 49: Boxplots representing all senses of presence categories. Box plot represents the median, interquartile (blue box), minimum, and maximum. ....   | 123 |
| Figure 50: Suitability of the viewpoint in clinical use.....   | 125 |
| Figure 51: Clinicians' responses to experience questions.....  | 126 |

# LIST OF TABLES

|  |     |
|--|-----|
| Table 1: 2 x 2 factorial design. ....  | 54  |
| Table 2: Means and standard deviations for path boundary violations.....   | 58  |
| Table 3: Means and standard deviations for wall collisions.....  | 58  |
| Table 4: Means and standard deviations for completion time .....   | 59  |
| Table 5: Means and standard deviations for overall driving performance ....  | 59  |
| Table 6: Signal detection confusion matrix.....  | 74  |
| Table 7: Mixed-subjects factorial design.....  | 76  |
| Table 8: Correct detection means and standard deviations for implicit and explicit measures.....                                     | 81  |
| Table 9: False alarm means and standard deviations for implicit and explicit measures.....   | 83  |
| Table 10: Non-detectors number and percentages for implicit and explicit measures.....   | 85  |
| Table 11: Means and standard deviations of PPP for implicit and explicit measures.....   | 86  |
| Table 12: Means and standard deviations of NPP for implicit and explicit measures.....   | 87  |
| Table 13: Means and standard deviations of participants' general sense of presence and realism .....                                 | 88  |
| Table 14: percentage and average rating of participants' simulator sickness .....  | 91  |
| Table 15: Scale for scoring skill capacity ("WST 4.2 form, n.d.).....  | 105 |
| Table 16: 4x3 factorial design. ....   | 115 |
| Table 17: A block of complete randomisation repeated every three subject (T <sub>1</sub> -0 means Task 1 – correct scores of 0)..... | 116 |
| Table 18: Virtual assessment means and standard deviations.....  | 119 |
| Table 19: means and standard deviations for easiness question.....   | 120 |
| Table 20: Means and standard deviations for confidence level.....  | 121 |
| Table 21: Means and standard deviations for general sense of presence, involvement, spatial presence, and realism .....              | 123 |

## CHAPTER 1: INTRODUCTION

Mobility is a key factor of the quality of life of any person, and there is no doubt that living with a disability substantially impacts life activities. A disability is an impairment that could impact, but is not limited to, cognitive, mental, or physical abilities. Disabilities can affect anyone's life; even healthy individuals will likely experience increasing impairments as they age. According to WHO (World Health Organization, 2011, p. 7), "disability is complex, and the interventions to overcome the disadvantages associated with disability are multiple and systemic – varying with the context". It is estimated that over one billion people across the world experience some degree of disability; of these people, 70 million need a wheelchair and only 5–15% of those have access to one (World Health Organization, 2011).

Receiving a power wheelchair (PWC) can drastically improve the user's quality of life by enabling them to participate in daily activities, thus decreasing their dependence on human assistance (Lee, 2014). But it is not as easy as simply giving the user a PWC; users must undertake assessment of and training for their competency. This is because PWC users are faced with restricted environments and limited space to manoeuvre, and are therefore vulnerable to collisions and serious injuries. Current assessment and training procedures are expensive, potentially unsafe, and time-consuming (Harrison, Derwent, Enticknap, Rose, & Attree, 2002).

In a rehabilitation clinic, clinicians personalise the available PWC to the client's needs. This personalisation is largely based on the clinician's experience and what has worked well for them in the past (LoPresti, Koester, & Simpson, 2008). After being seated and configuring the control device, the client will go through an assessment, which could be a set of questions and/or driving skills. Based on the assessment, training will then take place, often in a

restricted indoor environment. Swan, Stredney, Carlson, and Blostein (1994, p. 1) report that “the evaluation of user proficiency and the suitability of a given wheelchair is largely guesswork, and user training is limited to practice with a possibly unsuitable wheelchair”.

Currently, there is no standardised protocol for assessment, training, or customisation. Most clinics simply use their own observation measures. This lack of standardisation has resulted in demands for alternative approaches to overcome some of the limitations. Researchers in the past (Abellard, Randria, Abellard, Ben Khelifa, & Ramanantsizehe, 2010; Hafid & Inoue, 2005; Harrison et al., 2002) treated Virtual Reality (VR) as a potential tool to reduce constraints, evaluate capacities, solve safety conditions, diversify experiments, and quantify the individual’s needs in terms of functionalities. In addition to this, since it has been shown that skills learned in VRs do positively transfer into the real world (Blaauw, 1982; Holden, 2005; Rose et al., 2000), VRs are increasingly used for therapy and rehabilitation purposes.

According to Holden (2005), VRs provide all of the key elements for a successful rehabilitation practice: performance feedback, repetitive practice, and motivation. Moreover, VRs can help assess potential users and provide training in a safe and controlled environment (Johnson, Guediri, Kilkenney, & Clough, 2011). Previous research has shown that VR-based applications are increasingly used for tasks such as driving. Because of the conceptual similarities, a PWC driving simulator is also expected to afford equivalent benefits as indicated in other driving simulators (Cooper et al., 2005). In the 1980s, Pronk et al. (1980) were the first to introduce a VR simulation to overcome some of the traditional assessment and training limitations. Their aim was to help prospective PWC users adapt to actual PWCs and real-world environments. They concluded that such a simulation could help with the adaptation and/or evaluation of PWC users.

Subsequently, more studies to evaluate the use of PWC simulators were conducted.

Across the board, most PWC simulators are built with the same goal: to immerse the user in the environment. Despite the potential advantages and benefits of PWC simulators, existing simulators fail to offer the usability required for their success (Alshaer, Hoermann, & Regenbrecht, 2013). Previous research highlights several advantages of using PWC simulators: utility as an assessment and/or training device, transferability of skills from VEs to real environments, and easily generated objective measures of user performance. However, users experienced difficulties operating the simulator; these difficulties have been attributed to immersion factors, such as field of view (Archambault, Tremblay, Cachecho, Routhier, & Boissy, 2012; Harrison et al., 2002) and display type (Alshaer et al., 2013). In addition, all previous PWC simulators are built from a user's perspective, where, in fact, PWC simulators have the potential to be multi-user virtual worlds, especially in circumstances when clinicians seek to evaluate or train users.

Building a realistic and effective VR-based environment requires the consideration of many factors. According to Capustiac, Hesse, Schramm, and Banabic (2011), validation is the most challenging task when designing a driving simulator. The authors note that there are two major validation approaches: 1) validation of the simulated system (correct vehicle dynamic), and 2) the driver's responses to the offered simulation. The simulation must behave (dynamic movement), respond (to user's input), and support veridical perceptions of the task environment (Grant, Harrison, & Conway, 2004). For example, Rupp, Oppold, and McConnell (2015) report that the wrong input device "can affect performance, increase cognitive workload and increase errors that may lead to the loss of a vehicle". In a similar way, misperceptions of the simulation space can result in erroneous

judgements that could alter the user's behaviour (Henry & Furness, 1993; Sun, Li, Zhu, & Hsiao, 2015).

The aim of this thesis is to close the gap in the availability of a suitable research platform for the class of VR-based PWC applications. It aims to answer three main questions: 1) Which VR input devices are necessary and appropriate, and which virtual device representations can and should be implemented for PWC simulation? 2) How accurately can PWC users make the right decisions when navigating a VE? In particular, how do different immersion factors influence behaviour, perception and sense of presence? 3) How accurately can clinicians assess driving tasks in the VE compared with the real world? In particular, do different observational interfaces affect how clinicians observe driving in the VE, and result in different judgements?

To summarise, the principal goal of this thesis is to design and implement a PWC simulation that meets the previously mentioned criteria (behave, respond, and perceive) to exceed previous simulation on these three criteria. An improved PWC simulator will ensure that driving, assessment, and training in the simulation is as good as it would be in the real world. A wheelchair simulation review by Grant et al. concludes that,

... the field of driver training is one that is popular among researchers and if the goal is just to extend the user's capabilities in basic operations such as turning, stopping and obstacle avoidance then the demands on the technology are slight. Simulation not only offers the ability to train novice users in a safe environment but also gives those charged with equipping them an early insight into capabilities of the user. (2004, p. 108)

## 1.1 Importance of this Thesis

Research has shown that approximately 25% of disabled people who desire a PWC fail their clinical assessment (Fehr, Langbein, & Skaar, 2000). Fehr et al. also report that 40% of PWC users regularly experience issues surrounding the operation of PWCs. About 85% of 200 practising clinicians interviewed by Fehr et al. (2000) reported having clients who were refused a PWC because they lacked the requisite motor skills. The most common factors in the rejection are the absence of client involvement in the selection of the PWC, improper driving performance, and improper configuration (Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 2000; Scherer & Cushman, 2001). Chaves et al. (2004) concluded that the PWC itself was the most limiting factor when compared to the physical environment, physical impairment, or perceived participation.

A VE simulator would allow clients to practise with the PWC, thus removing fear; this is especially the case for those with no prior wheelchair- or vehicle-driving experience (Holden, 2005). It would also help them to learn from their mistakes, which would improve their chances of receiving a PWC. On the other hand, clinicians would be able to provide augmented feedback to the clients, which is important for motor learning (Holden, 2005). A VE would also open another gate for the clinician to go beyond current assessment/training techniques by providing quantitative data that could give them a better view of the client's progress/condition. At present, virtual assessment and training for PWC users is underdeveloped and under researched. This is evident from the fact that there is only one software product commercially available on the market, WheelSim (Abellard et al., 2010). Unfortunately, this product is unsuitable for training and assessment purposes (Alshaer et al., 2013).



## 1.2 Main Contributions

The findings of this research contribute to the bodies of knowledge in the multidisciplinary areas of computer and information sciences, applied psychology and ergonomics, and physiotherapy and physical rehabilitation. An ecologically relevant system was designed and implemented to benefit both PWC users and clinicians. This development is based on contemporary theories and technologies. The results from each of the experiments presented here have the potential to enhance and extend traditional clinical approaches. The results found in all studies are relevant to the PWC user community by way of developing better systems for those targets. In fact, the nature of the questions asked are general enough to be applied to other contexts. The studies conducted here led to the following main findings:

- The effect of VR input device representation has a significant impact on user experience and/or performance, thus visual properties need to be carefully selected. This is especially important for applications that seek ecologically valid simulation and transfer effects to real-world scenarios.
- Immersion factors such as display type, field of view (FOV), and self-avatar presence influence user behaviour, perception and sense of presence. This finding could help to guide VR simulator designers to evoke targeted user behaviour and perception.
- Different observational interfaces impact how clinicians observe driving in the VE and, therefore, the judgement. This supports the preferential use of embodied interaction techniques to provide more cues for an assessor. It indicates the usefulness of using VR as an assessment tool and the importance of the clinician's perspective (viewpoint) in such systems.

## 1.3 Structure

This thesis is divided into six chapters. In Chapter 2, the literature review is presented and the problem area is discussed. Chapters 3–5 contain the main three studies. In these three chapters the experiment and system developed for each experiment is discussed in detail. Chapter 6 summarises the results and offers a conclusion.

In detail:

Chapter 2 situates the present research by offering a detailed literature review including; current technologies and approaches used in PWC simulation. Furthermore, the chapter provides details on the technical implementation of related work and introduces the technological basis and requirements for the systems used in different experiment.

Chapter 3 presents the first experiment, where the virtual display of a standard gaming joystick is compared with that of a proprietary PWC joystick while users tested either of the real-world counterparts, and measured the effects on driving performance and experience. Four experimental conditions (comprising two virtual visual input modalities and their two real-world counterparts) are studied as independent variables. This chapter also includes a detailed discussion on the implementation of the system.

Chapter 4 identifies and evaluates immersion factors that affect perception, behaviour, and driving performance. Three immersion factors are identified: display type (head-mounted display (HMD) vs. monitor), FOV (static vs. changeable), and self-avatar (present vs. absent). All three potentially affect perception and behaviour. Eight experimental conditions comprising 2 display types x 2 FOV x 2 self-avatar presences are presented as independent variables.

## Introduction

Chapter 5 compares the effect of three observational interface techniques (viewpoints) on the assessment of PWC driving tasks: 1) PWC user's perspective; 2) clinician's perspective through embodied interaction (walking around in the virtual space); and 3) clinician's perspective through direct manipulation of the viewpoint (orbiting around the virtual PWC). The experiment consists of 12 conditions comprising 3 viewpoints x 4 different driving tasks. A discussion of the system implementation is also provided.

Chapter 6 summarises and discusses the findings of the previous chapters and suggests future work and research directions. Ultimately, the chapter provides final reflections and an overall conclusion of the thesis.

## CHAPTER 2: BACKGROUND & RELATED WORK

This chapter will cover four areas: 1) PWC, including input devices and methods of propulsion; 2) existing PWC training and assessment protocols; 3) a brief discussion of VEs, display types, tracking, software, and interaction techniques in VE; and 4) an in-depth review of PWC simulators, including their usage, technology, and limitations. This review is limited to power/electric wheelchair simulators; scooters and smart and manual wheelchair simulators are beyond the scope of this thesis.

Parts of this literature review have been previously published in the following:

Alshaer, A., Regenbrecht, H., & O'Hare, D. (2017). Immersion factors affecting perception and behaviour in a virtual reality power wheelchair simulator. *Applied Ergonomics*, 58, 1–12.

Alshaer, A., O'Hare, D., Hoermann, S., Regenbrecht, H. (2016) The impact of the visual representation of the input device on driving performance in a power wheelchair simulator. Proceedings of the 11th Intl Conf. Disability, Virtual Reality & Associated Technologies, Los Angeles, California, USA, 2016

Alshaer, A., Regenbrecht, H., & O'Hare, D. (2015). Investigating visual dominance with a virtual driving task. In 2015 IEEE Virtual Reality (VR) (pp. 145–146). Arles, Camargue, Provence, France.

## 2.1 Power Wheelchairs

A Power Wheelchair (PWC), also known as an Electric Wheelchair (EWC), is a motorised wheelchair electrically powered by a motor (Motorized wheelchair, 2016). This wheelchair was invented by George Klein to help veterans from World War II; since then, many different styles and models of PWCs have been invented to meet different needs. PWCs are used by a diverse user population, including, but not limited to, people who were born with congenital disorders or absence of limbs, or people who suffered from head injuries, or stroke. This diversity is what makes assessment and training complicated.

In general, PWCs fall into two categories: power wheelchairs and scooters (Axelson, Minkel, Perr, & Yamada, 2002). The main difference between scooters and conventional PWCs is the way they are steered. Scooters are usually steered by handlebars that are attached to the front wheels which mechanically turn the wheels, while PWCs are controlled by an electronic input device, such as a joystick (Axelson et al., 2002). This thesis focuses only on PWCs; the following two sections will briefly discuss PWC input devices and methods of propulsion.

### 2.1.1 Input devices

One of the most critical components of the PWC is the input device. While a joystick that is controlled by the user's hand is the most common device used to control a PWC, there are many other input devices, such as a head array, 'sip n' puff', and tongue switch to accommodate the user's different needs (Dicianno, Cooper, & Coltellaro, 2010). This thesis focuses only on the use of a hand joystick.

A standard PWC joystick is a proportional movement sensing controller where the amount of deflection from the user's hand force corresponds to the rate of the movement of the PWC (Dicianno et al., 2010). This means that the further the joystick is progressively moved from its centre, the faster the PWC will go. PWC joysticks are usually finger-based and have a variety of parameter settings that can be configured and programmed. Figure 1 shows one of the most common PWC joysticks that is currently available in the market (Q-logic). While the operations may differ depending on the model, the key principles of how the joystick functions remain the same. According to Dicianno et al. (2010), mounting and determining the compatibility of the joystick remain serious issues in clinical assessments when determining the best access point for users. PWC joysticks are specifically built for different types of chairs and are customised based on the user's needs; this makes them proprietary and expensive.



Figure 1: Q-logic Controller for PWC

## 2.1.2 Methods and Propulsion

A standard PWC is composed of a sturdy base with two motors to power two large wheels. It also includes rotating caster wheels and a joystick to control navigation (Archambault, Routhier, Hamel, & Boissy, 2008). While driving forwards or backwards, the two motors move at the same speed and in the same direction; while turning, the motors move at different speeds. When the joystick is released, the brakes automatically apply. PWCs typically have four to six wheels, and are categorized based on their propulsion methods: front-, rear-, or mid-wheel drive (Rabadi & Vincent, 2015). Each propulsion method allows for different driving characteristics such as indoor, outdoor, or a combination of indoor and outdoor. The user's environment defines the type of PWC that will best suit their needs. For example, smaller PWCs are more effective for indoor environments, offering users enhanced manoeuvrability. However, they are less stable when used outdoors (Axelson et al., 2002). Figure 2 illustrates the three varieties of propulsion.



Figure 2: PWC propulsion methods (Axelson et al., 2002)

**Front-wheel drive** features the propulsion wheels (large wheels) in the front and casters (usually small wheels) in the rear. It has better traction when driving downhill, but can lose traction when driving uphill, especially over sandy or slippery surfaces. It offers superior turning capabilities, which makes it ideal for tight spaces (Axelson et al., 2002).

**Rear-wheel drive** features the propulsion wheels in the rear and casters in the front, which gives it a similar feeling to a manual wheelchair. In contrast to the front-wheel PWC, it has better traction going uphill than going downhill. However, when driving the PWC backwards, the chair can turn unexpectedly and is more difficult to control. This type of PWC is best suited to outdoor environments (Axelson et al., 2002).

**Mid-wheel drive** features better traction than either rear-wheel or front-wheel drive because of the powered wheels located under the user's centre of mass. This type of PWC usually has six wheels: powered wheels, a pair of anti-tipping wheels located at the front, and a pair of casters in the rear. As a result, it combines both the manoeuvrability of the front-wheel and stability of the rear-wheel. In this thesis, for the real and virtual PWC, a mid-wheel PWC was used.

## 2.2 PWC Driving Assessment and Training

There are a number of functional difficulties associated with the use of PWCs such as manoeuvring in indoor environments, avoiding obstacles, and transporting the chair in vehicles; all of these present a risk to the user (Kirby et al., 2015). For instance, research has reported risk of falls and tips (Kirby, Ackroyd-Stolarz, Brown, Kirkland, & MacLeod, 1994; Xiang, Chany, & Smith, 2006), and others have reported risk of collisions with static or moving objects (Corfman, Cooper, Fitzgerald, & Cooper, 2003). To function independently, PWC users must develop a variety of specific driving skills to be able to deal with physical barriers and inevitable manoeuvrability challenges (Kilkens, Dallmeijer, De Witte, Van Der Woude, & Post, 2004). Training users is therefore a vital process of the rehabilitation programme, which requires eligibility assessment beforehand; not only to grant someone a PWC but also to provide useful information on the user's skill performance so that training



goals can be clearly defined (Kilkens, Post, Dallmeijer, Seelen, & van der Woude, 2003).

The assessment of an individual's eligibility to operate a PWC is not standardised (Holliday, Mihailidis, Rolfson, & Fernie, 2005). In general, clinics use existing measures or develop their own. Rehabilitation usually includes a hierarchy of measures, from a general overview of the user's functions to community reintegration and function measures (Kirby et al., 2004). Function measures include a set of questionnaires and/or more common driving tasks, which typically consist of manoeuvres (Holliday et al., 2005). Insufficient research on the ability of existing measures to reflect everyday use of PWCs has been reported (Holliday et al., 2005). McCrea, Eng, and Hodgson (2002) report that, while users tend to overestimate their ability to drive a PWC, clinicians both over- and underestimate the user's skills.

There are a few assessment and training tools available to rehabilitation centres for evaluation of PWC-driving capacities. One of the earliest assessment tools was developed by Dawson, Chan, and Kaiserman (1994): the Power Mobility Indoor Driving Assessment (PIDA). Another widely used tool in clinics today is the Wheelchair Skills Test (WST), which has been primarily used to assess manual wheelchair users (Kirby, Swuste, Dupuis, MacLeod, & Monroe, 2002), but recently it was adapted to evaluate PWC driving skills (Mountain et al., 2010). The WST is part of the Wheelchair Skills Program (WSP) that also includes the Wheelchair Skill Training Program (WSTP). WSTP is used to train wheelchair users, their caregivers, and clinicians ("Wheelchair Skills Program," n.d.).

The WST evaluates PWC driving skills by means of a comprehensive scoring system. There are 32 tasks that range from easy to advanced, where users receive a score: 0 (fail), 1 (pass with difficulty), or 2 (pass). After completion of all tasks, the user receives a total score that

indicates the percentage of overall task completion. The WST has proven to be practical, safe, valid, and reliable . A study by Kirby et al. (2004) evaluated the validity of the Wheelchair Skills Test (WST – version 2.4) with 298 subjects, and concluded that the WST 2.4 measurement properties are very good to excellent with intrarater and interrater reliabilities of .959 and .968 respectively. In this thesis, the WST is used as a reference for designing and developing the driving tasks.

### 2.3 Virtual Environments

A virtual environment (VE), also referred to as a virtual reality (VR), can be defined as a simulation of the real world that is generated by a computer in three dimensions and rendered in real time (Loeffler & Anderson, 1994). A wide range of hardware and software technologies can be utilised to create simulations of varying degrees of complexity. In the real world, one gains knowledge about the surrounding environment directly through the senses, whereas in a VE, information is obtained through interface technologies, such as head-mounted displays (Holden, 2005). One of the recent fields to benefit from VE technology is that of motor rehabilitation, where the technology has been used in cases of stroke rehabilitation, balance training, Parkinson's disease, and wheelchair mobility.

In a review of VEs used in motor rehabilitation by Holden (2005), three major findings were reported: 1) people with disabilities are able to learn from VEs; 2) in most cases, skills developed in VEs transfer positively to the real world; and 3) there are some advantages of VE training over real-world training. It is clear that VEs are a powerful tool for motor rehabilitation. There are three key benefits to users: 1) the possibility of repetitive practice, because the environment is safe; 2) motivation, as gaming concepts can be integrated; and 3) performance feedback, which can be augmented to the user (Holden,

2005). According to Kenyon and Ellis (2014, p. 48), “VEs are not constrained by the physics of the real world and can adapt very rapidly to almost any situation. This inherent versatility of VE is an influential factor in its acceptance and use in rehabilitation”.

A variety of hardware and software can be utilised to produce different VEs with different capabilities as reviewed in Hale and Stanney (2014). However, the basic components for a VE system include a computer, a powerful graphics card, the ability to create three-dimensional images, display device/s, input device/s, and software that allows these components to work together. VE interface devices consist of multimodal display devices (output devices), which include visual, auditory, and haptic feedback to present information to the users; and multimodal input devices, such as a camera, touch screen, joystick, or more advanced motion-tracking devices to control movements in the VE (Hale & Stanney, 2014). To provide a basic background of the varieties of technology used in this thesis, only the display types and position tracking devices will be discussed.

### 2.3.1 Display types

The display device could be as simple as a desktop monitor, or could be a more sophisticated device, such as the CAVE™ system (Cruz-Neira, Sandin, & DeFanti, 1993). Other display types include head-mounted displays (HMD), boom-mounted displays (BMD), arm-mounted displays (AMD), responsive workbench, fish-tank VR, and panoramic displays (examples of these displays can be seen in Figure 3, next page). The choice of the display type has an effect on the user’s immersion into the VE and their ‘feeling present’ (Schubert, Friedmann, & Regenbrecht, 2001). A study by Hou, Nam, Peng, and Lee (2012) has shown that feeling present is determined by the interaction between human influences and technological factors, such as the viewing angle and display type.



Figure 3: Display types in VE (D. Bowman, Kruijff, Jr, & Poupyrev, 2004)



Figure 4: At the top, full immersive display for VE (from left to right, CAVE (6 sides), HMD, and boom display). At the bottom, partial immersive display (desktop monitor, panoramic displays and 3-5 sides CAVE ) (Kjeldskov, 2001)

### 2.3.2 Sense of presence and immersion

Sense of presence and immersion are two important factors in the effectiveness of any virtual environment. The sense of presence has been the focus in many research studies (e.g., Barfield, Zeltzer, Sheridan, & Slater, 1995; Heeter, 1992; Loomis, 1992; Sheridan, 1992). This factor can be defined as “the subjective experience of being in one place or environment [e.g., VE], even when one is physically situated in another” (Witmer & Singer, 1998, p. 225); others also described it as “a state of consciousness, the (psychological) sense of being in the virtual environment” (Slater & Wilbur, 1997, p. 4). When users rate high levels of presence in the virtual environment, this results in perceiving this environment as a more engaging reality than the surrounding real world, and users consider the environment as a place they have visited rather than just images they have seen (Slater & Wilbur, 1997).

Although some studies argue that presence is related to performance (Welch, 1999), there is no evidence to support this claim (Schuemie, van der Straaten, Krijn, & van der Mast, 2001). However, there is evidence that presence is related to responses and emotions, as seen in Regenbrecht, Schubert, and Friedmann (1998) where the relationship between presence and fear of heights was investigated. The most common tool used to measure presence is through questionnaires (Schuemie et al., 2001). For example, the Igroup Presence Questionnaire (IPQ) has been recommended by Schuemie and his co-authors as a reliable and valid tool of evaluation. The IPQ questionnaire was developed by Schubert, Friedmann, and Regenbrecht (1999). It consists of 13 questions that measure three important factors: involvement, spatial, presence, and realism.

The sense of presence can be affected by hardware issues (immersion) subsequently decreasing the effectiveness of the virtual environment (Pallavicini et al., 2013). For example, Pallavicini et al. (2013)

examined the effect of reducing the levels of presence on emotions. The authors exposed a group of students to different forms of academic examinations (text, audio, video, and VR). In the VR condition, a technological breakdown was added, which led to a decreased level of the sense of presence. The results showed that there was a significant negative emotional reaction in all forms (increase in anxiety and decrease in relaxation). However, VR was the least-effective form to create stress-related reactions. This result revealed that the technological breakdowns impacted the levels of sense of presence, thus affecting the effectiveness of the virtual environment (i.e., emotions).

Immersion can be defined as “the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant” (Slater & Wilbur, 1997, p. 3). It can be evaluated on a spectrum, from non-immersive to fully immersive (Ogle, 2002). Kjeldskov (2001) divides immersion into two categories: full immersion and partial immersion. This classification largely depends on how much of the user’s field of view (FOV) is covered (Figure 4). For example, if the display provides an available FOV in any viewing angle, it is classified as a full immersive display (feeling of ‘being in’). On the other hand, if the display FOV is static, then it is a partial immersive display (feeling of ‘looking at’).

To distinguish between presence and immersion, Schubert et al. (2001) explain that presence involves the user’s experience of being part of the VE, whereas immersion involves the fidelity of the technologies used in the VE. Typically, having greater levels of immersion would result in higher levels of a sense of presence, and thus likely to create stronger psychological reactions (North & North, 2016). All three studies presented in this thesis measure the user’s sense of presence in the VE. While it might be intuitive that a more immersive VE would be preferable for simulators, this may not be the

case as immersive VEs can generate cyber sickness; symptoms may include vomiting, nausea, headaches, or loss of balance (Stanney, Kennedy, Drexler, & Harm, 1999). According to Holden (2005), newer technologies should decrease the effects of cyber sickness.

In addition, as simulator sickness is not the focus of the thesis, this topic was only treated as a confounding variable that was measured when needed through the studies. Simulator sickness was measured subjectively in the form of a questionnaire. The questionnaire was adapted from the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993) where only five symptoms out of 16 were chosen. These symptoms covered the three main components in the questionnaire of Kennedy et al.: nausea, disorientation, and oculomotor issues. The five symptoms are 1) general discomfort, 2) difficulty concentrating, 3) dizziness, 4) difficulty focusing, and 5) nausea.

### 2.3.3 Tracking

Besides the standard mouse and joystick interfaces that are regularly used to navigate in a VE, a variety of other devices monitor or simulate movements such as pressure, touch, or force. Input devices can be characterised by the degrees of freedom (DOF) that they offer (Bowman et al., 2004). For example, a tracker device usually captures three position and orientation values (a total of six DOF). According to Bowman et al. (2004, p. 88), “In many cases, input devices combine discrete and continuous components, providing a larger range of device-to-interaction technique mappings”. A discussion of tracking devices, in particular, motion tracking, will follow.

Motion tracking technologies allow correspondence between the physical and virtual world. In fact, it is fundamental to some interaction techniques where locomotion, manipulation, or avatar animation is needed (Hale & Stanney, 2014). As a result, tracking

must be accurate to make usable interaction with in VRs. According to Bowman et al. (2004), the essential characteristics of motion tracking devices include latency (delay from motion occurs until it is displayed), jitter (output noise that makes the image shake), tracking range, and accuracy. Different varieties of tracking methods are used today, such as magnetic tracking, acoustic tracking, optical tracking (most widely used in HMDs), and hybrid tracking.

Optical motion tracking typically uses cameras to detect the position and orientation of the user or object by means of reflected or emitted light. Optical tracking systems involve two methods (Figure 5): outside-in (the sensors/cameras are placed in fixed locations in the environment while the tracked user/object is marked with passive or active landmarks); and inside-out (the opposite of outside-in) where the individual wears optical markers (placed on specific parts of the hand or HMD), and cameras/sensors track these markers from a fixed position (Bowman et al., 2004). The most common issue associated with optical tracking is occlusion where the cameras cannot see the markers (Bowman et al., 2004). In many cases, optical tracking is combined with non-optical tracking such as gyroscopes, accelerometers, and magnetometers to increase accuracy and overcome some of the weaknesses of optical tracking.



Figure 5: Optical tracking methods (Bowman et al., 2004)

### 2.3.4 Software



Besides the hardware (input and output devices), software is needed to create VEs. Three software platforms were used to generate the interactive simulation for each experiment. Unity 3D is the core development platform in which the three systems were built. Unity 3D is a well-known virtual reality game engine, developed by Unity Technologies. It allows for the creation of 3D environments with rendering capabilities and integration with external applications and plugins that are essential for the implementation of simulators. It provides base application program interfaces (APIs) for multiple VE devices, such as Samsung Gear VR, Oculus Rift, PlayStation VR, and HTC VIVE. Unity supports three scripting languages, all of which can be mixed: C#, JavaScript, and Boo. It uses the unit measurement in the 3D virtual space, which is equivalent to one metre in reality. The virtual scene in Figure 6 demonstrates a 3D VE created with Unity.



Figure 6: Virtual scene created in Unity 3D

The Unity coordinate system is left-handed (X pointing to the right, Y pointing up, and Z pointing towards the screen). The Unity built-in physical engine handles the physical simulation, such as collisions, forces, and gravity. However, dynamic movements (such as vehicle) are controlled by scripts. The behaviour of any game object in the scene can be controlled by the components attached to it, such as a script, which can be used to trigger game events, respond to user

input, or modify the properties of the game object. The script is written using an external development environment, such as MonoDevelop or Visual Studio.

To create a scene, several components must be considered. For example, the position and orientation of the camera, and the camera properties such as viewing angle and aspect ratio. The remaining software used to implement the simulations are Google SketchUp and MakeHuman. SketchUp is used to create 3D models, such as the vehicle, joystick, and environment, any or all of which can later be imported by Unity as a game object in the scene. MakeHuman is an open-source graphics tool used to create realistic 3D humans for animations.

### 2.3.5 Interaction techniques in VEs

There are different classifications of interaction techniques in VEs, such as type of input device, viewpoint, or frame of reference (Jung et al., 2014). However, one of the most widely referred to interaction classifications is that of Bowman et al. (2004). They classify interaction techniques based on universal tasks such as navigation (include both travel and wayfinding), selection, and manipulation. This section will provide brief details on each of these techniques.

Selection and manipulation are most often paired together. Selection is a task requiring the picking of an objects for some purpose, while manipulation refers to the orientation and positioning of objects in the VE (Bowman et al., 2004). Each of these techniques involves different sub-techniques depending on the task in the VE. For instance, selection techniques involve touching, pointing, and naming, while manipulation techniques include virtual hands. In most cases, these sub-techniques are combined in the VE and largely depend on the properties of the input devices and visual display devices.

Travel is the most common technique in the VE because of its key importance in almost every environment. It refers to tasks in which the user positions and/or orients the viewpoint within the VE (the motor aspect of navigation). It involves both viewpoint orientation and translation. According to Bowman, there are different sub-tasks that involve travel, such as exploration, search, and manoeuvring. In exploration tasks, the user has no goal for their movement, but rather browses the VE to obtain information about the space. Search tasks include travel to specific target locations in the VE regardless of whether the user knows where the location is or how to reach it. Manoeuvring tasks involve more precise changes of the viewpoint to perform a specific task, such as examining 3D objects in the VE from different angles.

There are many different types of travel interaction techniques, including physical locomotion (e.g., walking); steering (where the user has full control of the direction of movement); route planning (where the user plans their route in the VE, e.g., drawing a path); target-based (e.g., zooming in or out); manual manipulation (hand-based, e.g., manipulation of a virtual object by a tracked hand); and viewpoint orientation, which includes head tracking, orbital viewing, non-isomorphic rotation, and virtual spheres. According to Bowman, head tracking is the most natural way to specify viewpoint orientation. Orbiting, on the other hand, is a slight twist on the natural head viewpoint (Koller, Mine, & Hudson, 1996). Orbiting allows the user to examine a particular object in the VE from all sides.

Wayfinding deals with the cognitive aspect of navigation. Wayfinding tasks are the same as travel tasks (exploration, search, and manoeuvring), except they are centred around cognitive navigation, or the process of determining the right path in the VE (Bowman, Koller, & Hodges, 1997). The egocentric and exocentric frames of reference play a crucial role in wayfinding. The difference between the two is that egocentric viewpoints are relative to a certain part of our body,

whereas exocentric viewpoints are relative to the world surrounding us (Bowman et al., 2004).

## 2.4 PWC Simulators

PWC simulators have been in existence since the 1980s when Pronk et al. (1980) developed a system to help wheelchair users adapt to PWCs. They concluded that such a simulation could help with adaptation and/or evaluation of PWC users. Other notable studies that have evaluated the driving skills of PWC users include Cooper et al. (2005) and Spaeth et al. (2008). The aim of these studies was to develop a risk-free VE which would allow for the evaluation of PWC users in a more efficient manner. The user's task was to drive along a path using a two-dimensional bird's-eye view (Figure 7). Completion time, number of path boundary violations, and errors between virtual PWC trajectory and desired path were recorded. The authors concluded that this data could be useful in assessing and/or training PWC users.



Figure 7: Simulator by Spaeth et al. (2008)

A number of studies have investigated PWC simulators in the domain of handicapped children, such as VEMS (Adelola, Cox, & Rahman, 2002), wheelchairNet (Inman, Loge, Cram, & Peterson, 2011), and VRTS (Desbonnet, Cox, & Rahman, 1998). These simulators used

desktop and adapted PWC joysticks. The main conclusion of the three studies was that PWC simulators could aid in the assessment and training of disabled children. Unlike other simulators, Rodriguez (2015) focused on the child motivation aspect by providing visual feedback. A desktop with an adapted PWC joystick was used; however, no study was conducted. VRTS, VEMS, and Rodriguez simulators can be seen in Figure 8.



Figure 8: VRTS simulator (left), VEMS (middle), and Rodriguez' simulator (right)

Other studies have tried to measure performance in the simulation. Harrison, Derwent, Enticknap, Rose, and Attree (2000) addressed the efficacy of their non-immersive VE in training a person with disabilities to improve their skills. Performance was measured in real and virtual worlds by recording completion time, number of separate manoeuvres, and number of collisions. The results showed that in the VE, participants tended to take longer, make significantly more collisions, and used a higher number of manoeuvres than in the real world. Harrison et al. (2000) attributed this to the lack of peripheral vision in the non-immersive VE. This issue was also reported by most of the participants. Similar issues were found in a study by Archambault et al. (2012) where task completion time was higher in the simulator compared to the real world for tasks that required lateral vision. However, it was concluded that performance was similar in the real and virtual world by means of joystick control smoothness.

Alshaer et al. (2013) investigated the effect of peripheral vision on the user's driving performance. Three conditions were compared: 1) narrow FOV, 2) wide FOV involving peripheral vision, and 3) stereoscopic vision. A triangular projection-based visualisation was used with a gaming joystick (Figure 9). Performance was measured in terms of completion time, and the number of boundary violations and wall collisions. It was found that the best performance was recorded when the wide FOV was used. Archambault, Chong, Sorrento, Routhier, and Boissy (2011) found no difference between driving performance in real and virtual worlds for simple tasks, but a significant difference for hard tasks involving lateral manoeuvres.



Figure 9: Simulator on the left and projection visualisation on the right (Alshaer et al., 2013)

ViEW is another VE developed by Morère, Fritsch, Remy, Noordhout, and Bourhis (2014) and aims to measure driving capacity by analysing objective data recorded by the simulator (completion time and number of collisions). A standard monitor with a customised PWC joystick were used (Figure 10). The research focused on individuals with multiple sclerosis (21 participants). The experiment sample was divided into four groups (experienced and inexperienced users, with and without multiple sclerosis). Each group completed six trials (three in the real world and three in the virtual world). In the real world, it was found that experienced groups performed the best in terms of completion time and number of collisions, whereas in the VE, groups

with no cognitive disorder had the best performance. The authors note that quantitative data can be used to evaluate the capacity of controlling a PWC in the VE.



Figure 10: ViEW simulator (Morère et al., 2014)

Some studies have shown the positive transfer from the virtual to the real world. For example, Linden, Whyatt, Craig, and Kerr (2013) investigated the efficacy of their PWC simulations in the context of training children to use a PWC. Assessed on their ability to drive a PWC, 28 children were evaluated using a functional evaluation rating scale, before and after the intervention. Completion times, errors, and total scores were recorded for the intervention group. Children who received training in the simulator showed significant improvement in time compared with those who had not received any training. While the simulation group showed greater improvement than the control group, it did not reach statistical significance. Interrater agreement was 0.74 between the two assessors. Similar results were found by Hasdai, Jessel, and Weiss (1998) where 22 children were assessed on their ability to drive a PWC before and after the intervention of the PWC simulator. A standard desktop and a gaming joystick were used for training. Using the functional evaluation rating scale, results showed that children scored significantly better after the intervention of the training simulator.

Studies have objectively investigated the assessment of PWC-driving skills in the VE. Mahajan, Dicianno, Cooper, and Ding (2013) developed a VE-based simulator (VRSIM-1) to assist therapists in carrying out PWC driving assessment (Figure 11). The authors implemented the Power Mobility Road Test (PMRT) in their simulator. The PMRT consists of 12 structured tasks with static obstacles and four unstructured tasks with moving/dynamic obstacles. In a 2x2 (PC screen vs. large screen x joystick input vs. roller input) within-subjects design, two clinicians assessed ten PWC users in all respective conditions. Results revealed that the virtual PMRT scores from the two clinicians showed a high interrater reliability (78–90%) as well as a high intrarater reliability (71–90%) for all test conditions. It should be acknowledged that the assessment was only undertaken in the VE and was not compared to a real-world standard. Further, assessments were conducted from the client's viewpoint and clinicians had to judge based on the client's visual information, which means that even if the two clinicians agreed on the score, it could be significantly different if the task were to be assessed in the real world.

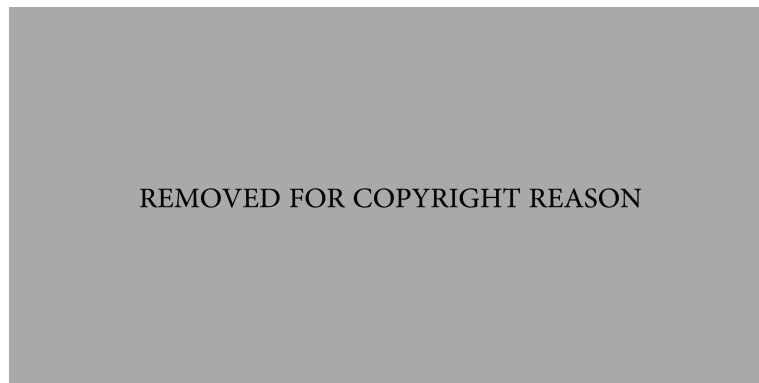


Figure 11: VRSIM-1, rollers platform (left) and VE (right), developed by (Mahajan et al., 2013)

The VRSIM-1 system was updated to VRSIM-2 and another study was conducted by Kamaraj, Dicianno, Mahajan, Buhari, and Cooper (2016). The only difference between the two studies is that a real-world condition was added to the experiment design resulting in five conditions instead of four in the VRSIM-1. Using the same PMRT



evaluation tool, participants were evaluated five times in all respective conditions by two clinicians (randomly assigned from five clinicians for each participant). The results showed that the interrater reliability was > 75% between the two assessors. Besides the experiment design issues discussed in the VRSIM-1, it is suggested that driving in the real world is different from driving in the VE, as seen in Archambault et al. (2011), Archambault et al. (2012), and Harrison et al. (2000), which means that participants behave differently in the real and virtual driving tasks; this could affect the assessment.

In addition to this, the assigned clinicians would know the participant performance from the first trial, which would make it easy for them to evaluate in the second, third, fourth, and fifth conditions. Also, the participant's driving skills would dramatically improve by repeating the same tasks five times, even though the conditions were randomised. Finally, all participants were expert PWC users, which could limit the external validity of the study.

Some studies integrated a motion platform into their simulation. For example, Archambault et al. (2008) measured the acceleration during different driving tasks in a real PWC and reproduced the same experience in the motion platform to provide a realistic setting when driving a virtual PWC. Their system consisted of a motion platform and back projection screen with a stereoscopic image (2.45 x 1.80m) that was synchronised with the motion platform.

Another study, by Hafi and Inoue (2005), used a mobile platform (six degrees of freedom) combined with a hemispherical display (providing 110° FOV; Figure 12). The aim was to investigate the joystick input as a potential evaluation criterion. It was proven that specific patterns of the joystick input could be used to recognise skilled users and unskilled ones. However, some participants reported motion sickness when using the platform. Also, adding a platform to the simulator

increases the cost and complexity of the simulation (Grant et al., 2004; Pithon, Weiss, Richir, & Klinger, 2009).



Figure 12: The hemispherical display and mobile platform (Hafid & Inoue, 2005)

From desktop-based simulator to an integrated mobile platform, a study by Browning, Cruz-Neira, Sandin, DeFanti, and Edel (1996) implemented an immersive virtual environment (like a CAVE system) where the user is surrounded by walls to display the projected image. The system was explored by PWC users and clinicians, and received positive feedback. The authors claim that such a system could have the potential for sharing the environment with more than one person. Although a projection-based system may reduce simulation sickness (Browning, Cruz-Neira, Sandin, & DeFanti, 1994), it is expensive and complex, and may not be feasible to set up in clinics.

### 2.4.1 Summary

Several research-based PWC simulators are available, covering a wide spectrum of applications. Some were developed for driving training, others to evaluate driving performance; some to test the transferability between virtual and real worlds. One area in PWC simulators that has been particularly well covered is the training aspect and positive transfer from the virtual to the real world (Hasdai et al., 1998; Linden et al., 2013). In general, many studies have collected common objective data logged by the simulator. These data include the number

of collisions, time to perform a task, data on user trajectories, joystick position, and correct perception of distance. Other subjective data were obtained through questionnaires, such as data on the user's sense of presence, behaviour, and perceived force feedback. But most of the current simulators (if not all) are subject to the following characteristics:

- The simulations are too simple and unrealistic (Adelola et al., 2002; Cooper et al., 2005; Desbonnet et al., 1998; Inman et al., 2011; Spaeth et al., 2008). This could potentially affect the training and/or assessment purpose because PWC users would apply what they learn in VR to reality.
- Lack of scientific experimentation, such as Rodriguez (2015). The author only discusses the advantage of using such a system for clinical purposes.
- All studies used (adapted) expensive PWC joysticks or gaming joysticks to run the simulator leaving out questions of the affordability of the real PWC joystick and effects of the gaming joystick.
- Others focused on more costly, complex set-ups such as the use of a physically moving platform (Archambault et al., 2008; Browning et al., 1996; Hafid & Inoue, 2005).
- Only one commercial PC-based system ("WheelSim") is available for users and proves to be unsuitable for training purposes.
- Some measure driving performance by means of objective data. However, the question of simulator fidelity remains.
- Most clinics, if not all, still use traditional assessment and training methods, a costly and time-consuming procedure because of safety and availability concerns.
- No existing simulator is designed to incorporate the clinician into the simulator for assessment purposes.

As with any VR system, building an effective PWC-based simulator requires a deep enough understanding of the research area, tailored VR components (hardware and software), and the technological skills to implement such a system (programming and design). Despite the potential advantages and benefits of PWC simulators, existing simulators fail to offer the usability required for effective assessment and training. For example, users experienced difficulties operating the simulator for reasons attributed to immersion factors, such as field of view (Archambault, Tremblay, Cachecho, Routhier, & Boissy, 2012; Harrison et al., 2002) and display type (Alshaer et al., 2013). In addition, all previous PWC simulators are built from a user's perspective, where, in fact, PWC simulators have the potential to be multi-user virtual worlds, especially in circumstances when clinicians seek to evaluate or train users.

PWC VEs mainly consist of three parts: 1) the interfaces (input and output); 2) the VE itself; and 3) the user (client, clinicians, or both). To close the gap in the availability of a suitable research platform for the class of VR-based PWC applications, three main gaps were identified in respect of these parts: 1) the input devices (Which VR input devices are necessary and appropriate, and which virtual device representations can and should be implemented for PWC simulation?); 2) simulator fidelity (How accurately can PWC users navigate a VE?); and 3) virtual assessment (How accurately can clinicians assess driving tasks in VE compared to the real world?). Each of those is investigated independently in the following chapters (chapters 3–5).

## CHAPTER 3: INTERACTION & VISUALIZATION

**Objective:** The experiment presented in this chapter evaluates the virtual display of a standard gaming joystick and a proprietary power wheelchair joystick, compared against their real-world counterparts; driving performance and experience will be measured.

**Background:** Gaming joysticks are used across various PWC simulators because of their availability and low cost. However, creating a realistic VE requires the consideration of the visualisation of the input device. It is thus important to not only evaluate the different physical input devices but also their virtual representations, and the effect on perception and performance.

**Method:** For this study, 48 participants navigated a simulated PWC environment using two different physical joysticks; a virtual representation of the joysticks was also presented to the participants. Four experimental conditions comprising two visual virtual input modalities (standard gaming joystick vs. proprietary PWC joystick) and the two real counterparts as independent variables have been studied.

**Results:** The results of the study show that the best performance was obtained for two of three performance indicators when a virtual representation of the PWC joystick was displayed, regardless of what type of physical joystick (real PWC or gaming joystick) was used. Despite not being explicitly notified by the experimenter, participants reported noticing the change in the visual representation of the joysticks during the experiment.

**Conclusion:** These results support the theory that VE representations have a significant effect on user experience and/or performance. Therefore, visual properties of input devices need to be carefully selected.

Parts of this chapter have been previously published in the following:

Alshaer, A., O'Hare, D, Hoermann, S., Regenbrecht, H. (2016) The impact of the visual representation of the input device on driving performance in a power wheelchair simulator. Proceedings of the 11th Intl Conf. Disability, Virtual Reality & Associated Technologies Los Angeles, California, USA. 2016

Alshaer, A., Regenbrecht, H., & O'Hare, D. (2015). Investigating visual dominance with a virtual driving task. In 2015 IEEE Virtual Reality (VR) (pp. 145–146). Arles, France. 23-27 March 2015.

### 3.1 Introduction

The study discussed in this chapter is designed to evaluate the effects of the visual representation of the input devices in a virtual power wheelchair simulator. Participants in the experiment used either a standard gaming joystick or a proprietary power wheelchair joystick, and the effects of the different joysticks on driving performance and reported experience were measured. An essential hardware component of PWCs is a finger-operated joystick. Because actual PWC joysticks are proprietary, purpose-built, and expensive, PWC simulators often use commercial gaming joysticks to interact with the simulator (Alshaer et al., 2013; Archambault et al., 2012) or adapted PWC joysticks (Hasdai et al. 1998; Adelola et al., 2002; Harrison et al., 2002).

Two overview papers by Schuler et al. (2014, 2015) show that movement visualisation, feedback and context information can have a significant impact on the user experience, as well as on therapy outcomes for patients. This also applies to VE-based vehicle simulators such as PWC simulators, where accurate physical simulation, realistic 3D modelling of the environment and the PWC, provision and/or simulation of the physical environment, and an appropriate interaction device can affect user experience and the functionality of the system. According to Fehr et al. (2000), approximately 40% of PWC users struggle to use the standard PWC joystick for even simple tasks.

Previous research has evaluated different input devices for different applications, either from the perspective of usability, or in terms of performance. Rupp et al. (2015) report that the incorrect input device “can affect performance, increase cognitive workload and increase errors that may lead to the loss of a vehicle”. However, no previous study of PWC simulation has investigated the impact of using a PWC

joystick compared to a gaming joystick. This also raises the question of the virtual representations of these input devices.

According to Powell and Powell (2014), small changes in the virtual representation of the geometry of objects can have an impact on user experience and can affect the perception of spatial location. This was demonstrated in their study, where participants were asked to reach and grasp three different shapes in a VE (apple, sphere and polyhedron); the time it took them to reach the target was measured. The experimenters found that users performed significantly slower when locating and grasping a sphere compared to a polyhedron of the same size. This would indicate that the design of virtual objects, such as PWC components, could have a considerable effect on user performance, influencing training and assessment outcomes in PWC simulations. Powell and Powell (2014, p. 164) report: “If altering the visual properties of an object can improve the ability to locate the object in virtual space then this may improve task performance and improve the rehabilitation outcomes”.

The goal in this study is to evaluate the effects of the combination of real and virtual proprietary PWC and standard gaming joysticks. This study is designed to answer the question: would one type of joystick be perceived better than the other, therefore leading to better user performance and experience? After consideration of the literature, this is the first study to investigate the visualisation of the input device, in particular when different input devices are used. The impact was assessed in the context of driving performance, where the path, wall collisions, and completion times were recorded as participants drove a simulated PWC. In addition, participants reported on their experience and awareness.

This study is designed to provide information that could help designers and developers create optimised PWC simulations. It also extends the literature on the effects of visual representation in VEs on



user performance. In particular, the results have potential for applied use in training simulators and driving assessments in clinical populations requiring physical PWCs for mobility. The physical joysticks commonly found on PWCs are significantly more expensive than commonly available gaming joysticks. The virtual visualisation of an authentic PWC control joystick overrides the haptic information of a cheaper gaming joystick, leading the participant to feel and act as if they were using the real PWC joystick. This supports the hypothesis that a low-cost joystick could be substituted in training and assessment systems to increase their availability and affordability. The effect of VR input device representation has a significant impact on user experience and/or performance, thus visual properties need to be carefully selected in general. The findings of this thesis raise the question of which VR input devices are necessary and appropriate, and which virtual device representations should be implemented in PWC simulators.

It was hypothesized: 1) users' driving performance, awareness, and perception will be better with a virtual PWC joystick, regardless of the actual joysticks used; 2) users' driving performance, awareness, and perception will be better with the actual PWC joystick used, regardless of the virtual joystick presented; and 3) users' driving performance, awareness, and perception will be better with a match between visual and physical joysticks.

## 3.2 System

### 3.2.1 Technical Apparatus

Two aspects of the virtual reality (VR) simulation were considered: (1) the actual joystick, operated physically by the user; and (2) the virtual representation of the joystick, within the virtual environment. Two popular joysticks were selected to be evaluated: a standard off-the-

shelf gaming joystick (Logitech Attack 3), which is affordable and readily available in the gaming accessories market; and an expensive, purpose-built PWC joystick (Q-Logic control), which is used on many PWCs and only works with PWCs (Figure 13).



Figure 13: (Left picture) virtual PWC. (Right picture) real PWC and gaming joysticks (top), virtual PWC and gaming joysticks (bottom).

Because of the specialist design of the PWC joystick, it was modified for use with USB input functionality. To achieve this modification, an Arduino-based LeoStick<sup>1</sup> board was electronically connected, programmed, and calibrated to read the PWC joystick outputs (Figure 14). These outputs were then mapped to function in the virtual environment. Hence, both the PWC and the gaming joystick worked the same for the user. The two joysticks were placed on a wooden frame so that the participant's hand position resembled that of a PWC user (Figure 14). The particular way in which the virtual joystick was presented offers a convenient view of the input state near the centre of the display. Both joysticks were connected to a laptop via USB. A 17"

<sup>1</sup> [www.freetronics.com/products/leostick](http://www.freetronics.com/products/leostick)

Alienware high-end graphics laptop was used to run the simulator with a resolution of  $1,920 \times 1,080$  pixels at 120Hz.



Figure 14: On the left, experiment setup: Alienware laptop and joysticks. On the right, Arduino board connected to the PWC joystick

### 3.2.2 Environment and driving task

Google SketchUp was used to design the 3D models, including the indoor environment (house), the virtual mid-wheel PWC, the virtual gaming and PWC joysticks, and the ideal path to be followed by participants. A domestic environment (Figure 15) was used for the simulation. The environment was built to meet the Americans with Disabilities Act standards for accessible design (ADA) (Americans with Disabilities Act of 1990, as amended, n.d.). The standard width for internal doors accessed from corridors was 1.2 metres (equal to 1.2 unit in Unity 3D) and the corridor's minimum width was 1.5 metres (equal to 1.5 units in Unity 3D) to facilitate 360° turning (Desmyter, Garvin, Lefèbvre, Stirano, & Vaturi, 2010).

The user's task was to drive as quickly and accurately as possible through this indoor environment by following an ideal path (driving between two black lines). The path was devised to contain most of the movements a PWC user would make in a domestic environment (Figure 15). These movements were inspired by the Wheelchair Skills

Test (WST), discussed in the literature review. Yellow arrows were placed on the path pointing in the direction of movement. This task of 'path following' was used in a previous study (Alshaer et al., 2013) and yielded a sufficiently variable performance. Unity3D was used as the graphic engine platform for the simulation, which also provided physical simulation capabilities.

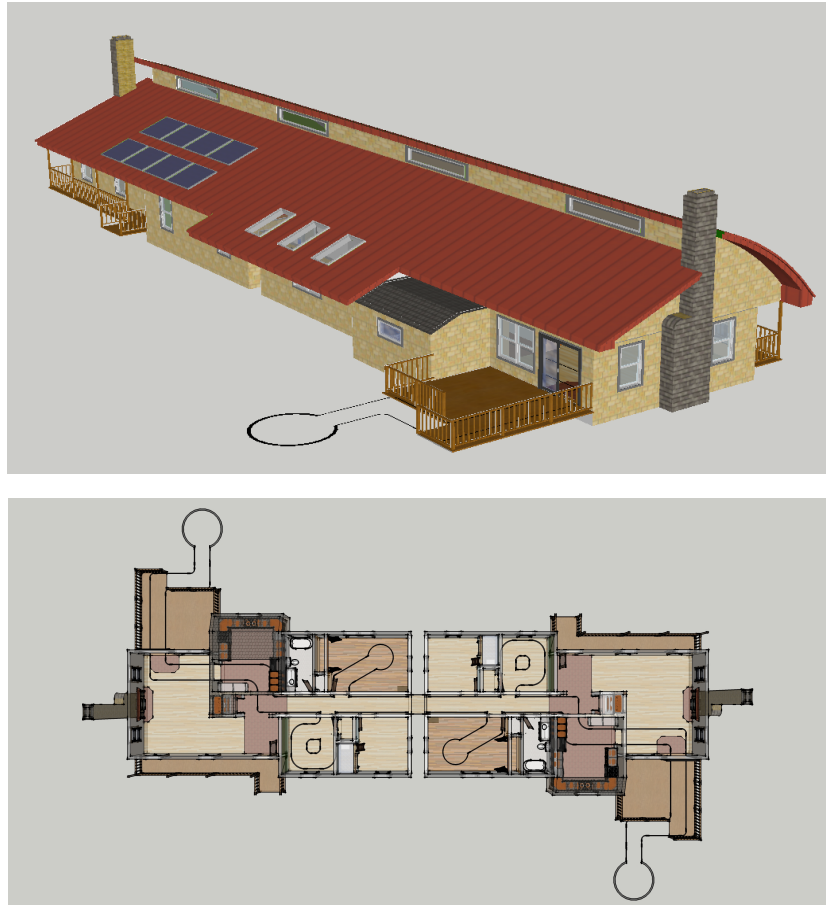


Figure 15: (On the top) outside view of the house environment used in the simulator (on the bottom) inside view of the house and the path

### 3.2.3 Collision detection

To record the number of collisions, either with objects or path, collision detection is implemented in the simulator. This feature also keeps track of time. To achieve this in Unity3D, a 'collider' component must be attached to the game object (in this case, the virtual PWC).

Colliders are invisible and come in various shapes and sizes. In the event of collisions, script or other events can be triggered, such as counting the number of collisions, preventing the virtual PWC from going through walls, and recording time. A script was written to control these colliders. Unity3D can apply a reaction force to the collider, which adds to the realism of the simulator.

### 3.3 Method

#### 3.3.1 Participants

The study sample was recruited from people who attended the science festival at the University of Otago, Dunedin, New Zealand. A statistical power analysis was performed to estimate the required sample size before running the experiment. The effect size (0.27) was estimated from a similar, previous experiment (Alshaer et al., 2013), where the same measure (driving performance) was used to calculate the required sample size using G\*power (<http://www.gpower.hhu.de/en.html>). The required sample size to detect differences at the level of  $p < .05$  was calculated to be 40. Forty-eight participants (31 males, 17 females) were recruited. The data from two participants were not analysed because they were the only left-handed users. The age range of the 48 participants was 18 to 73 years old, with a mean age of 34 (SD=11.97). Participants were also asked about their joystick experience before the experiment to determine how much information and training they needed to receive. None of the participants were actual PWC users. Ethical approval was obtained from the University of Otago Information Science Department. Figure 16 shows a participant completing the experiment.



Figure 16: A participant completing the experiment

### 3.3.2 Measures

#### 3.3.2.1 Driving performance

For user performance, the following objective metrics were measured per condition: completion time, path boundary violations (when any of the PWC's wheels went beyond one of the black lines), and wall collisions. The overall performance score was calculated from the number of path boundary violations (`pathViolations`), the number of wall collisions (`wallCollisions`) and the total time in seconds (`totalTime`) required for the completion of the driving route using Eq. (1). The scoring system was used in Alshaer et al. (2013), which was also inspired by Abellard et al. (2010), Hasdai et al. (1998), and WheelSim (2007).

$$\text{Score} = 1000 - (\text{pathViolations} + 2 \times \text{wallCollisions} + \text{totalTime}) \quad (1)$$

### 3.3.2.2 User experience and awareness

To measure user experience and awareness, four questions were developed, consisting of seven-point Likert scale items, where ‘-3’ means ‘strongly disagree’ and ‘3’ means ‘strongly agree’. These questions were to obtain information about the participants’ experience, therefore they were presented after completion of all conditions. The four questions were as follows: 1) Overall, I felt as though I was operating the virtual joystick presented on the screen; 2) Overall, I felt as though I was operating the physical joystick in my hand; 3) Overall, I was aware of the switching between the virtual joysticks; and 4) Overall, I was aware of the differences between the joystick on the screen and the one in my hand.

### 3.3.3 Experimental Design

The design for this experiment is a 2 (physical joystick: PWC vs. Gaming) x 2 (virtual joystick: PWC vs. Gaming) within-subjects factorial design: the physical joystick handled by the participant (Attack 3 Gaming or Q-Logic Control PWC) and the virtual joystick represented on the screen (Attack 3 Gaming or Q-Logic Control PWC). This yielded four conditions as shown in Table 1. “G” stands for Gaming joystick, “P” stands for PWC joystick, and “v” stands for virtual.

Table 1: 2 x 2 factorial design.

|                   |                | Physical Joysticks |      |
|-------------------|----------------|--------------------|------|
|                   |                | Gaming             | PWC  |
| Virtual Joysticks | Virtual Gaming | G-vG               | P-vG |
|                   | Virtual PWC    | G-vP               | P-vP |

### 3.3.4 Counterbalancing

Because of a potential learning effect associated with repeating the task four times, control for ordering effects was taken. First, subjects were randomised in counterbalanced order. Second, although subjects repeated the tasks four times, they were generally unaware of the repetition. The participants followed one layout on a return path, which created a balanced set of comparable paths that the user could traverse without interruption (Figure 17). The users could not predict what would come next (e.g., it was hard for them to know which direction to travel next as the right turn became left when driving in the reverse direction). In addition to this, the condition order set was generated using Latin Square Generator<sup>2</sup>.

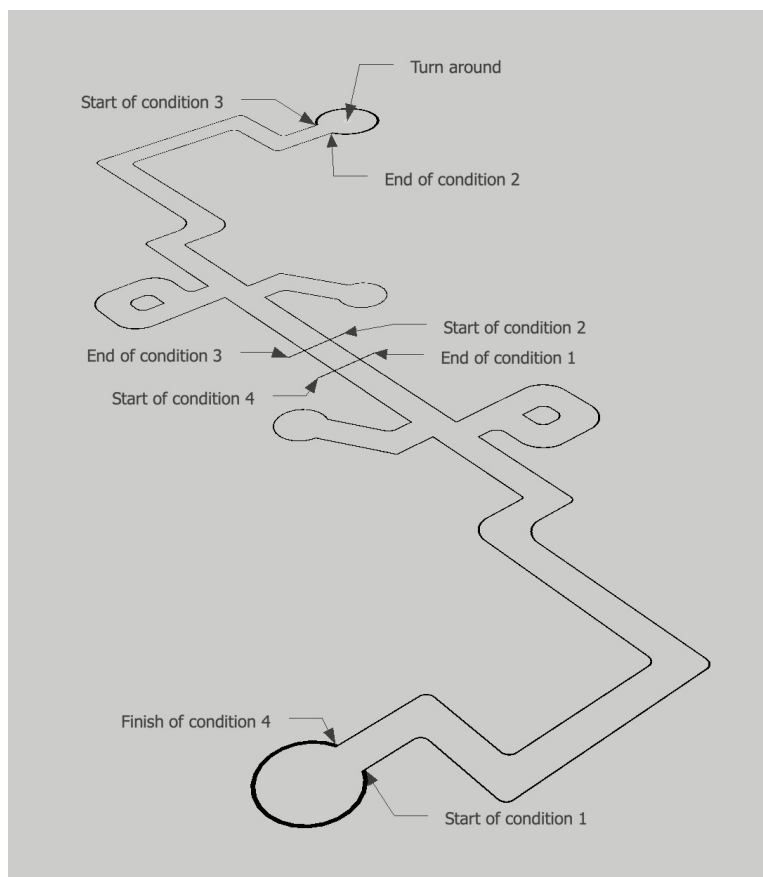


Figure 17: Ideal path through the environment

<sup>2</sup> <http://hamsterandwheel.com/grids/index2d.php>



### 3.3.5 Participant's Task

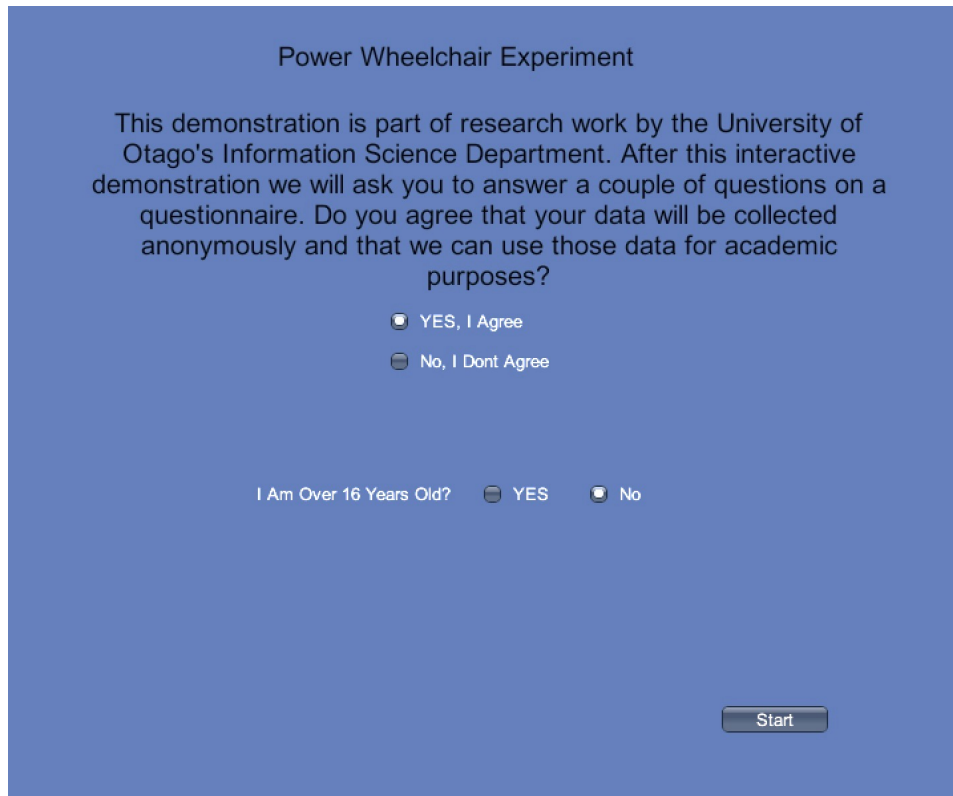
The participant's task was to drive as fast and as accurately as possible by following an ideal path represented with black lines on the ground. In addition, participants were encouraged to avoid collisions with the path boundaries and walls. This task included turning left and right, and going through doorframes. Directions were given by means of yellow arrows on the floor. The path had beginning and end points representing each condition. Stop signs were placed at each of the end points to allow for the physical joysticks to be switched. Virtual joysticks were automatically switched depending on the condition order set.

### 3.3.6 Procedure

The experiment took place during a local science exhibition where participants, including schools and university students, university staff, and the general public, came to participate in a wide range of scientific activities at the University of Otago. All visitors were free to take part in any of the available activities. Upon arrival, participants were welcomed and consent was obtained electronically by clicking 'YES' if they wanted to be part of the experiment (Figure 18). Participants were verbally informed about the type of virtual PWC (mid-wheel) and how it moved. They also received verbal instructions on how to use the joystick and were given the opportunity to practise before starting the task. Information about the PWC, joystick, and task were supported with visual aids (See Appendix A).

Once participants were ready to start, they were reminded of the task (driving as fast and as accurately as possible). They were also told that they would be using two different joysticks and would see virtual counterpart representations in the VE. They were told to follow the ideal path, and stop when encountering a stop sign. When a stop sign appeared on the screen, participants were asked to switch between

the physical joysticks. At the end, participants were asked to fill in a demographic questionnaire and “overall” perception/awareness questionnaire (four questions). All experiment documents including questionnaires can be seen in Appendix A.



The screenshot shows a blue background with white text. At the top, it says "Power Wheelchair Experiment". Below that, it reads: "This demonstration is part of research work by the University of Otago's Information Science Department. After this interactive demonstration we will ask you to answer a couple of questions on a questionnaire. Do you agree that your data will be collected anonymously and that we can use those data for academic purposes?". There are two radio button options: "YES, I Agree" (which is selected) and "No, I Dont Agree". Below this, there is a question "I Am Over 16 Years Old?" with two radio button options: "YES" (which is unselected) and "No" (which is selected). At the bottom right, there is a "Start" button.

Figure 18: Screenshot of the electronic consent

## 3.4 Results

### 3.4.1 Path Boundary Violations

The means of path boundary violations (driving beyond the black lines) together with standard deviations are reported in Table 2. A two-way, repeated-measures ANOVA was performed. The results showed that neither physical joysticks nor the interaction between physical and virtual joysticks had a significant main effect, but that virtual joysticks had a significant effect where participants had fewer path collisions when the virtual PWC joystick was represented ( $F(1, 47)=4.513$ ,  $p < 0.039$ ,  $\omega^2=0.088$ ).

Table 2: Means and standard deviations for path boundary violations

|                  |        | Physical Joystick |                |       |
|------------------|--------|-------------------|----------------|-------|
|                  |        | Gaming            | PWC            |       |
| Virtual Joystick | Gaming | 13.27<br>(9.75)   | 10.48<br>(.73) | 11.88 |
|                  | PWC    | 10.71<br>(7.81)   | 9.42<br>(8.43) | 10.06 |
|                  |        | 11.99             | 9.94           |       |

### 3.4.2 Wall Collisions

The means of wall collisions together with standard deviations are reported in Table 3. A two-way, repeated-measures ANOVA was performed. The results indicated that the virtual joystick had a significant effect ( $F(1, 47)=7.009$ ,  $p<0.011$ ,  $\omega^2=0.130$ ) with participants performing better when the PWC virtual joystick was represented. Neither the physical joystick nor the interaction between the physical and virtual joystick had significant effects on the number of wall collisions.

Table 3: Means and standard deviations for wall collisions

|                  |        | Physical Joystick |                |      |
|------------------|--------|-------------------|----------------|------|
|                  |        | Gaming            | PWC            |      |
| Virtual Joystick | Gaming | 2.50<br>(2.24)    | 1.81<br>(2.09) | 2.15 |
|                  | PWC    | 1.65<br>(2.22)    | 1.65<br>(2.19) | 1.65 |
|                  |        | 2.08              | 1.73           |      |

### 3.4.3 Completion Time

The means of completion time together with standard deviations are reported in Table 4. The time spent to complete the task was similar between each condition. Two-way, repeated-measures ANOVA was performed, but neither of the independent variables nor the interaction between them had significant effects on the participants' completion time.

Table 4: Means and standard deviations for completion time

|                  |        | Physical Joystick |                  |       |
|------------------|--------|-------------------|------------------|-------|
|                  |        | Gaming            | PWC              |       |
| Virtual Joystick | Gaming | 57.35<br>(12.95)  | 58.42<br>(12.49) | 57.89 |
|                  | PWC    | 56.75<br>(14.18)  | 58.94<br>(14.32) | 57.84 |
|                  |        | 57.05             | 58.68            |       |

### 3.4.4 Overall Driving Performance

The means of overall driving performance, together with standard deviations are reported in Table 5. The overall performance score was calculated with Equation 1 where a higher score indicated a better performance. A two-way, repeated-measures ANOVA was performed, but neither of the independent variables nor the interaction between them had significant effects on the participants' overall driving performance score.

Table 5: Means and standard deviations for overall driving performance

|                  |        | Physical Joystick |                   |        |
|------------------|--------|-------------------|-------------------|--------|
|                  |        | Gaming            | PWC               |        |
| Virtual Joystick | Gaming | 924.37<br>(19.68) | 927.46<br>(18.75) | 925.92 |
|                  | PWC    | 929.24<br>(17.15) | 928<br>(19.65)    | 928.62 |
|                  |        | 926.81            | 927.73            |        |

### 3.4.5 Experience and awareness

For the questions concerning experience and awareness (Figure 19), a Wilcoxon Signed-Rank rank test was performed against the midpoint (0) to see if the participants agreed or disagreed with the statements. Although participant answers to question 1 (“Overall, I felt as though I was operating the virtual joystick presented on the screen”) were slightly above the midpoint ( $M=0.1$ ,  $SD=1.88$ ), the one-sample Wilcoxon test did not show a significant difference. On the other hand, the test showed a significant difference on question 2 (“Overall, I felt as though I was operating the physical joystick in my hand”):  $p<0.001$ , with ( $M=2.15$ ,  $SD=1.11$ ).

A Wilcoxon Signed-Rank test was performed to compare responses on the two questions. The analysis showed a significant main difference in favour of the physical joystick. Responses to both questions (Q3: “Overall, I was aware of the switching between the virtual joysticks” and Q4: “Overall, I was aware of the differences between the joystick on the screen and the one in my hand”) were above midpoint ( $M=1.04$ ,  $SD=2.0$ , and  $M=0.85$ ,  $SD=1.86$  respectively). Both questions showed significant effects  $p=0.002$  for Q3,  $p=0.003$  for Q4. A Wilcoxon Signed-Rank test was performed to compare responses on the two questions. There was no main difference between the two questions.

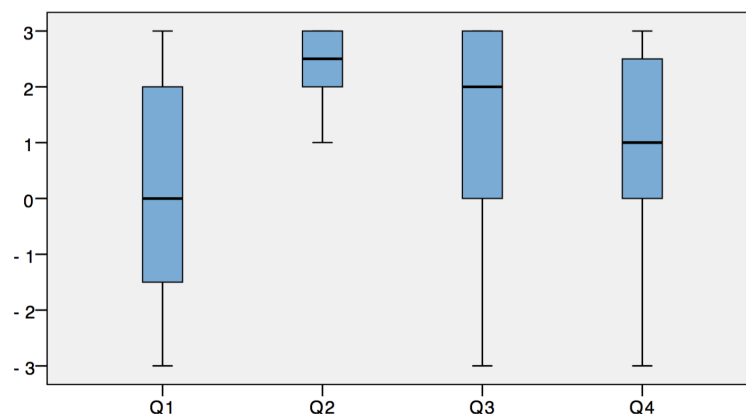


Figure 19: Participants' answers to experience and awareness questions. Box plot represents the median, interquartile (blue box), minimum, and maximum.

### 3.5 Discussion

The results of the study suggest that users of the simulator paid attention to the visual representation of the joystick and used it to guide their control of the PWC. An explanation for this could be that the differences in the driving performance between the two virtual representations of the joystick is due to the degree of which participants deduced steering information from the position of the virtual joystick's handle. While the PWC joystick is equipped with a straight handle, the gaming joystick has a curved handle pointing forward on the top (Figure 13). This property of the gaming joystick could make it more difficult for participants to notice visual differences between small forward or backward positions of the handle, therefore impeding the inclusion of this information in steering decisions. On the other hand, the properly aligned virtual joystick could help to enhance the participants' sense of alignment of the physical joystick. This might have led to better performance, in particular with novice participants. Another explanation could be that the virtual gaming joystick was an out-of-place distraction because of its size in the VE compared to the smaller virtual PWC joystick. Paying attention to the virtual gaming joystick could have degraded performance in a way that the PWC joystick did not.

The so-called visual dominance theory (Posner, Nissen, & Klein, 1976) could also explain aspects of these findings. In situations where some discrepancy exists between visual information and other sensory information, the visual information tends to dominate responses (Rock, 1966; Rock & Victory, 1964). In similar situations in the related literature, visual information has been found to dominate touch and kinaesthesia (Srinivasan, Beauregard, & Brock, 1996), as well as haptic feedback (Lecuyer, Coquillart, Kheddar, Richard, & Coiffet, 2000). In many experimental situations, psychophysical research has shown evidence that vision is so powerful that it tends to

override other sensory information. For example, a study by Srinivasan et al. (1996) performed a series of psychophysical experiments investigating the impact of visual appearance on human perception of the discrimination stiffness of virtual springs in a virtual environment. While subjects pressed the springs, they also visually observed the displacement of the springs on a computer monitor. The results clearly showed that vision was dominant over the kinaesthetic sense.

The findings here suggest that visual properties of input devices represented in the VE need to be carefully selected and chosen specifically for applications where the transfer effects to real-world scenarios are sought and ecologically valid simulation is desired. It also provides guidance on which VR input devices are necessary and appropriate and which virtual device representations can and should be implemented for PWC simulators. This study also lays the foundations for a more comprehensive PWC simulation system, including aspects of the use of simulator data to assess individual driving performance, and correct physical simulation of PWCs. It also advises that consideration of the appropriate dimensions of the indoor environment to meet the standards for accessible design. This study and system provides an interesting testbed for future investigations.

### 3.6 Conclusion

In this study, the effects of visual representation of input devices, together with their real-world counterparts, in a virtual PWC simulator were evaluated. This study compared the virtual display of a standard gaming joystick to a proprietary PWC joystick, while participants used either of the real-world counterparts. The effects of the different joysticks on driving performance and reported experience were measured.

The results show that for two of three performance metrics, driving performance was significantly affected by the form of the virtual joysticks, but not by the type of physical joystick used. This indicates that performance can be influenced by changing visual properties such as the type of input device visualised. It also indicates that an inexpensive gaming joystick is adequate for using in a virtual PWC simulator. These findings offer guidance on which VR input devices are necessary and appropriate and which virtual device representations can and should be implemented for PWC simulators. There are other factors besides the input device that could influence user perception and behaviour, and, therefore, performance. Chapter 4 explores the effect of other factors on user perception and behaviour, such as display type, FOV, and avatar presence.



## CHAPTER 4: PERCEPTION & BEHAVIOUR

**Objective:** The effect of three immersion factors on user perception, behaviour, and sense of presence while driving a simulated PWC were examined. The three immersion factors were display type (HMD vs. monitor), FOV (changeable vs. static), and avatar presence (present vs. absent).

**Background:** VE-based driving simulators are increasingly used to train and assess user's abilities to operate vehicles in a controlled and safe way. For the development of these simulators, including PWC simulators, it is important to identify and evaluate design factors affecting perception and behaviour.

**Method:** In this study, 72 participants drove a simulated PWC in eight different conditions: 2 (display type) x 2 (FOV) x 2 (avatar presence). User perception (explicit judgement of doorframe passability) and embedded behaviour (implicit measure of gap passability) were mainly based on the user's decision-making, which took place in the presence of uncertainty. This was assessed in signal detection terms.

**Results:** The result showed that all three factors affected the user's sense of presence in the virtual environment. In particular, the display type significantly affected both perceptual and behavioural measures, whereas FOV only affected behavioural measures.

**Conclusion:** This experiment explored how accurately users were able to behave and perceive action possibilities in the VE; this is a prerequisite of transferable training and assessment. The results provide potential design guidelines for future VE application, in particular, PWC simulator design.

Parts of this chapter have been previously published in the following:

Alshaer, A., Regenbrecht, H., & O'Hare, D. (2017). Immersion factors affecting perception and behaviour in a virtual reality power wheelchair simulator. *Applied Ergonomics*, 58, 1–12.

## 4.1 Introduction

This chapter identifies and evaluates the immersion factors that affect user perception, behaviour, and driving performance while operating a virtual PWC. Affordance theory is used to measure perception and behaviour, and is assessed in signal detection terms. The initial interviews with professional experts (four occupational therapists) and consultation of the appropriate literature led to the identification of these immersion factors (Alshaer et al., 2013; C. Harrison et al., 2000; Kjeldskov, 2001; Pithon et al., 2009). The ability of users to accurately drive depends on how they perceive the scale of the VE, which is a prerequisite for the validity of the simulator to be used as a training and/or assessment tool. Immersion has been reported to improve depth perception and thus facilitates the user's judgement of distance (Heineken & Schulte, 2000). Driving performance in the PWC simulator, as in the Massengale, Folden, McConnell, Stratton, and Whitehead (2005) report, is directly associated with visual perception.

Another aspect that could affect perception and behaviour in VEs is the presentation of a self-avatar (a visual representation of the user's own body or body parts). Avatar presentation has been shown to not only increase the sense of presence but also to improve judgement of size and distance (Schultze, 2010). There is evidence that a self-avatar could serve as a familiar size cue that provides scaling information and also act as a frame of reference in the VE (Dodds, Mohler, Rosa, Streuber, & Bulthoff, 2011; Lim & Reeves, 2009; Ries, Interrante, Kaeding, & Anderson, 2008). Sun et al. (2015) add that the presence aspect of the user's body can lead to a significant impact on performance. In a PWC simulator, the visualisation of the virtual PWC itself would provide scaling information about the dimensions of the virtual space and act as a usable frame of reference for spatial judgements. This chapter explores the question: Would the self-avatar provide additional cues and serve as a dual reference?

Previous studies have shown that misperceptions of a simulation space can result in erroneous judgements that alter the user's behaviour (Mohler, Creem-Regehr, Thompson, & Bühlhoff, 2010; Henry & Furness, 1993). Therefore, it is important to not only measure user perception but also to differentiate behaviour. With that said, how to best measure the accuracy of space perception in VEs remains a difficult question (Geuss, Stefanucci, Creem-Regehr, & Thompson, 2010). Previous studies have used verbal estimation, or perceptually-direct and imagined action, to estimate perceived distance in a VE (Rébillat, Boutillon, Corteel, & Katz, 2012). In verbal estimation, perceived distance is assessed through familiar units, such as metres. In perceptually-direct action, subjects would perform an action, such as blind walking or an imagined action which only provides indirect measures (Rébillat et al., 2012; Geuss et al., 2010).

In 1979, Gibson (2014) introduced the concept of 'affordance' which emphasises the relationship between objects and their observers. For instance, a gap can 'afford' passage if it is wide enough for the user. Studies since then have demonstrated the practicality and usefulness of using affordance theory to measure user perception in VEs (Mark, 1987; Warren & Whang, 1987). According to Geuss et al. (2010), "affordance judgements may be especially useful as a perceptual measure of size in graphic displays because they require the user to see the space in terms of their own ability to act and therefore may be considered more task-relevant".

Geuss et al. (2010) made use of perceived affordance as a means of measuring the perceptual fidelity of VEs. In their experiment, the spatial structure of the real and virtual environments was varied, and the user verbally indicated whether they believed that an action could or could not be performed. The study used two vertical poles that formed a gap (Figure 20) and compared three methods to evaluate perceived distance: verbal size estimate, blind walking, and affordance judgement. The results showed that affordance judgement had an

advantage over the other measures. Perceiving distance and behaving accurately in VEs is a prerequisite for its validity as a training and/or assessment tool (Heineken & Schulte, 2000). In this study, the affordance of ‘passability’ through wall openings and gaps to measure perceived spatial size and distance was used.



Figure 20: Left, real world and right virtual environment, (Geuss et al., 2010)

The present study explored the following questions: How accurately can PWC users make the right decisions when navigating a virtual environment? How do they perceive a particular gap as passable? How do different immersion factors (display type, FOV, and self-avatar presence) influence their behaviour, perception and sense of presence? This study used a methodology that involved both self-report indication from participants (whether a particular action can or cannot be performed) and behavioural decision-making (whether the participant actually passed through, or went around, a particular gap). Behaviour was measured through embedded actions (implicit performance) and perception was measured through self-report of the perceived size/distance in the VE (explicit judgement).

The manipulated factors were self-avatar presence vs. absence; a static FOV vs. a changeable FOV; and monitor display vs. head-mounted display (HMD). It was hypothesised: 1) Users’ implicit performance, explicit judgements, and sense of presence, would be better with the more immersive HMD, regardless of changes to FOV or avatar presence; 2) Users’ implicit performance, explicit judgements, and sense of presence would be better with the changeable FOV

regardless of display type or avatar presence; 3) Users' implicit performance, explicit judgements, and sense of presence would be better with the presence of a self-avatar regardless of the display type; and 4) Users' implicit performance, explicit judgements, and sense of presence would be better with the changeable FOV, HMD display, and self-avatar.

## 4.2 System

### 4.2.1 Technical Apparatus

The hardware apparatus used in this experiment involved a monitor, head-mounted display (Oculus Rift DK2), a laptop, and a joystick. The monitor size was 21.50" with a resolution of 1920x1080 pixels. The resolution of the HMD was 960x1080 pixels, spread over two eye point displays with a 100° field of view horizontally and vertically. The Oculus Rift supported head position and orientation tracking. Head movements were tracked by a three-axis orientation sensing system integrated into the Oculus headset and were used to continuously update the simulated viewpoint. A real-time positional tracker attached to the top of the monitor was used to track the user's position. The system latency (delay between participant movement and updates in the HMD) was less than 20 milliseconds.

For both monitor and HMD, the aspect ratio was 19:6. A gaming joystick (Logitech Attack3) was used to drive the virtual PWC and to control the FOV in the monitor condition, using the hat switch at the top of the joystick. A 17" Alienware high-end graphics laptop was used to run the simulator in both monitor and HMD conditions. The Unity3D game engine was used to assimilate tracking and rendering. Two versions of the simulator were built with Unity3D: one for the monitor display, and the other for the Oculus Rift, because of the specific configuration required by the Oculus. A virtual hand and a

virtual joystick were animated in the environment to represent the user's hand movements. Figure 21 shows all the hardware components used in the experiment.



Figure 21: Experiment components, including monitor, joystick, HMD, laptop, and HMD tracker placed at the top of the screen

### 4.2.2 Environment and driving tasks

All 3D models were built using Google SketchUp. The virtual PWC, including the virtual joystick, was modelled on real PWC dimensions with an average width of 68cm. The VE used in this experiment was a high-fidelity 3D model of an abstracted (low distraction) hallway. The hallway consisted of walls, doorframes, and sets of two poles designed to represent gaps of varying widths throughout the hallway (Figure 22). To avoid the user from getting distracted, and to remove cues to size and distance provided by familiar objects, neither furnishings nor decorations were added.

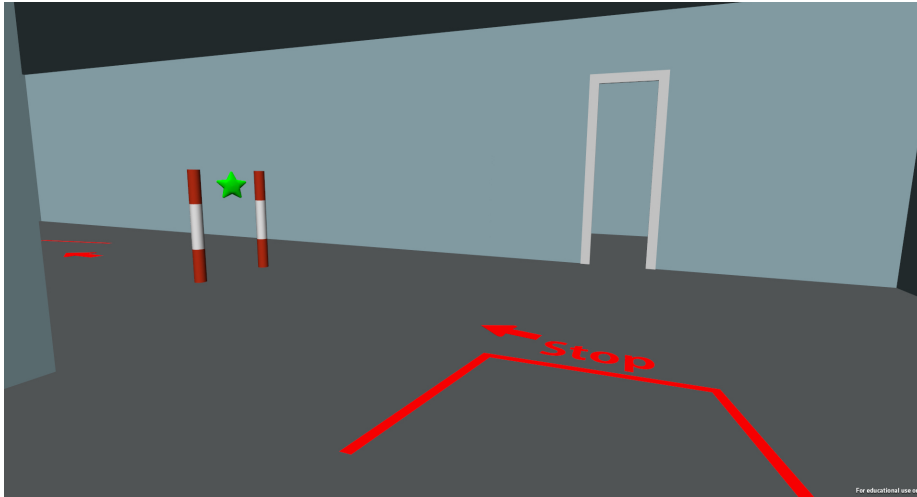


Figure 22: The indoor VE consisting of stop sign, walls, doorframe, and set of two poles.

The hallway was wide enough throughout so that users could freely and easily navigate the environment (Figure 23). The virtual self-avatar was produced by MakeHuman, a 3D character-building application. Animation was applied to the avatar's hand that was holding the joystick. Avatar animation has been proven to improve distance judgement (Mohler et al., 2010).



Figure 23: PWC simulator (hallway)

The hallway consisted of four doorframes of different widths, distributed throughout the space. Similarly, there were four gaps of different widths between two poles (Figure 23) spread along the



hallway. The doorframe and gap widths were differentiated based on the minimum clear gap width that the PWC could pass through, which is 76cm (Design for Access and Mobility – Buildings and Associated Facilities, 2001). Two doorframes/gaps were passable (easy to pass=76cm; hard to pass=72cm) and two were not passable (hard to judge=64cm; easy to judge=60cm). Figure 24 shows the widths of all four gaps/doorframes and how they were associated with the PWC width.

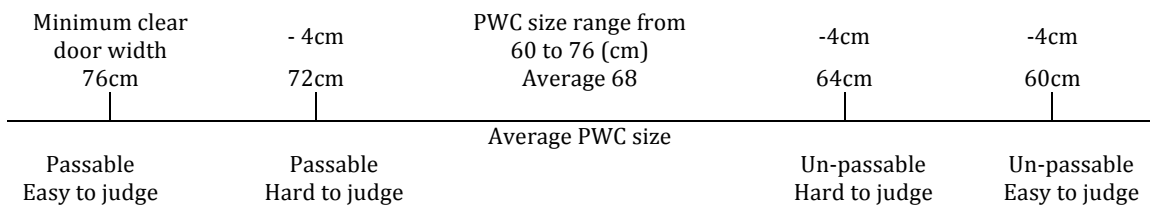


Figure 24: Doorframes/gaps width differences

### 4.2.3 Data recording

Simulator data were logged in a txt file on their occurrence. The data recorded included the participant’s number, condition name, condition order, attempted gap width, number of correct attempts (hits), number of incorrect attempts (false alarms), number of collisions with the poles, and time spent to complete the task. Example of the recorded data is shown in Figure 25.

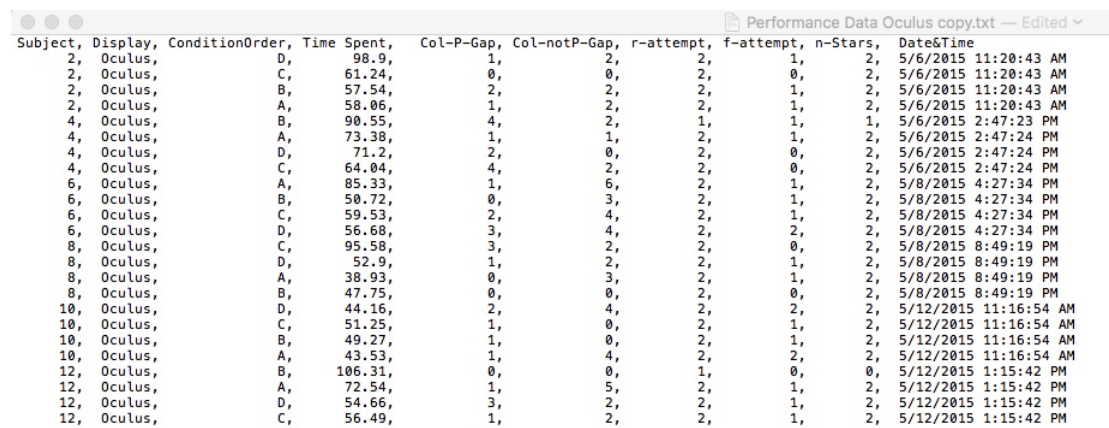


Figure 25: Simulator outputs

## 4.3 Method

### 4.3.1 Participants

A pilot study with five participants was conducted to provide a formative evaluation of the procedures and instruments. This was followed by the actual experiment. A statistical power analysis was performed to estimate the required sample size before running the experiment. A medium effect size (0.25) was estimated to calculate the required sample size using G\*power (<http://www.gpower.hhu.de/en.html>). The required sample size to detect differences at the level of  $p < .05$  was calculated to be 120. However, for practical reasons, only 72 participants could be recruited. There were 46 males and 26 females with a mean age of 21.9 years ( $SD=4.68$ ; age range=18–47), including students from the departments of Psychology and Information Science of the University of Otago. Participants from the department of Psychology were recruited via an online system and students were rewarded with class credits, whereas participants from Information Science were recruited via personal connections and classroom announcements, and they were rewarded with chocolate bars. All participants had normal or corrected-to-normal vision. Institutional ethical approvals were obtained from both departments. Figure 26 shows participants performing the task.

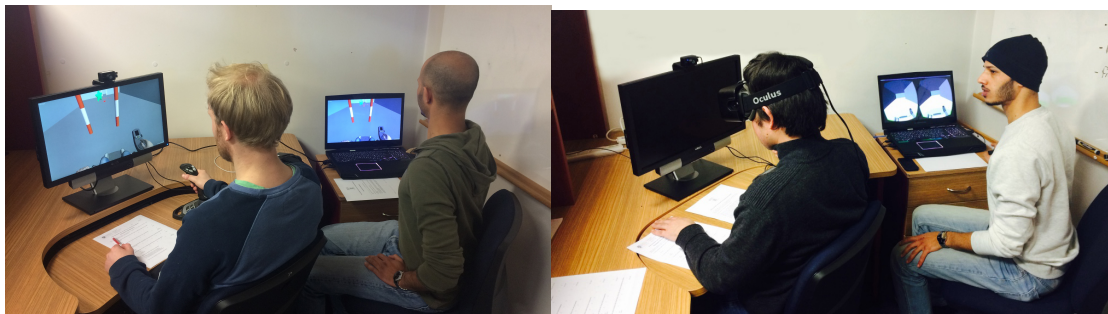


Figure 26: Monitor condition (on the left) and HMD condition (on the right)

## 4.3.2 Measures

### 4.3.2.1 Primary explicit and implicit measures

User perception (explicit judgement of doorframe passability) and embedded behaviour (implicit measure of gap passability) were mainly based on the user’s decision-making, which took place in the presence of uncertainty. This was assessed in signal detection terms. A ‘hit’ occurred when the user explicitly said ‘Yes’ to passable doorframes or attempted passable gaps. False alarms, on the other hand, occurred when participants explicitly said ‘Yes’ to unpassable doorframes or attempted unpassable gaps. Correct Rejections involved judging the unpassable doorframes as too small or not attempting to pass through the gaps that were unpassable. Misses involved incorrectly judging passable doorframes as unpassable, or incorrectly avoiding passable gaps. Table 6 contains all the information about the observer’s performance.

Table 6: Signal detection confusion matrix

|                 |     | Door passability |                   |
|-----------------|-----|------------------|-------------------|
|                 |     | Passable         | Not passable      |
| User’s response | Yes | Hit              | False Alarm       |
|                 | No  | Miss             | Correct rejection |

The number of hits and false alarms alone do not measure the diagnostic accuracy of response (Szalma, Hancock, Warm, Dember, & Parsons, 2006). Optimal performance occurs when a participant

indicates that a signal is present when the signal is actually present, and absent when it is actually absent. Szalma et al. (2006), proposed that overall performance could best be captured by the measures of Positive Predictive Power (PPP) and Negative Predictive Power (NPP). PPP is the proportion of 'Yes' responses that are correct and is computed using the formula  $H/(H+FA)$ , where H is the number of correctly detected signals, and FA the number of false alarms.

A perfectly accurate participant would achieve a PPP score of 1. A score of 0 would indicate no correct detection or a complete inability to correctly discriminate between passable and unpassable gaps. NPP is the proportion of 'No' responses that are correct and computed using the formula  $CR/(CR+M)$ , where CR is the number of correct rejections, and M is the number of missed signals. Similar to PPP, a participant who correctly rejected all non-signals and had no misses would yield a NPP score of 1.

#### 4.3.2.2 Sense of presence and simulator sickness

The sense of presence was measured by a standard questionnaire, the Igroup Presence Questionnaire (IPQ) (Regenbrecht & Schubert, 2002). This study only assessed the general sense of presence and realism facets of the IPQ questionnaire; only related questions were measured. Each question took the form of a seven-point scale after each condition. Simulator sickness questions were part of the sense-of-presence questionnaire. Five questions were adapted, each with a four-point scale from 'none' to 'severe'. This allowed for the measurement of the respondent's physical well-being after each condition in group B (HMD group).

#### 4.3.2.3 Post-driving questionnaire

This was designed to obtain subjective ratings of the simulator features (FOV and self-avatar). Participants were asked to rate the ease and comfort of each feature on a seven-point Likert-scale. For

example, “Do you think the self-avatar/controllability of the FOV made it easier to judge door/gaps in the virtual environment” (1=Harder, 7=Easier); “When the self-avatar/ field-of-view static was not there, did you feel more or less comfortable” (1=Less comfortable, 7=More comfortable). The last question of the post-driving questionnaire required participants to indicate which condition they preferred. Participants had to choose one of the four conditions generated by the combination of FOV levels and self-avatar levels.

### 4.3.3 Experimental Design

The design of this experiment was 2 (display type) x 2 (FOV) x 2 (avatar presence) mixed factorial, in which display type was a between-subjects variable, and FOV and self-avatar presence were within-subjects variables. This design yielded eight treatment conditions for both groups. In the within-subject variables, each variable consisted of low-level immersion (represented by X) and high-level immersion (represented by the first letter of each those levels); FOV – either static FOV (X) or changeable FOV, being able to look around (C); Self-avatar – either absent (X) or present (A).

Table 7 depicts the mixed-subject factorial design. Measured variables included implicit performance, explicit judgements, sense of presence, opinions, and preference for the conditions.

Table 7: Mixed-subjects factorial design

|     |          | Group A<br>Monitor |          | Group B<br>HMD |          |
|-----|----------|--------------------|----------|----------------|----------|
|     |          | Self-avatar        |          | Self-avatar    |          |
|     |          | No<br>X            | Yes<br>A | No<br>X        | Yes<br>A |
| FOV | No<br>X  | X-X                | X-A      | X-X            | X-A      |
|     | Yes<br>C | C-X                | C-A      | C-X            | C-A      |
|     |          | Subjects 1-36      |          | Subjects 37-72 |          |

### 4.3.4 Counterbalancing

The mixed design was chosen to reduce the learning effect that would result from repeating the task eight times. To further control for any possible learning effects, 1) subjects were randomised in counterbalanced order, and 2) the combinations of the doorframes and gaps widths were also randomised across all four conditions in counterbalanced order. Although participants repeated the tasks four times, they were generally unaware of the repetition. The participants followed one layout, which created a balanced set of comparable paths that the user could traverse without interruption (Figure 27). The absence of textures, decorations and indoor furnishings made it difficult for participants to predict what was coming next (e.g., it was hard for them to know which direction to travel next as the right turn became left when driving in the reverse direction). Moreover, the randomisation of the gaps and doorframes across all conditions made it hard for participants to memorise which doorframes and/or gaps were passable and which were not.

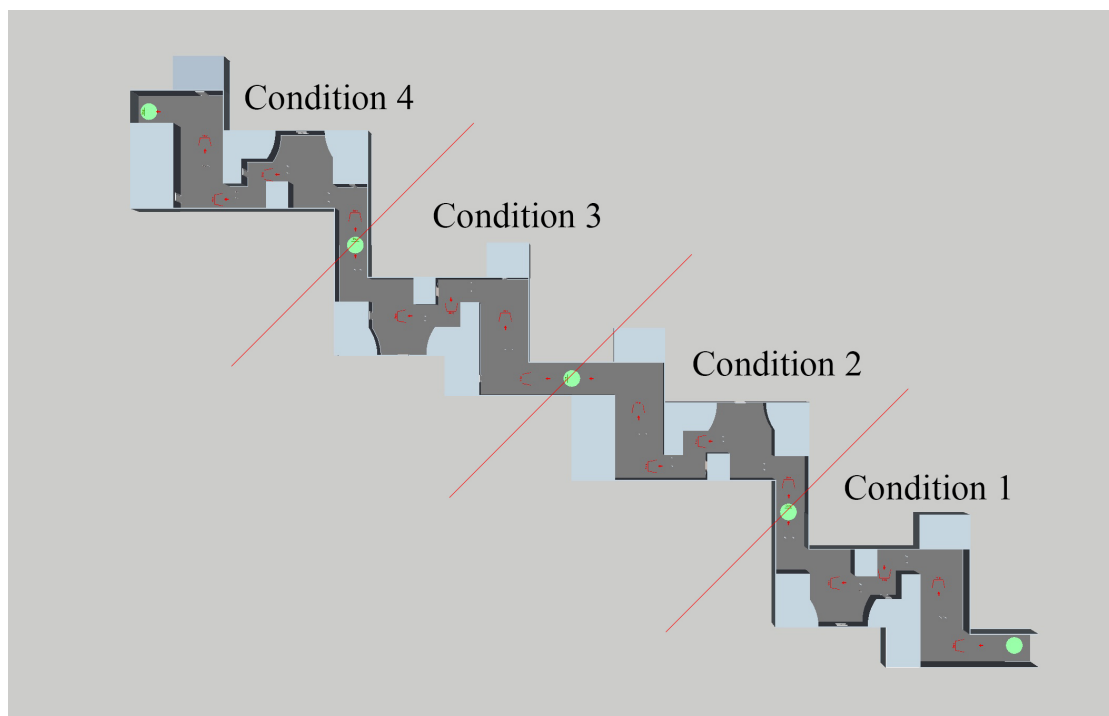


Figure 27: Balanced set of comparable paths

### 4.3.5 Participant's Task

Participants were tasked with following directions (red arrows on the floor), stopping at stop signs (where they had to judge the passability of doorframes), avoiding collisions with poles, and collecting stars (placed in the middle of each set of poles). The stars were used as an incentive to encourage participants to attempt to pass through any of the gaps they judged to be passable. To preserve as much realism as possible, participants were not specifically told about the passability of the doorframes or gaps. Moreover, the stars pulsed and rotated to prevent them from being used as a frame of reference to judge the gap width. The stars were placed at the virtual PWC user's chest height so that the participant had to drive completely through the gap to collect them. Once collected, the system provided visual and sound effects, signalling success.

### 4.3.6 Procedure

Upon arrival, participants read the information sheet and signed the consent form. This was followed by filling out a demographics questionnaire. Confounding variables such as prior experience with the joystick and/or HMD were controlled (participants were asked questions prior to the experiment about their experience with the joystick and HMD). These questions determined how much information and training was needed before beginning the experiment. Then, a specific version of the simulator (training version for both Monitor and HMD) was used to provide the participants with a basic understanding of how to drive the virtual PWC using the joystick. The training version involved no specific task; neither doorframes nor gaps were displayed (Figure 28).

Participants were given enough time to practise their skills, and a simple set of criteria was observed by the experimenter to make sure each participant was confident in using the joystick and HMD. Those

criteria were 1) Driving forwards/backwards and turning right/left, 2) being able to follow the guiding arrows, 3) experience the orientation and position tracking of the HMD for those in the HMD group, and 4) experience the changeability of the FOV in the Monitor group using the joystick (hat switch).

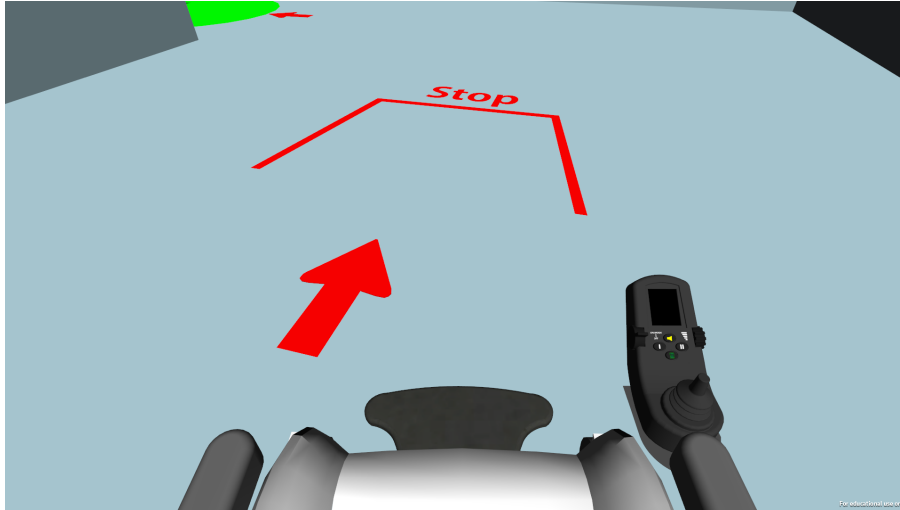


Figure 28: Training version used for demonstration, no gaps or doorframes added

After successful completion of the training session, the participants were given the task description. Meanwhile, the experimenter started the actual experiment version. The order of the conditions was randomised beforehand. During each condition, the system automatically stopped participants at stop signs and corrected their position and orientation so that all participants judged doorframes from an exact distance and orientation. The experimenter then asked participants, “Can you pass through the door in front of you?” and to then record their “Yes” or “No” answer on a sheet of paper. After each condition, participants were given the sense-of-presence questionnaire. After the completion of all four conditions, participants answered the perceived comparison questionnaire. Finally, participants were debriefed and given a chocolate bar. The entire procedure took approximately 20 minutes per participant. All experiment documents including questionnaires can be seen in Appendix B.



## 4.4 Results

This study employed two methods of measuring performance in the VE: (1) implicit performance, where subjects had to judge passability through embedded behaviour; and (2) explicit judgement, obtained through self-report indications. In addition, the study also measured the participants' sense of presence, simulator sickness, opinions, and preferences. The design was 2 (avatar presence) x 2 (FOV) x 2 (display type) mixed factorial; ANOVAs were run and the main interaction effects were examined.

### 4.4.1 Correct detection (Hit)

Implicit performance: The means of correct detection, together with standard deviations, are reported in Table 8. The HMD group showed higher means in all conditions with the C-A condition being the highest ( $M=2$ ). For implicit performance, ANOVA confirmed significant interaction effects between FOV and display-type,  $F(1,70)=4.84$ ,  $p<.031$ ,  $\omega^2=.06$ , and between FOV, self-avatar, and display-type,  $F(1,70)=7.14$ ,  $p<.009$ ,  $\omega^2=.09$  (Figure 29 shows significant interactions graphs). There was no significant interaction between FOV and self-avatar on user behaviour. ANOVA also indicated a significant FOV main effect on user behaviour,  $F(1,70)=13.46$ ,  $p<.001$ ,  $\omega^2=.16$ , and a significant main effect for display type,  $F(1,70)=25.52$ ,  $p<.001$ ,  $\omega^2=.26$ . The presence of the self-avatar was not statistically significant.

Explicit judgements: Means and standard deviations are reported in Table 8. An ANOVA of user judgements indicated that explicit judgements did not significantly differ across any of the three immersion factors. The interaction between these factors also lacked significance.

Table 8: Correct detection means and standard deviations for implicit and explicit measures

|                         |            | Monitor         |                 |               | HMD            |                 |               |             |
|-------------------------|------------|-----------------|-----------------|---------------|----------------|-----------------|---------------|-------------|
|                         |            | Self-avatar     |                 |               | Self-avatar    |                 |               |             |
|                         |            | No<br><b>X</b>  | Yes<br><b>A</b> |               | No<br><b>X</b> | Yes<br><b>A</b> |               |             |
| Implicit<br>Performance | <b>FOV</b> | No<br><b>X</b>  | 1.25<br>(.69)   | 1.56<br>(.73) | 1.40           | 1.88<br>(.39)   | 1.86<br>(.42) | 1.87        |
|                         |            | Yes<br><b>C</b> | 1.8<br>(.40)    | 1.67<br>(.53) | 1.73           | 1.92<br>(.28)   | 2<br>(0)      | 1.96        |
|                         |            |                 | 1.53            | 1.61          | <b>1.57</b>    | 1.9             | 1.93          | <b>1.92</b> |
| Explicit<br>Judgements  | <b>FOV</b> | No<br><b>X</b>  | 1.28<br>(.70)   | 1.47<br>(.73) | 1.38           | 1.31<br>(.71)   | 1.56<br>(.65) | 1.43        |
|                         |            | Yes<br><b>C</b> | 1.44<br>(.65)   | 1.36<br>(.72) | 1.4            | 1.64<br>(.59)   | 1.67<br>(.53) | 1.65        |
|                         |            |                 | 1.36            | 1.42          | <b>1.39</b>    | 1.47            | 1.61          | <b>1.54</b> |

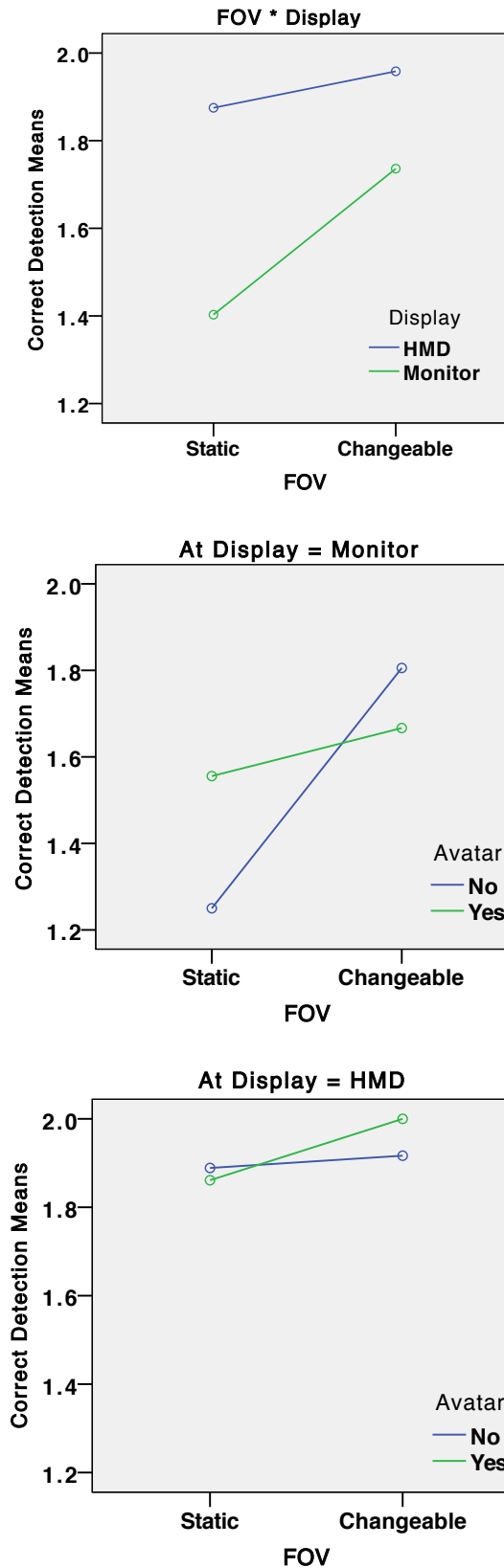


Figure 29: Top: interaction between FOV and Display factors. Middle: interaction between FOV and Avatar factors for Monitor condition. Bottom: interaction between FOV and Avatar factors for HMD condition.

### 4.4.2 False alarm (FA)

Implicit performance: The means and standard deviations of false alarms, for both implicit and explicit measures, are reported in Table 9. Although means differ slightly between conditions, the overall scores of the two groups were very close. However, ANOVA revealed a significant interaction effect between FOV and self-avatar factor,  $F(1,70)=7.18$ ,  $p<.009$ ,  $\omega^2=.09$  (Figure 30). There were no significant main effects or other interactions between factors.

Explicit judgements: Participants in the monitor group produced substantially more false alarms ( $M=.39$ ) than those who used HMD ( $M=.09$ ). In fact, there were no false alarms in 91% of the cases in the HMD group. An ANOVA revealed a significant main effect for display type on user judgements,  $F(1,70)=16.17$ ,  $p<.001$ ,  $\omega^2=.19$ . The interaction between factors was not statistically significant.

Table 9: False alarm means and standard deviations for implicit and explicit measures

|                         |     | Monitor     |              |               | HMD         |               |               |      |
|-------------------------|-----|-------------|--------------|---------------|-------------|---------------|---------------|------|
|                         |     | Self-avatar |              | C             | Self-avatar |               | C             |      |
|                         |     | No<br>X     | Yes<br>A     |               | No<br>X     | Yes<br>A      |               |      |
| Implicit<br>Performance | FOV | No<br>X     | .92<br>(.81) | .97<br>(.77)  | .95         | 1.08<br>(.73) | .94<br>(.83)  | 1.01 |
|                         |     | Yes<br>C    | .72<br>(.70) | 1.06<br>(.75) | .89         | .67<br>(.53)  | 1.03<br>(.74) | .85  |
|                         |     |             | .82          | 1.02          | .92         | .88           | .99           | .93  |
| Explicit<br>Judgements  | FOV | No<br>X     | .53<br>(.73) | .31<br>(.62)  | .42         | .17<br>(.44)  | .11<br>(.32)  | .14  |
|                         |     | Yes<br>C    | .39<br>(.65) | .33<br>(.63)  | .36         | .06<br>(.23)  | .03<br>(.17)  | .04  |
|                         |     |             | .46          | .32           | .39         | 0.12          | .07           | .09  |

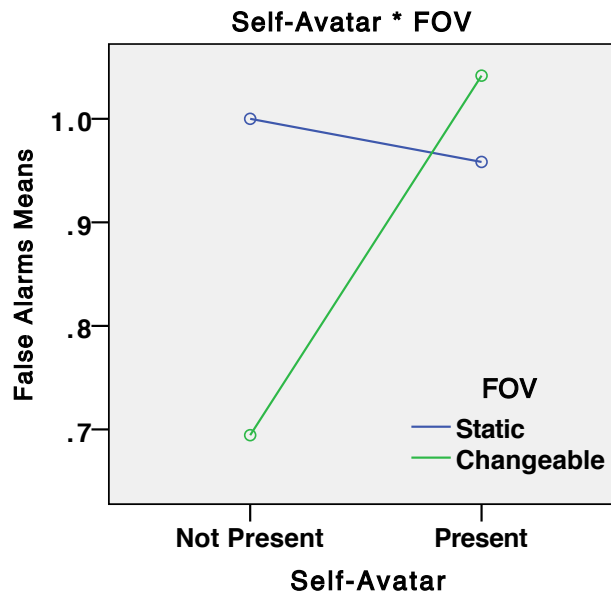


Figure 30: Interaction between FOV and avatar

### 4.4.3 Diagnosticity Measures

#### 4.4.3.1 Inclusion and exclusion criteria

To further evaluate user decision-making, PPP and NPP were used. Before analysing PPP and NPP, the experiment set decision criteria for detectors and non-detectors (either participants discriminated between the stimuli or they did not). Non-detectors were participants who tried to go through every gap, regardless if they were passable or not; or who avoided all the gaps, regardless if they were passable or not. These participants were eliminated from that condition because they did not provide any data about their ability to discriminate between the gaps. Participants were only removed from the condition where they were non-detectors. Data from other conditions were retained. This is important since non-detectors, by definition, do not show any sensitivity to perceptual changes in a specific condition.

Table 10 shows different numbers in each condition indicating the different number of participants that were removed from that condition because they were non-discriminating. The percentages of

non-detectors for each condition are also shown in Table 10. The number of excluded (non-detectors) participants from analysis appeared to be reduced whenever participants could look around. The presence of the self-avatar appeared to increase the number of non-detectors, especially with the monitor group. However, nonparametric tests revealed no statistical difference between FOV and self-avatar levels in each group and no statistical difference between the two groups (display type).

Table 10: Non-detectors number and percentages for implicit and explicit measures

|                         |     | Monitor         |                 |             | HMD            |                 |             |            |
|-------------------------|-----|-----------------|-----------------|-------------|----------------|-----------------|-------------|------------|
|                         |     | Self-avatar     |                 |             | Self-avatar    |                 |             |            |
|                         |     | No<br><b>X</b>  | Yes<br><b>A</b> |             | No<br><b>X</b> | Yes<br><b>A</b> |             |            |
| Implicit<br>Performance | FOV | No<br><b>X</b>  | 9<br>25%        | 10<br>27.9% | 26.5%          | 12<br>33.3%     | 10<br>27.9% | 30.6%      |
|                         |     | Yes<br><b>C</b> | 4<br>11.1%      | 10<br>27.9% | 19.5%          | 1<br>2.9%       | 10<br>27.9% | 15.4%      |
|                         |     |                 | 18.1%           | 27.9%       | <b>23%</b>     | 18.1%           | 27.9%       | <b>23%</b> |
| Explicit<br>Judgements  | FOV | No<br><b>X</b>  | 6<br>16.7%      | 6<br>16.7%  | 16.7%          | 4<br>11.1%      | 3<br>8.33%  | 9.7%       |
|                         |     | Yes<br><b>C</b> | 2<br>5.56%      | 5<br>13.9%  | 9.7%           | 2<br>5.56%      | 1<br>2.9%   | 4.2%       |
|                         |     |                 | 11.1%           | 15.3%       | <b>13.2%</b>   | 8.3%            | 5.6%        | <b>7%</b>  |

#### 4.4.3.2 Positive predictive power

Implicit performance: The means and standard deviations of PPP for both implicit and explicit measures are reported in Table 11. An ANOVA of the PPP revealed a significant interaction between FOV and avatar  $F(1,63)=7.22, p<.009, \omega^2=.10$  (Figure 31). None of the other interactions were statistically significant. ANOVA also indicated a significant main effect for FOV  $F(1,63)=4.85, p<.031, \omega^2=.07$ .

Explicit judgements: An ANOVA revealed a significant main effect for display type,  $F(1,51)=13.7$ ,  $p<.001$ ,  $\omega^2=.21$ . No significant effects were observed for FOV, self-avatar, or the interaction between factors.

Table 11: Means and standard deviations of PPP for implicit and explicit measures

|                         |     | Monitor         |                 |              | HMD            |                 |              |            |
|-------------------------|-----|-----------------|-----------------|--------------|----------------|-----------------|--------------|------------|
|                         |     | Self-avatar     |                 |              | Self-avatar    |                 |              |            |
|                         |     | No<br><b>X</b>  | Yes<br><b>A</b> |              | No<br><b>X</b> | Yes<br><b>A</b> |              |            |
| Implicit<br>Performance | FOV | No<br><b>X</b>  | .64<br>(.27)    | .65<br>(.24) | .64            | .67<br>(.18)    | .71<br>(.25) | .69        |
|                         |     | Yes<br><b>C</b> | .78<br>(.20)    | .66<br>(.21) | .72            | .78<br>(.18)    | .70<br>(.18) | .74        |
|                         |     |                 | .71             | .65          | <b>.67</b>     | .73             | .70          | <b>.72</b> |
| Explicit<br>Judgements  | FOV | No<br><b>X</b>  | .73<br>(.29)    | .87<br>(.25) | .80            | .88<br>(.28)    | .95<br>(.12) | .92        |
|                         |     | Yes<br><b>C</b> | .81<br>(.28)    | .84<br>(.28) | .82            | .99<br>(.08)    | .98<br>(.09) | .98        |
|                         |     |                 | .77             | .85          | <b>.81</b>     | .93             | .97          | <b>.95</b> |

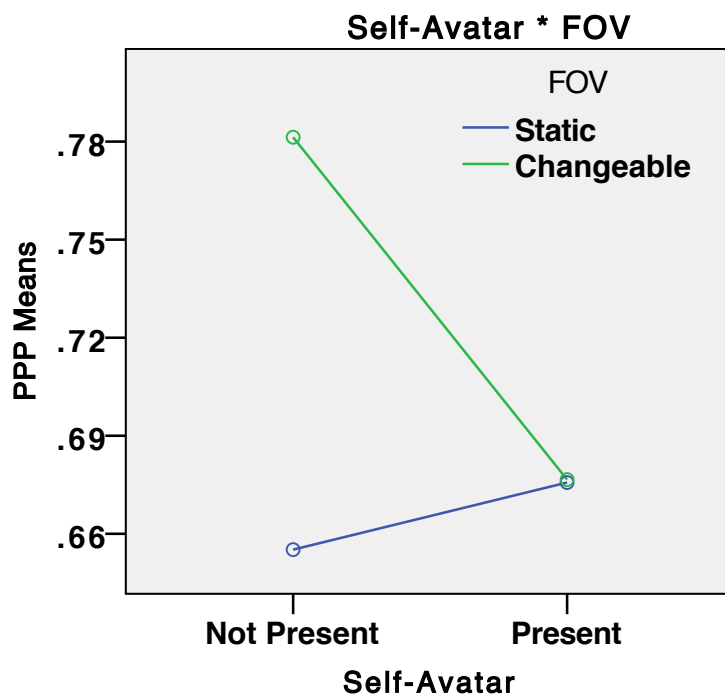


Figure 31: Interaction between FOV and self-avatar factors

### 4.4.3.3 Negative predictive power

Implicit performance: The means and standard deviations of NPP for both implicit and explicit measures are reported in Table 12. An ANOVA revealed significant main effects for FOV,  $F(1,33)=5.405$ ,  $p<.026$ ,  $\omega^2=.14$ , and display type  $F(1,33)=26.8$ ,  $p<.001$ ,  $\omega^2=.45$ . No significant effects were observed for the self-avatar factor, nor for the interaction between factors.

Explicit judgements: An ANOVA revealed a significant main effect for display type,  $F(1,46)=6.59$ ,  $p<.013$ ,  $\omega^2=.09$ . No significant effects were observed for FOV, self-avatar, or the interaction between factors.

Table 12: Means and standard deviations of NPP for implicit and explicit measures

|                         |     | Monitor     |              |              | HMD         |              |              |            |
|-------------------------|-----|-------------|--------------|--------------|-------------|--------------|--------------|------------|
|                         |     | Self-avatar |              | C            | Self-avatar |              | C            |            |
|                         |     | No<br>X     | Yes<br>A     |              | No<br>X     | Yes<br>A     |              |            |
| Implicit<br>Performance | FOV | No<br>X     | .57<br>(.36) | .72<br>(.38) | .65         | .97<br>(.13) | .91<br>(.19) | .94        |
|                         |     | Yes<br>C    | .86<br>(.27) | .75<br>(.33) | .81         | 1<br>(0)     | 1<br>(0)     | 1          |
|                         |     |             | .72          | .74          | <b>.73</b>  | .98          | .95          | <b>.97</b> |
|                         |     |             |              |              |             |              |              |            |
| Explicit<br>Judgements  | FOV | No<br>X     | .73<br>(.24) | .83<br>(.25) | .78         | .77<br>(.22) | .86<br>(.25) | .82        |
|                         |     | Yes<br>C    | .79<br>(.26) | .75<br>(.3)  | .77         | .89<br>(.17) | .9<br>(.17)  | .90        |
|                         |     |             | .76          | .79          | <b>.78</b>  | .83          | .88          | <b>.85</b> |
|                         |     |             |              |              |             |              |              |            |

### 4.4.4 Sense of presence and simulator sickness

For sense of presence, the study was focused only on the general sense of presence and realism. The means and standard deviations of the general sense of presence and realism are reported in Table 13.



Table 13: Means and standard deviations of participants' general sense of presence and realism

|                           |     | Monitor         |                 |                 | HMD            |                 |                 |              |
|---------------------------|-----|-----------------|-----------------|-----------------|----------------|-----------------|-----------------|--------------|
|                           |     | Self-avatar     |                 |                 | Self-avatar    |                 |                 |              |
|                           |     | No<br><b>X</b>  | Yes<br><b>A</b> |                 | No<br><b>X</b> | Yes<br><b>A</b> |                 |              |
| General sense of presence | FOV | No<br><b>X</b>  | .25<br>(1.62)   | 1.28<br>(1.34)  | .76            | 1.61<br>(1.02)  | 1.6<br>(1.20)   | 1.60         |
|                           |     | Yes<br><b>C</b> | .81<br>(1.47)   | 1.33<br>(1.26)  | 1.07           | 2.08<br>(.84)   | 2.31<br>(.71)   | 2.19         |
|                           |     |                 | .53             | 1.31            | <b>0.92</b>    | 1.85            | 1.94            | <b>1.90</b>  |
| Realism                   | FOV | No<br><b>X</b>  | -0.73<br>(1.06) | -0.36<br>(1.23) | -0.55          | -0.47<br>(1.25) | -0.54<br>(1.39) | -0.51        |
|                           |     | Yes<br><b>C</b> | -0.43<br>(1.22) | -0.22<br>(1.31) | -0.33          | -0.23<br>(1.47) | -0.14<br>(1.49) | -0.19        |
|                           |     |                 | -0.58           | -0.29           | <b>-0.44</b>   | -0.35           | -0.34           | <b>-0.35</b> |

Sense of presence: The participant's general sense of presence was obtained in response to the following question: "In the computer-generated world I had a sense of 'being there'?" The question consisted of a seven-point Likert-like item from -3 (not at all) to 3 (very much). An ANOVA indicated significant interaction effects between self-avatar and display type,  $F(1,70)=11.88$ ,  $p<.001$ ,  $\omega^2=.14$ , and between FOV, self-avatar, and display type,  $F(1,70)=4.38$ ,  $p<.04$ ,  $\omega^2=.06$ . Interaction graphs can be seen in Figure 32. Significant main effects were also revealed for all three factors (FOV, self-avatar, and display type) and were highly significant,  $F(1,70)=18.32$ ,  $p<.001$ ,  $\omega^2=.21$ ,  $F(1,70)=19.63$ ,  $p<.001$ ,  $\omega^2=.22$ ,  $F(1,70)=17.78$ ,  $p<.001$ ,  $\omega^2=.20$  respectively.

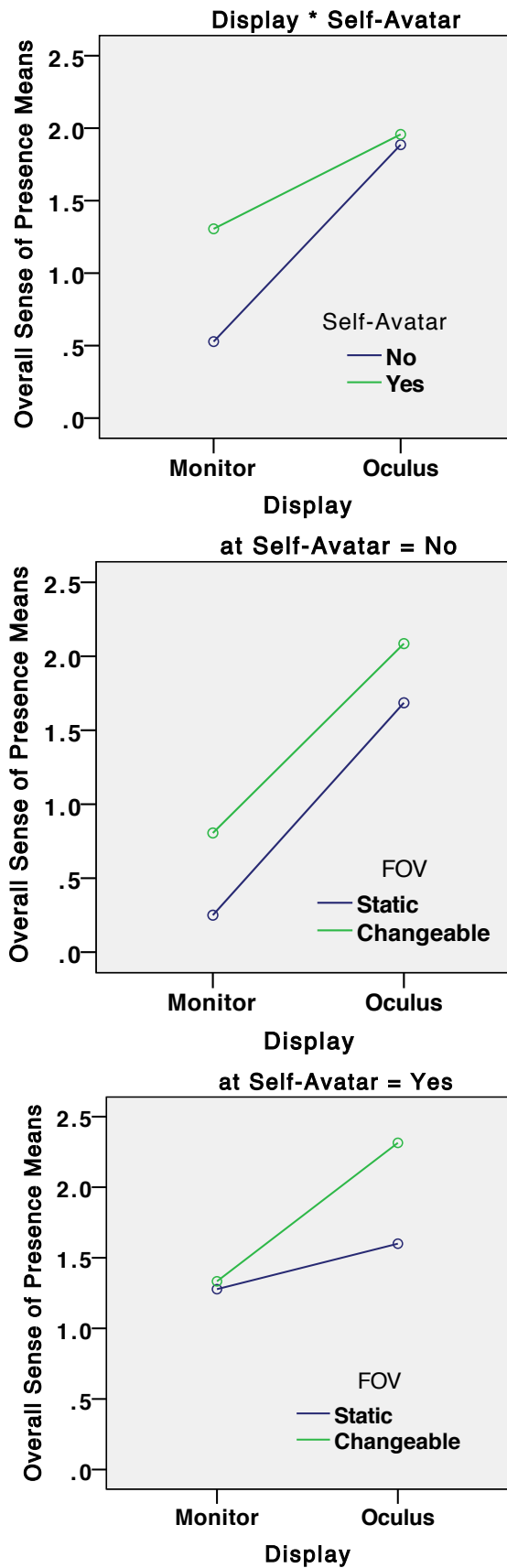


Figure 32: Top: Interaction between Display and Self-Avatar factors. Middle: interaction between Display and FOV factors for none-Avatar condition. Bottom: interaction between Display and FOV factors for Self-Avatar condition.

Realism: Two Likert-like items of the sense-of-presence questionnaire were used to measure realism: 1) “How much did your experience in the virtual environment seem consistent with your real-world experience?”, anchored with -3 (not consistent) and 3 (very consistent); and 2) “The virtual world seemed more realistic than the real world”, anchored with -3 (fully disagree) and 3 (fully agree). The averages of these two questions were used to perform the analyses. An ANOVA revealed a significant main effect for the FOV factor,  $F(1,70)=6.03$ ,  $p<.017$ ,  $\omega^2=.08$ , and the self-avatar factor,  $F(1,70)=4.07$ ,  $p<.06$ ,  $\omega^2=.08$ . No significant effects were observed for display type, or the interaction between factors.

Simulator sickness is usually associated with immersive VEs such as HMDs; as a confounding variable, it was measured using a standard simulator sickness questionnaire (SSQ). Subjects in the HMD group had to answer the SSQ as part of the sense-of-presence questionnaire. Because simulator sickness is not the focus of this study, only selected symptoms (general discomfort, difficulty concentrating, dizziness, difficulty focusing, and nausea) out of 16 (original SSQ), were measured. Each subject had to rate each symptom from 0 (none) to 4 (severe).

The percentage of the number of participants who felt sick and their average ratings are reported in Table 14. As expected, more participants experienced simulator sickness symptoms when the FOV was static (60%) and the number dropped almost to half when they could look around (33%). However, their symptoms were slight (the average rating varied from 1.1 to 1.4 for each condition) and did not affect their ability to complete the study.

Table 14: percentage and average rating of participants' simulator sickness

|     |                 | <b>HMD</b>     |                 |            |
|-----|-----------------|----------------|-----------------|------------|
|     |                 | Self-avatar    |                 |            |
|     |                 | No<br><b>X</b> | Yes<br><b>A</b> |            |
| FOV | No<br><b>X</b>  | 58%<br>1.3     | 63%<br>1.1      | 60%        |
|     | Yes<br><b>C</b> | 36%<br>1.2     | 30%<br>1.4      | 33%        |
|     |                 | 47%            | 46%             | <b>46%</b> |

#### 4.4.5 Experience

The comparative questionnaire was answered only once by each participant after completing all conditions. Four questions, consisting of seven-point Likert-like scale items, were developed to measure user experience in each group. The first two questions corresponded to the self-avatar factor as follows: Q1) “Do you think the virtual body (self-avatar) made it easier to judge door/gaps in the virtual environment?”, and Q2) “When the avatar was not there, did you feel more or less comfortable?” Participants, in both groups, found it easier to judge doorframes/gaps when the self-avatar was present, with both means above mid-point (Monitor group: M=4.69, SD=1.56; HMD group: M=4.61, SD=1.40). However, they felt less comfortable when the self-avatar was absent (Monitor group: M=3.42, SD=1.79; HMD group: M=3.50, SD=1.30). An independent-sample t-test was conducted to compare ease of judgement (Q1) and comfort (Q2) between monitor and HMD groups. No statistically significant difference between means was found.

The final two questions (Q3 and Q4) corresponded to the FOV factor. Question 3 asked: “Do you think the controllability of the field of view made it easier to judge door/gaps in the virtual environment?” Similar to self-avatar presence, participants believed it was easier to judge doorframes/gaps when they could look around, with both means

above mid-point (Monitor group:  $M=5.14$ ,  $SD=1.51$ ; HMD group:  $M=5.47$ ,  $SD=1.42$ ). No statistical significance was found between the two groups. Question 4 asked: “When the field of view was static, did you feel more or less comfortable?” An independent-sample t-test indicated that there was a significant difference between the scores for the monitor group ( $M=3$ ,  $SD=1.74$ ) and the HMD group ( $M=2.22$ ,  $SD=1.40$ ). A boxplot of all 4 questions can be seen in Figure 33.

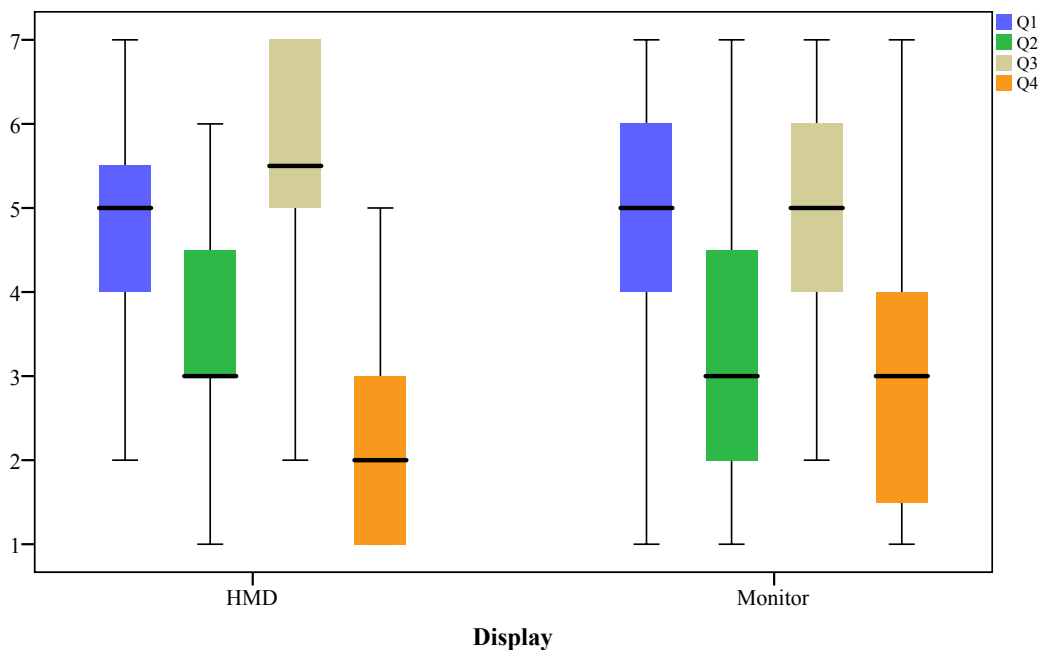


Figure 33: Boxplot of all 4 comparative questions: Q1: self-avatar ease of judgement, Q2: self-avatar comfort, Q3: FOV ease of judgement, Q4: FOV comfort. Box plot represents the median, interquartile (blue box), minimum, and maximum.

#### 4.4.6 Preference

Participants were asked about their preference in which they had to choose one of the four conditions in each group. In both groups, the C-A (controlled field of view, with self-avatar present) condition was the most favoured, with 63% of the response in the monitor group and 68% in the HMD group. The following graphs represent the responses of subjects to question five (Figure 34).

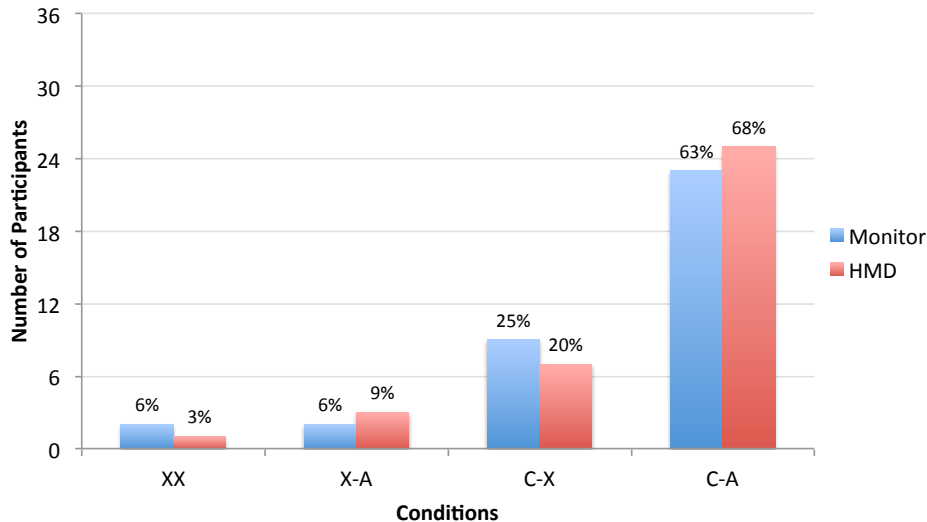


Figure 34: Participants' preferences for each condition within each group

## 4.5 Discussion

This study investigated how different immersion factors influence user perception, behaviour, and sense of presence while driving a virtual PWC. Findings suggest that while the main effects of display type (Monitor v HMD) were strong and persistent on the behaviour and perception of most participants, the main effects of FOV were only strong on behaviour, whereas the self-avatar had no effects at all. Furthermore, all immersion factors significantly affected the participants' sense of presence.

### 4.5.1 Correct Detection and False Alarms

Correct detection: Participants showed significantly more accurate behaviour in detecting passable gaps with the HMD and changeable FOV than when using the monitor display or a static FOV. The effects of the FOV were different for the two displays. For example, the difference between having the FOV changeable or not did not make much difference when participants used the HMD compared to those who used the monitor. In addition, with the static FOV, participants showed much better detection scores on the HMD, whereas when

using the changeable FOV, there was no such performance difference between the displays. The effects of the three factors were found for the participants' behaviour in manoeuvring between or around the gaps but did not affect how participants explicitly judged the passability of the doorframes in the VE. One possible explanation is that accurate detection was easier from a close distance to the virtual gaps. In contrast, the explicit doorframe judgements were made from a fixed distance (3 units in Unity=3 metres relative to the VE). Another explanation could be that accurate detection is better enabled when moving in the VE as more information is extracted compared to when being static (Gibson, 1978).

The significant three-way interactions between the immersion factors were different across the display factors. For the monitor group, the best and worst detection scores occurred when the avatar was absent (best with the changeable FOV, worst with the static FOV). On the other hand, for those using the HMD, the best and worst detection scores happened when the avatar was present (best with the changeable FOV, worst with the static FOV). This could be because participants were able to look around and see their full body, which could have facilitated better judgement rather than only seeing the hands and parts of the legs with the static FOV. This is consistent with other research findings. For example, Mohler, Bühlhoff, Thompson, and Creem-Regehr (2008) provide evidence that participants make fewer errors judging distance in immersive VEs if they can fully explore a self-avatar of themselves.

False alarms: The effects of the display factors were significant only on explicit perceptual judgements of participants. With the HMD, participants significantly reduced the number of false alarms and were better able to correctly reject/perceive the passability of the doorframes. However, neither FOV nor self-avatar affected behaviour or perception of participants. This may be because the HMD improves depth perception, therefore enhancing spatial sensitivity, which

enabled more accurate judgement of distance in the VE (Heineken & Schulte, 2000). Interestingly, the interactions between FOV and self-avatar were significant on behaviour. In particular, participants made fewer false alarms when they were able to look around and the self-avatar was absent. With the avatar present, participants seemed to better detect passability but they also committed more false alarms.

### 4.5.2 PPP and NPP

A few participants failed to discriminate between the stimuli in each condition. In terms of behaviour, the number of non-discriminators was the same in both display groups. In terms of perception, the number of non-discriminators in the monitor group was almost twice the number in the HMD group. However, these differences were not statistically significant. The proportion of correct “Yes” responses and “No” responses were calculated for the remaining discriminators to yield the measures of positive (PPP) and negative (NPP) predictive power.

The main findings were that display type affected PPP for the perceptual judgements and NPP for both behavioural and perceptual measures. The FOV factor affected both PPP and NPP for the behavioural measures, whereas self-avatar had no main effects at all. With the HMD, participants had a significantly better PPP than those using the monitor display when judging passable doorframes. It was clear that with the HMD and changeable FOV most participants were better able to avoid all unpassable gaps while driving, regardless of the self-avatar presence.

### 4.5.3 Sense of presence and preference

All the immersion factors affected the participants’ general sense of presence. Their sense of presence was increased when using the HMD, changeable FOV, or self-avatar. Realism was only affected by



the changeable FOV. The interaction between the display and self-avatar was better with the HMD regardless of the self-avatar presence. The self-avatar did increase the sense of presence when a monitor was used. In the three-way interactions, self-avatar presence did not have effects in the monitor group but it did in the HMD group. The changeable FOV increased sense of presence in both groups.

Although participants thought that the self-avatar presence made it easier to judge passability, the self-avatar factor did not have effects on either perception or behaviour across all measures. Furthermore, participants also felt less comfortable when the avatar was absent. Unlike the self-avatar, changeable FOV affected behaviour while participants thought it made it easier for them to judge passability. It was found that not having the changeable FOV features made participants significantly less comfortable when using the HMD compared to the monitor display. The preference result was quite similar in both groups in which participants preferred the changeable FOV with self-avatar presence in both groups. Changeable FOV with no self-avatar presence was the second-most preferred in both groups.

## 4.6 Conclusion

This study investigated three properties of driving simulators – display type, field of view changeability, and self-avatar presence – and their effects on user perception and behaviour. The findings provide strong evidence for the potential benefits of using an HMD, such as an Oculus Rift, and the powerful effects of being able to look around inside the VE. The key contribution of this study lies in the fact that this experiment showed how accurately PWC users could behave and perceive action possibilities in the VE, which is a prerequisite of transferable training and assessment. The results provide potential design guidelines for future PWC simulator design.

In summary, only display type and FOV affected the participants' behaviours in detecting passable gaps. In addition, the HMD worked better in both FOVs. The changeable FOV was more effective when the self-avatar was present in the HMD and absent in the monitor display. The use of the HMD also improved perceptual sensitivity and reduced the number of false alarms in judging passable doorframes, in particular with the changeable FOV and the absence of the self-avatar. The self-avatar did not play a large role in detecting passability; in fact, it reduced sensitivity to some degree as shown with the number of false alarms.

The previous chapter (Chapter 3) and the current chapter (Chapter 4) provided guidance for better PWC simulator design, from PWC users' perspectives. The following chapter (Chapter 5) provides guidance from the clinician's perspective. It explores the effect of different viewpoints (observational techniques) on clinicians' assessment of PWC driving tasks.

## CHAPTER 5: VIRTUAL ASSESSMENT

**Objective:** This study evaluated the effect of three observational techniques (viewpoints) on clinician assessment of PWC driving tasks in a VE. In addition, perceived ease of use, confidence level, and sense of presence were also examined.

**Background:** Building a PWC simulator for clinical use involves both the PWC user (client) and the assessor (clinician). This kind of multi-user VE requires complementary perspectives (viewpoints) for all involved users. Although a few studies have incorporated clinical assessment into the VE, no study has incorporated the clinician into the simulator.

**Method:** Fifteen expert clinicians assessed four pre-recorded driving tasks in a VE using three different observational techniques: egocentric viewpoint (walk – HMD), orbited tethered viewpoint (orbit – monitor), and exocentric (standard – monitor). The virtual assessment was compared to real-world ‘gold standard’ scores on which the pre-recorded tasks were based.

**Results:** The findings of this study suggest that with more immersive techniques, clinicians can make accurate judgements as well as experience a high confidence level. It also shows the importance of incorporating viewpoints on clinician judgement. Furthermore, being able to walk and/or orbit around the view significantly affected the clinicians’ sense of presence.

**Conclusion:** This experiment shows that incorporating the clinician into the VE, through embodied interaction, is an effective method for the assessment of PWC skills. The results provide potential design guidelines for future VE applications, in particular, PWC simulator design.

## 5.1 Introduction

The study reported in this chapter was designed to evaluate the effect of different viewpoints on clinician assessment of PWC driving tasks. Three viewpoints were explored: egocentric (clinician walks around the driving tasks), orbited tethered (orbiting through the virtual scene around the driving task using a standard mouse), and exocentric (commonly used viewpoint). In addition to the assessment, ease of using each system, confidence level when assessing the tasks, and sense of presence were measured. These observational techniques were then directly compared to real-world standard scores to determine the validity of virtual driving task evaluations.

Current PWC assessment tools are time-consuming and non-standardised, which presents clinicians with serious difficulty in the assessment of capacity (Dawson et al., 1994; Kirby et al., 2004). With that said, many researchers have implemented PWC simulators, yet the study of virtual reality-based assessment remains embryonic. This is largely because most PWC simulators rely solely on client-centric information, thus suffering from a 'locked' frame of reference that clinicians do not have in real-world scenarios (Kamaraj et al., 2016). This can be attributed to two factors: 1) the lack of standardised assessment tools, as reported in Mahajan et al. (2013) and Mortenson et al. (2008); 2) limitations of the technologies at that time, either because they were too expensive or they did not exist.

Argelaguet, Kunert, Kulik, and Froehlich (2010, p. 56) argue that "co-located collaboration in virtual environments requires to render perspectively correct views of the scene for each involved user". In reality, the evaluation requires the clinician to constantly follow the PWC to observe user performance from different angles (Hafid & Inoue, 2005). Hughes and Lewis (2005) claim that navigation in VEs requires active engagement of involved observers. In this environment, clinicians find it difficult to estimate certain parameters that they

would determine by observation during real-world assessment. This could lead to 1) poor decisions, 2) inaccurate judgements, and 3) insufficient feedback to PWC users.

Only a handful of studies have incorporated clinical assessment into their PWC simulator (Kamaraj et al., 2016; Mahajan et al., 2013). Although these studies show high interrater reliability between assessors (>75%), they present some common experiment design issues with regard to virtual assessment: 1) the same clinician/s assessed the same user doing the same tasks in all conditions, which could lead to similar scores for all conditions; 2) all participants are expert PWC users, which could influence the assessor/s score, given the fact that they are expert PWC users; and 3) driving assessment was based on client-centric information. In the real world, assessment requires clinicians to constantly follow and walk around the PWC user (Hafid & Inoue, 2005).

According to Wang (2001), successful navigation in VEs is essential in training and assessment tasks. Building a PWC simulator for clinical use involves both the PWC user (client) and the assessor (clinician). This means that replicating real-world assessment in the VE should provide correct views for both client and clinician (Argelaguet et al., 2010). Bowman, Koller, and Hodges (1997) reported that studying human navigation is of great importance to building an effective VE travel interface. Different viewpoint techniques have been introduced and studied in the past. However, the most widely used techniques in VEs are egocentric and exocentric, and, more recently, tethered (which integrates information from both egocentric and exocentric viewpoints) (Colquhoun, 2000; McCormick, Wickens, Banks, & Yeh, 1998). With tethered viewpoint, the virtual camera (observer's viewpoint) is attached to the controlled object.

A study by McCormick et al. (1998) analysed the effect of the viewpoints (egocentric, exocentric, and tethered) on different

interaction tasks, such as search, travel, local and global judgement support. They found that viewpoints that utilised tethered or egocentric support had better performance in travel tasks. Similarly, a study by Hollands and Lamb (2011) concluded that the egocentric viewpoint produced the most effective navigation task, while the tethered viewpoint is better suited to applications that involve understanding the relation of close objects in the VE to one's own location. In summary, different viewpoints offer different advantages for navigation and travel task. However, it is not clear how different viewpoints would affect clinician assessment in a PWC simulator.

To address this gap existing in the availability of a suitable research platform for the investigation of VE assessment validity and clinicians' visual information, two fundamental questions were asked: 1) How can clinicians validly assess driving tasks in the VE compared to pre-assessed real-world driving tasks? 2) Do different viewpoints (frames of references) affect how clinicians observe driving in the VE, and lead them to a different judgement? 3) How do each of the three viewpoints affect the clinician's sense of presence, confidence level, and ease of use? It is hypothesised that the more immersive viewpoints will lead to more valid judgements, a higher confidence level, and a greater sense of presence. For the sake of simplicity, the three viewpoint conditions are named as follows: walk (egocentric viewpoint), orbit (orbited tethered viewpoint), and standard (exocentric viewpoint).

## 5.2 System

This experiment involved two phases. First was the task recording, which took place at University of Otago (Dunedin, New Zealand). Second was the experimental assessment, which took place at University of McGill (Montreal, Canada). Each of the phases will be described separately.

### 5.2.1 Task Recording

The clinician-assessed driving tasks were pre-recorded based on real-world driving tasks. Ideally, this experiment would have involved a real PWC user performing the driving tasks in the simulator while being assessed by clinicians. This would allow a direct comparison of the real and virtual score assessment. However, this would have introduced some practical and experiment design issues. For instance, it would have been almost impossible to recruit clinicians and real PWC users at the same time, given the timeframe for this study. Driving in the real and virtual world would introduce variability, as it would be very difficult for PWC users to perform the tasks exactly the same way for each evaluating clinician (Archambault et al., 2011; Archambault et al., 2012; and Harrison et al., 2000). Moreover, clinicians would know the capacity level of a participant from their first trial, which may lead to a biased assessment in the other conditions.

Since the main goal of this experiment is to evaluate the different observational techniques from the clinician's point of view, it was necessary to come up with a solution to overcome the reported issues raised by Kamaraj et al. (2016) and Mahajan et al. (2013) in regard to experiment design (this is discussed in the introduction of this chapter and is explored in deeper detail in the related work section). The solution to this was to record a real PWC user by tracking their movements while they performed different driving tasks with varying difficulties and capacity levels, then to replay those tasks in the virtual condition to be assessed by clinicians. This allowed for 1) the same tasks were assessed in all conditions; and 2) using the real-world gold standard scores to directly compare with the virtual score. Tracking real PWC movement instead of just creating it in the simulator removes one potential confounding variable: that the task

performance represented in the VE is not the same task as would be observed in the real world.

Four driving tasks were chosen from the wheelchair skill test (WST) with varying difficulties. These tasks were turn in place, turn while moving forwards, turn while moving backwards, and sideways manoeuvres (Figure 35). Each task had specific requirements and dimensions and was designed accordingly. Task descriptions, based on the WST, are as follows:

- Turn in place: “The subject turns the wheelchair around 180° to the left and right to face in the opposite direction, while remaining within a square space with 1.5 m sides”.
- Turn while moving forwards: “The subject turns the wheelchair 90° to the left and right around a corner while moving forwards”.
- Turn while moving backwards: “The subject turns the wheelchair 90° to the left and right around a corner while moving backwards”.
- Sideways manoeuvres: “The subject manoeuvres the wheelchair 0.5 m sideways to the left and right parallel to an object”.



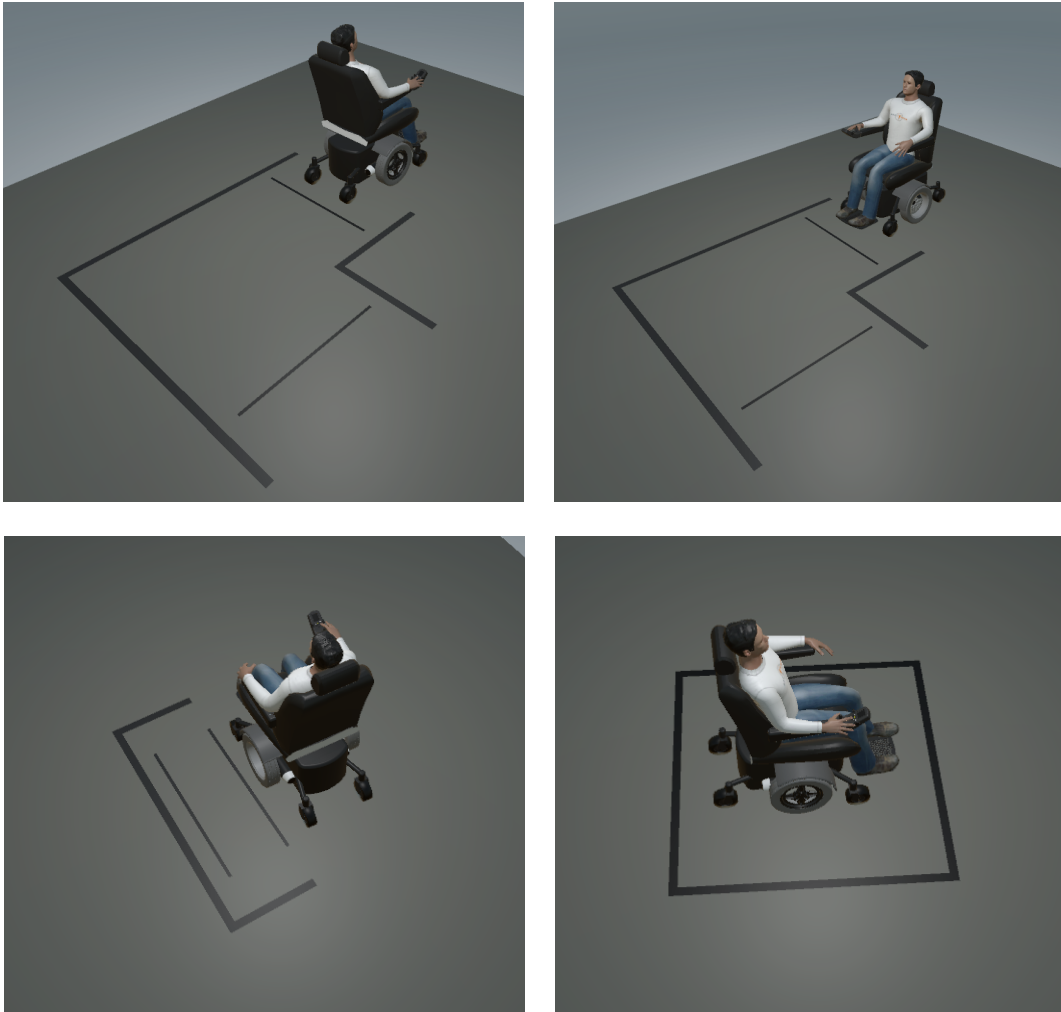


Figure 35: Illustration of the selected driving task based on WST. Driving backwards (top left), Driving forwards (top right), sideways manoeuvre (bottom left), and turn 180° (bottom right).

In a real-world scenario, when the WST tool is used clinicians use the scoring skill capacity to assess users (Table 15). The scoring capacity is a scale from 0 to 2 where “0” means (fail), “1” means (pass with difficulty), and “2” means (pass). This scoring system is used to model the four driving tasks in the real world. Both an expert clinician (from RATA South Rehabilitation Clinic, Dunedin) and expert PWC users were involved in the modelling of the driving tasks. The clinician gave the PWC users instructions on how to complete each task, as a “0” (fail), a “1” (pass with difficulty), or a “2” (pass). The PWC movements were tracked in real time, animated, and then saved in the simulator. This subsequently led to a total of 12 modelled driving tasks.

Table 15: Scale for scoring skill capacity ("WST 4.2 form, n.d.)

| <b>Score</b>         | <b>Score</b> | <b>What this means</b>   |
|----------------------|--------------|--|
| Pass                 | 2            | Task independently and safely accomplished without any difficulty.                           |
| Pass with difficulty | 1            | The evaluation criteria are met, but the subject experienced some difficulty worthy of note. |
| Fail                 | 0            | Task incomplete or unsafe.   |

### 5.2.1.1 Tracking

The movement of the real PWC was tracked instantly using the HTC Vive System and recorded using a Unity3D animation recorder script. To do this, one of the HTC Vive controllers was placed on the real PWC over a wood frame, specifically designed for this task (Figure 36). The X and Y positions and orientations of the controller were tracked with two stationaries mounted on the walls (Figure 37). In Unity3D, an invisible object was assigned to the controller movement and placed exactly where the physical control is (Figure 38). The virtual PWC repositioned automatically based on the controller when starting the application. The controller was positioned high to minimise any possible interference with the tracking.

## Virtual Assessment



Figure 36: HTC controller placed on the wood frame to track the PWC movement



Figure 37: HTC base stations mounted on the walls and HTC controller placed on the PWC (This is not the actual PWC used for recording)

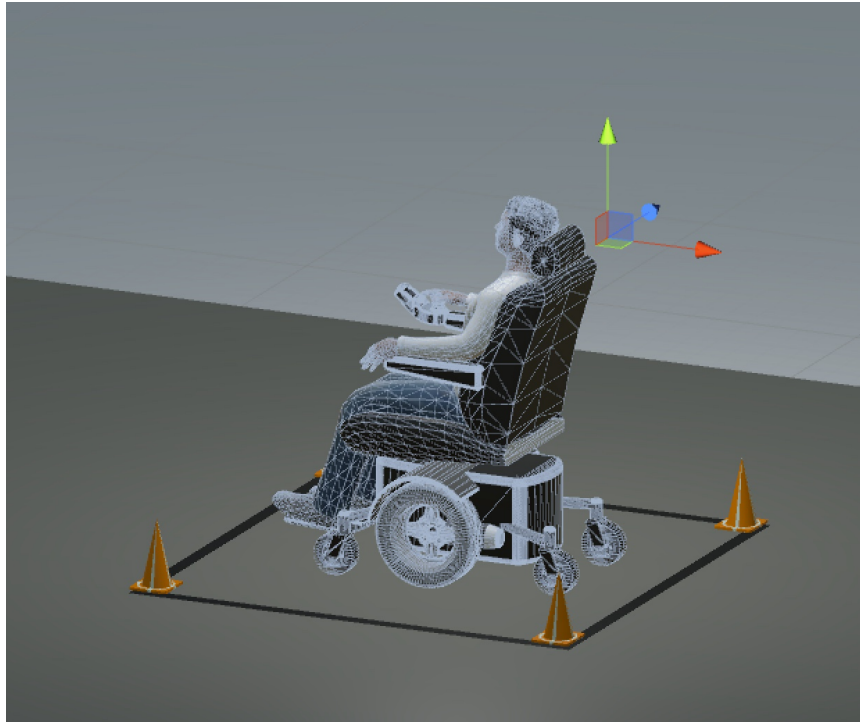


Figure 38: “Invisible” Unity3D game object to track the controller movement

Many trials were completed to ensure that the exact movement of the real PWC was mapped to the virtual PWC movement; for example, crossing the line or stopping over the line are matched in both the virtual and real world. After all of this, the tasks were recorded in the simulator. Figure 39 shows an example of recording each of the driving tasks. Once all the driving tasks were recorded, the tasks were played back in Unity3D and screen recorded. These videos were then evaluated by three independent professional therapists (Centre for Interdisciplinary Research in Rehabilitation and Social Integration, Laval University, Quebec City, Canada) to verify the scores originally assigned by the expert clinician in Dunedin, New Zealand. This was done in collaboration with McGill University, Canada. The three assessors were blinded from the real driving tasks scores. The videotapes were taken from angles that would allow the assessors to see the whole virtual PWC, enabling them to make an accurate decision. Three out of 12 driving tasks were re-modelled based on assessor feedback and re-assessed to make sure that each task represents its score.



Figure 39: Examples of the tracking of the PWC movements for each task. In those pictures, the expert clinician instructing the PWC user, the expert PWC user, and the researcher running the simulator to record the driving tasks.

## 5.2.2 Technical Apparatus

This experiment consisted of two screens (24 inches) and an HMD (HTC Vive). One screen was controlled by the experimenter to watch the driving task and change the viewpoint. The other one was used by the participants for the orbit and standard conditions (Figure 40). Participants in the orbit condition used a standard mouse to orbit around the virtual PWC. In the walk condition, the HTC Vive headset was used by the participants to walk around the virtual PWC (Figure 41). The HTC Vive<sup>3</sup> consists of an HMD display featuring 2160x1200 combined resolution and gives 110° FOV (runs at 90Hz). The headset includes a gyrosensor, accelerometer, and laser position sensors (32

<sup>3</sup> www.vive.com

sensors). The headset comes with two-motion tracking (wireless synced infrared lighthouse cameras) and two controllers with a trackpad, pressure-sensitive grip, buttons, and 24 laser sensors for each.

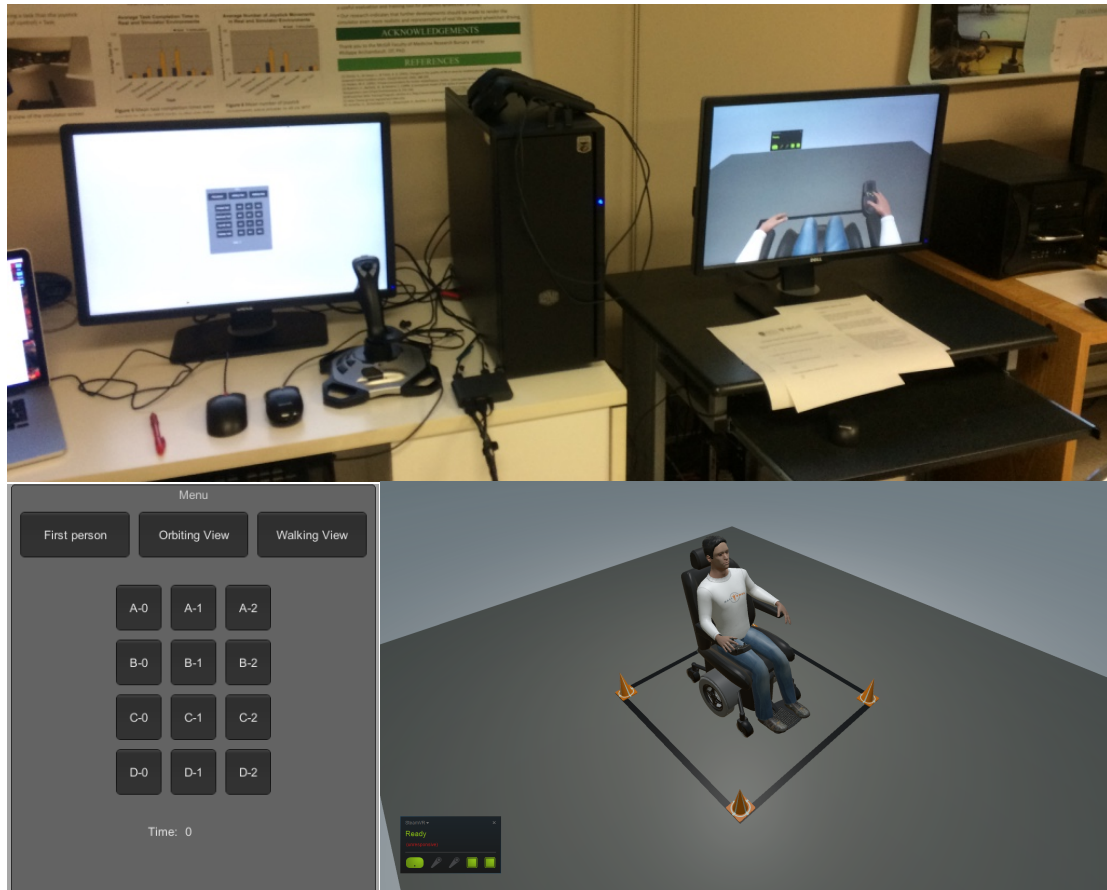


Figure 40: Top picture, the two screens. Bottom pictures, (on the left) the experimenter view to change the viewpoints and play the driving tasks, (on the right) a screenshot of the orbiting view



Figure 41: HTC Vive headset <sup>4</sup>

<sup>4</sup> Taken from <https://arstechnica.com/gaming/2016/10/best-vr-headset-2016-psvr-rift-vive/>

For the walk condition, a space of 4\*4 metres was cleared and tracked (Figure 42). The wireless stationary trackers were mounted on two separate tripods at 2.5 metres high. A safety step was taken to stop the viewer from going beyond the limited space by showing red boundaries once the user got within 50 cm of the limited edges. Unity3D was used to build the simulator with the support of the streamVR plugin, which provides virtual reality stream support for HMDs. Finally, a desktop with a powerful graphics card was used to run the simulator.



Figure 42: Panorama picture of the Jewish Hospital Rehabilitation lab where the experiment took place.

### 5.2.3 Environment

The virtual environment in this experiment consisted of the virtual PWC, avatar, and the driving tasks. The virtual PWC and driving tasks were modelled by Google SketchUp, whereas the virtual self-avatar was produced by “MakeHuman”. The VE used in this experiment was a high-fidelity 3D model of an abstracted (low distraction) VE. Special consideration went into the designing of the virtual PWC; it was modelled on the dimensions of the real PWC that was used in this experiment to record the driving tasks. The wheels of the virtual PWC were positioned to exactly match those in the real one.

Another special consideration went into the orbiting implementation. First, the zoom in/out function, using the mouse's scroll, allowed clinicians to set their favourite distance from the virtual PWC. Default distance was set at 3 units from the virtual PWC (1 unit in Unity=1 m in reality). The minimum distance was set at 2 units, with the maximum set at 5 units. Second, the interaction technique was set up in such a way so it felt like the point of view around the virtual PWC was changing rather than rotating the virtual world around the virtual PWC (standard orbiting technique feeling). This was achieved by changing the direction of the VE response when dragging the mouse cursor. Third, the sphere in which the orbiting viewpoint moved around was limited from both the top and bottom (as can be seen in Figure 43). This was done to ignore any extra drag in the mouse to avoid spinning around the virtual PWC.

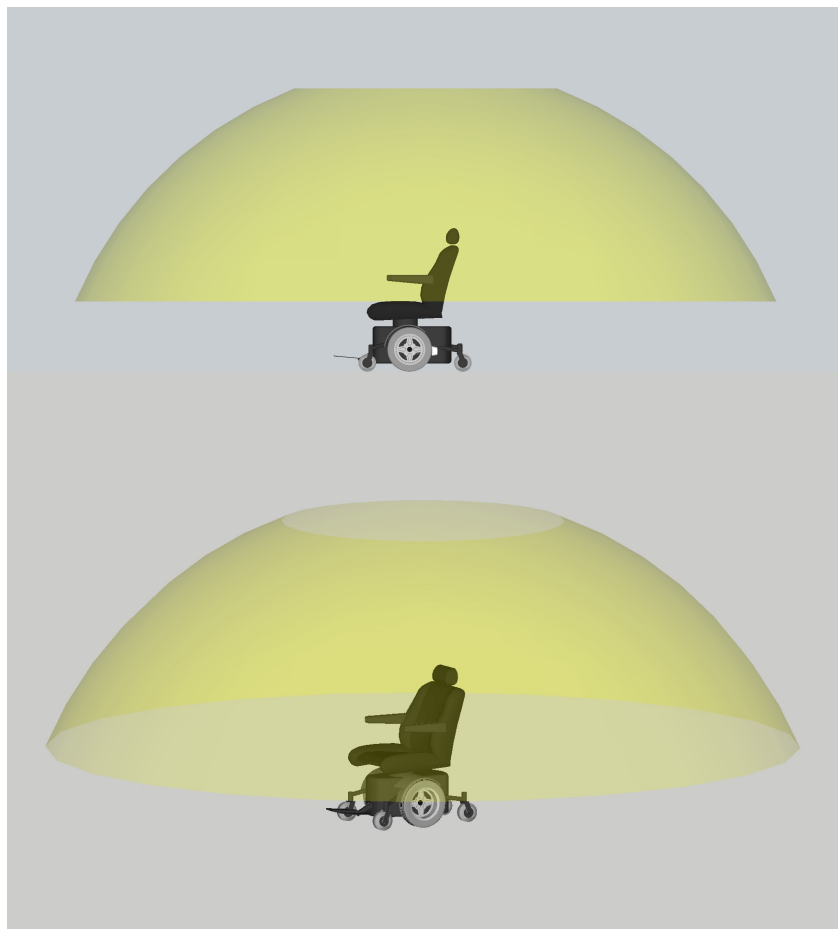


Figure 43: The yellow sphere is where clinicians can orbit around the virtual PWC with the ability to zoom in and out at any given time.



## 5.3 Method

### 5.3.1 Participants

This study was completed in collaboration with McGill University, Canada. All participants were recruited from the Jewish Rehabilitation Hospital (CISSS Laval), Montreal. A pilot study with three expert clinicians was conducted to provide a formative evaluation of the procedures and instruments. Recruiting highly specialised domain experts is a common challenge in all studies targeting ecological validity. This study is no different. I have been fortunate to recruit as many as fifteen expert clinicians (eight Physiotherapists (PT) and seven Occupational Therapists (OT)). There were four males and 11 females with an average age of 34.9 years ( $SD=9.4$ , age range=23 – 55). The average working experience of the PT or OP was 9.3 years ( $SD=7.73$ ). Eight clinicians had experience with PWC assessment with an average of 1.6 years. All participants were rewarded with chocolate bars. All participants had normal or corrected-to-normal vision. Institutional ethical approvals were obtained from McGill University. Figure 44 shows participants performing the task.

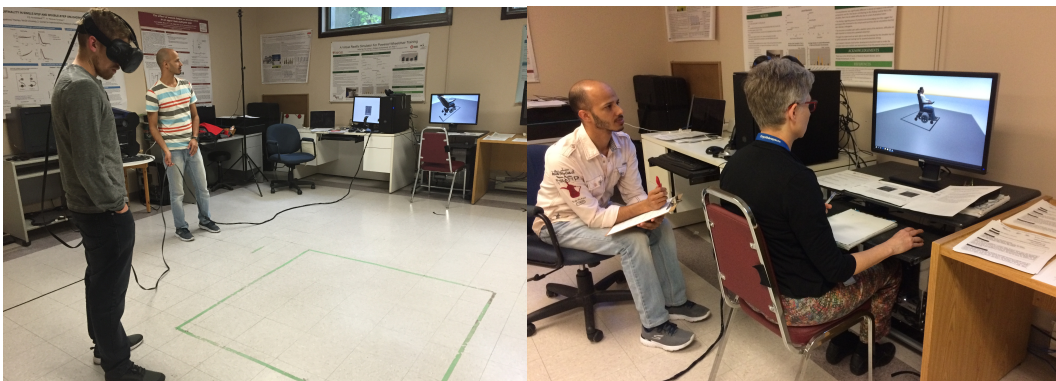


Figure 44: Walk condition (on the left) and orbit condition (on the right)

## 5.3.2 Measures

### 5.3.2.1 Assessment score

Assessment scores were based on the WST. The scoring system consisted of three levels, 0, 1, and 2 where “0” means ‘task incomplete or unsafe’, “1” means ‘evaluation criteria are met but the subject experienced some difficulty worthy of note’, and “2” means ‘task independently and safely accomplished without any difficulty’. To analyse the virtual assessment score and compare it to the original score from the real-world designed driving tasks (correct score), the square of the difference score (Correct Score – Judged Score) was calculated. The squared difference was calculated to give an indication of the overall size of the difference between the correct and assigned scores and perform a standard ANOVA with condition (Standard, Orbit, Walk) and task (T<sub>1</sub>,T<sub>2</sub>,T<sub>3</sub>,T<sub>4</sub>) as within-subjects factors. The number of correct answers was also measured in this study. Correct answers involve the correct score matched to the assigned score (a number out of 4).

### 5.3.2.2 Ease of use and confidence level

It was important to know how easy it was for clinicians to use each observation setup. Clinicians were asked to rate the ease of assessing each task in each condition on a seven-point Likert-scale (“Using this setup, the assessment of this task was 1=Difficult, 7=Easy”). For confidence level, the influence of each condition on the clinician’s confidence level when they gave their assessment score was measured. According to Jonsson and Allwood (2003), “Poor realism in confidence judgements of the correctness of one’s own decisions can have devastating consequences”. The confidence level expressed how sure the clinicians were about the accuracy of their assessment score. Clinicians were asked to rate their confidence level on a seven-point

Likert-scale question after assessing each task (“Confidence level when the task was assessed: 1=Very Uncertain, 7=Very Certain”).

### 5.3.2.3 Sense of presence & simulator sickness

The sense of presence was measured by a standard questionnaire, the Igroup Presence Questionnaire (IPQ) (Regenbrecht & Schubert, 2002). The IPQ questionnaire consists of 13 questions and defines the user’s general sense of presence, involvement, spatial, and realism; each question took the form of a seven-point scale after each condition. Questions related to simulator sickness were part of the sense-of-presence questionnaire. Similar to the experiment presented in the last chapter (Chapter 4), five questions were adapted.

### 5.3.2.4 User experience

Clinicians were asked to rate the ease and comfort of the simulator features on seven-point Likert-scale questions. These questions were the following: 1) “Do you think the controllability of the field of view made it easier to assess in the virtual environment?” (1=Harder, 7=Easier); 2) “When the field of view was static, did you feel more or less comfortable in your assessment?” (1=Less comfortable, 7=More comfortable); and 3) “When you were able to walk around, did you feel more or less comfortable in your assessment?” (1=Less comfortable, 7=More comfortable). There was also a question about the suitability of each of the observational techniques. Clinicians were asked: “For each of the following interfaces, how suitable is it for clinical assessment?” Clinicians had to indicate the suitability of each condition for clinical use. They were asked to rate each observation technique on a seven-point Likert-scale (1=Very Unsuitable, 7=Very Suitable).

### 5.3.3 Experimental Design

The design of this experiment was 3 (observational techniques) x 4 (virtual driving tasks) within-subjects factorial design. This yielded 12 conditions. Table 16 depicts the within-subjects factorial design. Measured variables included assessment score, ease, confidence level, sense of presence, experience, and clinical suitability. The driving tasks are turn while moving forwards (T<sub>1</sub>), turn while moving backwards (T<sub>2</sub>), turn in place (T<sub>3</sub>), and sideways manoeuvres (T<sub>4</sub>).

Table 16: 3x4 factorial design.

|            |          | Driving Tasks    |                  |                  |                  |
|------------|----------|------------------|------------------|------------------|------------------|
|            |          | T <sub>1</sub>   | T <sub>2</sub>   | T <sub>3</sub>   | T <sub>4</sub>   |
| Viewpoints | Standard | S-T <sub>1</sub> | S-T <sub>2</sub> | S-T <sub>3</sub> | S-T <sub>4</sub> |
|            | Orbit    | O-T <sub>1</sub> | O-T <sub>2</sub> | O-T <sub>3</sub> | O-T <sub>4</sub> |
|            | Walk     | W-T <sub>1</sub> | W-T <sub>2</sub> | W-T <sub>3</sub> | W-T <sub>4</sub> |

### 5.3.4 Counterbalancing

To control potential learning effects that could arise from assessing the same tasks in all three conditions, 1) the condition order was randomised in a counterbalanced order and 2) within each subject the score of the tasks was different in each condition, for example, T<sub>1</sub> would be “0” in the first condition, “1” in the second condition, and “2” in the third condition regardless of the condition order. In this case, the subject assessed four different tasks in each condition. In addition, the order of the tasks represented in each condition was randomised, which made it impossible for participants to guess the task score in the third condition. A block of three subjects completed one round of the randomisation. The following table (Table 17) shows the randomisation of the conditions, tasks, and task level.

Table 17: A block of complete randomisation repeated by every three subjects (T<sub>1-0</sub> means Task 1 – correct scores of 0).

|              |                      |                      |                      |                      |                      |                      |                      |                      |                      |                      |                      |                      |
|--------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Subject<br>1 | Standard             |                      |                      |                      | Orbit                |                      |                      |                      | Walk                 |                      |                      |                      |
|              | T <sub>1-</sub><br>0 | T <sub>4-</sub><br>2 | T <sub>2-</sub><br>1 | T <sub>3-</sub><br>0 | T <sub>3-</sub><br>1 | T <sub>2-</sub><br>2 | T <sub>4-</sub><br>0 | T <sub>1-</sub><br>1 | T <sub>4-</sub><br>1 | T <sub>3-</sub><br>2 | T <sub>1-</sub><br>2 | T <sub>2-</sub><br>0 |
| Subject<br>2 | Walk                 |                      |                      |                      | Standard             |                      |                      |                      | Orbit                |                      |                      |                      |
|              | T <sub>1-</sub><br>0 | T <sub>4-</sub><br>2 | T <sub>2-</sub><br>1 | T <sub>3-</sub><br>0 | T <sub>3-</sub><br>1 | T <sub>2-</sub><br>2 | T <sub>4-</sub><br>0 | T <sub>1-</sub><br>1 | T <sub>4-</sub><br>1 | T <sub>3-</sub><br>2 | T <sub>1-</sub><br>2 | T <sub>2-</sub><br>0 |
| Subject<br>3 | Orbit                |                      |                      |                      | Walk                 |                      |                      |                      | Standard             |                      |                      |                      |
|              | T <sub>1-</sub><br>0 | T <sub>4-</sub><br>2 | T <sub>2-</sub><br>1 | T <sub>3-</sub><br>0 | T <sub>3-</sub><br>1 | T <sub>2-</sub><br>2 | T <sub>4-</sub><br>0 | T <sub>1-</sub><br>1 | T <sub>4-</sub><br>1 | T <sub>3-</sub><br>2 | T <sub>1-</sub><br>2 | T <sub>2-</sub><br>0 |

### 5.3.5 Participant’s Task

The participant’s (clinician’s) task was to watch pre-recorded PWC driving tasks and assess them based on the WST. In the standard condition, the participant’s task was to sit down, watch the driving task (from the perspective of the PWC user), and assign a score at the end. In the orbit condition, the participant’s task was to use the mouse to zoom in and out, orbit around the driving tasks, and assign a score at the end. In the walk condition, the participant’s task was to put on the HMD, walk around the recorded driving task, and assign a score at the end.

### 5.3.6 Procedure

All experiment sheets were in English and French because the experiment was run in Montreal, a Francophone city. A translator was also available if required. Upon arrival, clinicians were welcomed, given the information sheet to read, and then asked to sign the consent form. This was followed by filling out a demographics questionnaire. Confounding variables such as prior experience with the HMD were controlled: Prior to the experiment, participants were asked questions about their experience with the HMD. These

questions determined how much information and training was needed before starting the actual experiment. All three observational techniques were then introduced to the participants and they had the chance to try each setup for as long as they needed with pre-recorded driving tasks for this purpose. The experiment procedure was then explained to the participants, including the condition order and the nature of the driving tasks. Participants were given the driving task description sheet and the assessment score criteria (all based on the WST). They were told they could refer to it as many times as they liked during the experiment.

After reading the task information sheet and the scoring schema, participants were asked to read the assessment questionnaire and told they would verbally answer the questions after each task. These questions were the following: 1) “Based on the Wheelchair Skills Test (WST) Version 4.2, I give this driving task a capacity score of X” (three-point scale); 2) “Using this setup, the assessment of this task was X” (seven-point scale); and 3) “Confidence level when the task was assessed” (seven-point scale). The clinician was then told that they would be asked these questions by the experimenter and that they needed to answer verbally. This was to make the procedure easier, especially when participants used the walk condition (HMD).

The order of the conditions was randomised beforehand. The experimenter selected the condition and task order from the menu (Figure 45) based on the pre-randomised order. After each condition, participants were given the sense-of-presence questionnaire and sickness questionnaire. After the completion of all three conditions, participants answered the perceived comparison questionnaire. Finally, participants were debriefed and given a chocolate bar. The entire procedure took approximately 40 minutes per participant. All experiment documents including questionnaires can be seen in Appendix C.

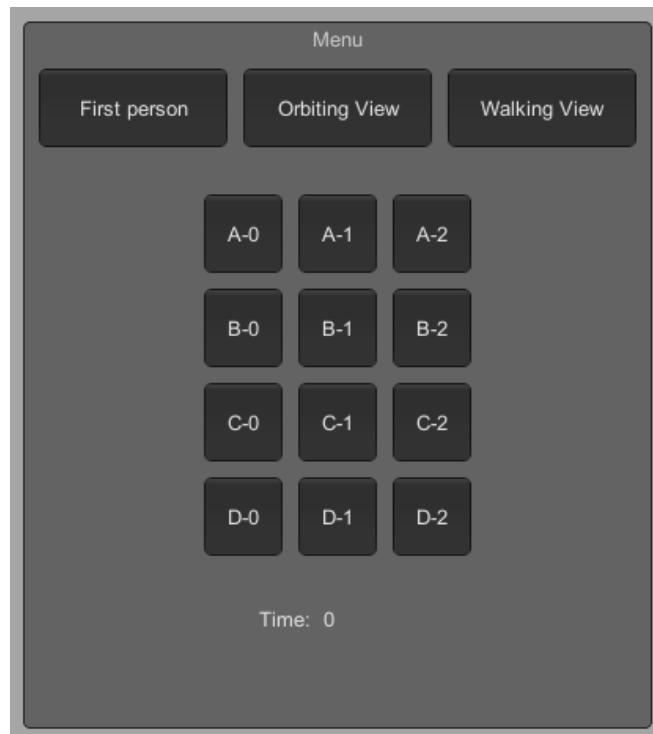


Figure 45: Experimenter menu to select the condition and the driving task based on a pre-randomised order

## 5.4 Results

In this study, the clinicians reported their assessment score and confidence level on four pre-recorded driving tasks in each condition. In addition, they indicated how easy it was to make their judgement using each condition. Their sense of presence, motion sickness, and opinion was obtained after each condition. The experiment was a 3 (viewpoints)  $\times$  4 (driving tasks) within-subjects factorial design; ANOVAs were run and main and interaction effects were examined.

### 5.4.1 Assessment scores

Virtual assessment scores were compared to the correct scores based on the pre-recorded driving tasks. To give an indication of the overall size of the difference between the correct and assigned scores, the square of the difference between correct score and judged score

(correct score – judge score) was calculated. The means of the assessment score, together with standard deviations are reported in Table 18. The walk condition showed the lowest difference between correct and judged scores ( $M=0.1$ ,  $SD=0.04$ ) followed by orbit ( $M=0.23$ ,  $SD=0.5$ ) and standard condition ( $M=0.73$ ,  $SD=0.14$ ). ANOVA showed no significant interaction between viewpoints and tasks on the clinicians’ assessment. There was also no significant mean effect for tasks. However, ANOVA confirmed a significant viewpoints main effect on clinician assessment,  $F(2, 28)=14.1$ ,  $p<.001$ ,  $\omega^2=0.5$ . A post hoc test showed that standard condition differs significantly from both orbit ( $p=.013$ ) and walk conditions ( $p=.001$ ). There was no significant effect between orbit and walk conditions.

Table 18: Virtual assessment means and standard deviations

|            |          | Driving Tasks  |                |                |                |             |
|------------|----------|----------------|----------------|----------------|----------------|-------------|
|            |          | T <sub>1</sub> | T <sub>2</sub> | T <sub>3</sub> | T <sub>4</sub> |             |
| Viewpoints | Standard | 0.6<br>(0.13)  | 1.1<br>(0.41)  | 0.7<br>(0.31)  | 0.5<br>(0.27)  | <b>0.73</b> |
|            | Orbit    | 0.13<br>(0.1)  | 0.33<br>(0.13) | 0.2<br>(0.11)  | 0.27<br>(0.12) | <b>0.23</b> |
|            | Walk     | 0.07<br>(0.07) | 0.13<br>(0.1)  | 0.00<br>(0.00) | 0.2<br>(0.11)  | <b>0.1</b>  |
|            |          | <b>0.27</b>    | <b>0.51</b>    | <b>0.31</b>    | <b>0.33</b>    |             |

### 5.4.2 Perceived ease of use

Means and standard deviations are reported in Table 19. It can be seen that the orbit and walk conditions were the easiest to assess each task compared to the standard condition. ANOVA confirmed significant interaction effects between viewpoint and task,  $F(3.06,84)=3.3$ ,  $p<.006$ ,  $\omega^2=.19$ , (Figure 46 shows significant interactions graphs). Significant main effects were also revealed for both viewpoints ( $F(2,28)=19.63$ ,  $p<.001$ ,  $\omega^2=0.58$ ) and tasks ( $F(3,42)=3.76$ ,  $p<.018$ ,  $\omega^2=0.21$ ). A post hoc test showed that standard viewpoint differs significantly from both orbit and walk viewpoints



( $p=.001$ ). It also showed that T<sub>2</sub> (moving backwards task) is perceived significantly harder to assess than T<sub>3</sub> (turn in place task) and T<sub>4</sub> (sideways manoeuvre task) with  $p=.046$  and  $p=.016$  (respectively).

Table 19: Means and standard deviations for easiness question

|            |          | Driving Tasks |               |               |               |             |
|------------|----------|---------------|---------------|---------------|---------------|-------------|
|            |          | T1            | T2            | T3            | T4            |             |
| Viewpoints | Standard | 4.5<br>(0.3)  | 3<br>(0.43)   | 4.5<br>(.43)  | 3.9<br>(0.44) | <b>3.96</b> |
|            | Orbit    | 5.5<br>(0.35) | 6.2<br>(0.17) | 6<br>(0.36)   | 6.3<br>(0.25) | <b>6.01</b> |
|            | Walk     | 5.7<br>(0.42) | 5.9<br>(0.32) | 6.1<br>(0.32) | 6.4<br>(0.34) | <b>6.02</b> |
|            |          | <b>5.22</b>   | <b>5.02</b>   | <b>5.55</b>   | <b>5.53</b>   |             |

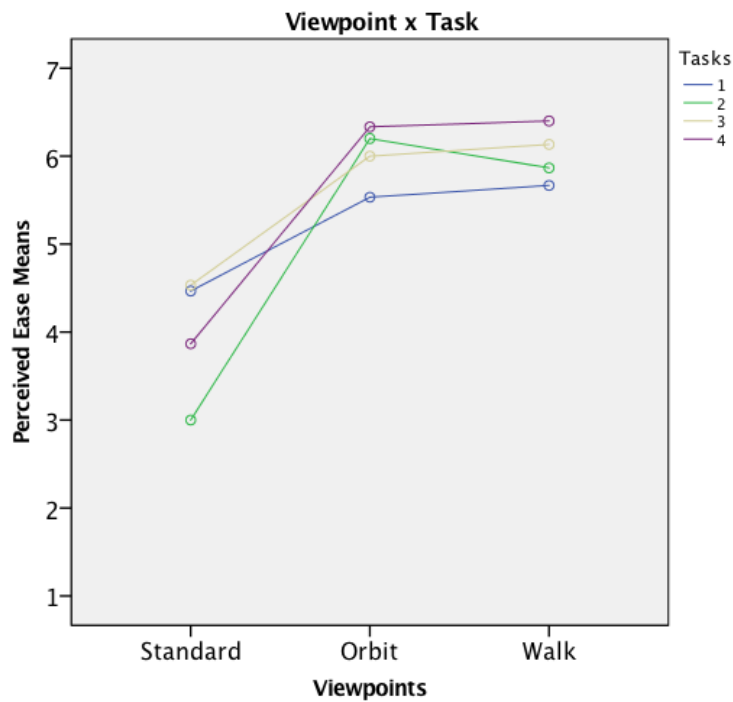


Figure 46: Interaction between viewpoints and tasks for perceived ease.

### 5.4.3 Confidence level

Means and standard deviations are reported in Table 20. An ANOVA of the confidence level revealed a significant interaction between viewpoints and tasks  $F(6, 84)=2.94$ ,  $p<.012$ ,  $\omega^2=.174$ . Figure 47 shows interaction between viewpoints and tasks. ANOVA also revealed a significant viewpoints main effect on the clinicians' confidence level,  $F(2,28)=21.3$ ,  $p<.001$ ,  $\omega^2=0.6$  with the walk condition being the highest ( $M=6.03$ ,  $SD=0.23$ ), followed by orbit ( $M=5.86$ ,  $SD=0.24$ ) and standard conditions ( $M=4.15$ ,  $SD=0.26$ ). Although means differ slightly between tasks, there were no significant differences.

Table 20: Means and standard deviations for confidence level

|            |          | Driving Tasks  |                |                |                |             |
|------------|----------|----------------|----------------|----------------|----------------|-------------|
|            |          | T <sub>1</sub> | T <sub>2</sub> | T <sub>3</sub> | T <sub>4</sub> |             |
| Viewpoints | Standard | 4.8<br>(0.3)   | 3.2<br>(0.43)  | 4.4<br>(.4)    | 4.2<br>(0.46)  | <b>4.15</b> |
|            | Orbit    | 5.3<br>(0.34)  | 6.06<br>(0.2)  | 6.06<br>(0.35) | 6<br>(0.29)    | <b>5.86</b> |
|            | Walk     | 6.1<br>(0.28)  | 5.6<br>(0.29)  | 6.1<br>(0.4)   | 6.4<br>(0.25)  | <b>6.03</b> |
|            |          | <b>5.4</b>     | <b>5.0</b>     | <b>5.5</b>     | <b>5.53</b>    |             |

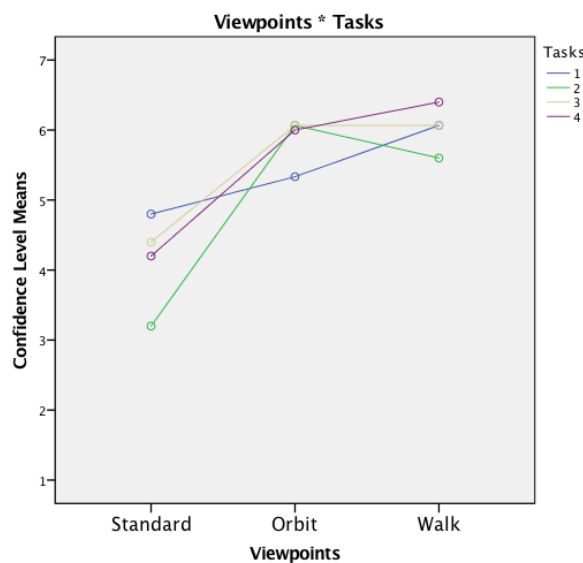


Figure 47: Interactions between viewpoints and tasks for confidence level.

#### 5.4.4 Correct answers

Correct answers are based on the number of matched judged scores to correct scores. A one-way ANOVA was conducted to compare the effect of the viewpoints on the clinician's judgement. The overall number of correct answers (out of 60) rose from 34 (standard) to 42 (orbit) and 54 (walk). Participants made more correct answers when using the walk condition ( $M=3.53$ ,  $SD=0.64$ ), followed by the orbit ( $M=3.07$ ,  $SD=0.7$ ) and standard ( $M=2.27$ ,  $SD=1.03$ ). Figure 48 show boxplots representing the correct answers responses. This was confirmed by the results of the statistical analysis (one-way ANOVA), which showed that the viewpoints had a significant main effect on the number of correct answers ( $F(2, 42)=9.36$ ,  $p=.001$ ). A post hoc test showed that there was a significant main effect between standard and orbit ( $p=.030$ ) and standard and walk ( $p=001$ ). However, there was no significant effect between orbit and walk conditions.

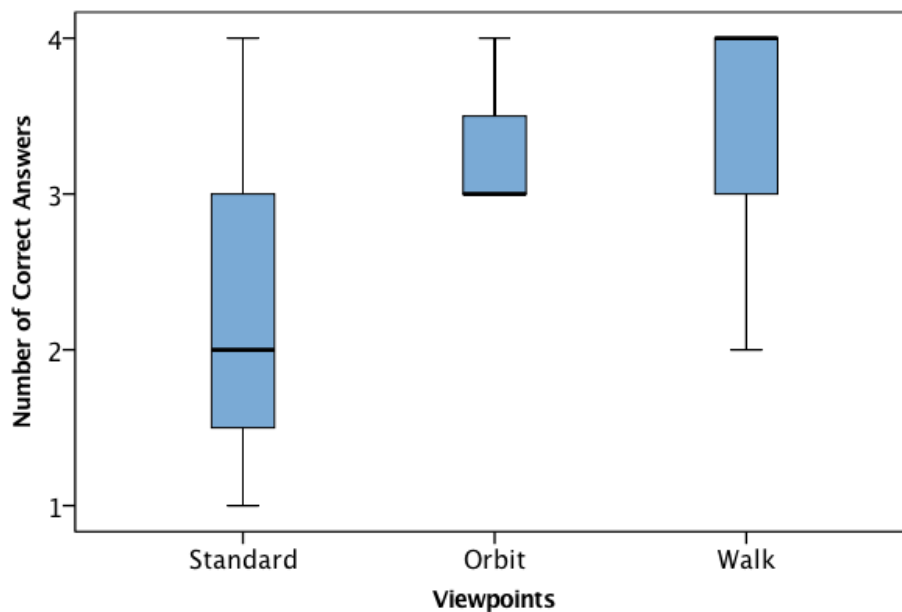


Figure 48: Number of correct answers. Box plot represents the median, interquartile (blue box), minimum, and maximum.

### 5.4.5 Sense of presence and simulator sickness

For sense of presence, the general sense of presence, involvement, spatial presence and realism were measured. The means and standard deviations are reported in Table 21. Overall, the walk condition was rated the highest in overall general sense of presence, involvement, spatial, and realism where all means were above the mid-point, whereas the means of the standard and orbit conditions were below the mid-point (see Figure 49).

Table 21: Means and standard deviations for general sense of presence, involvement, spatial presence, and realism (Scale -3 to 3).

|                           | Standard       | Orbit           | Walk          |
|---------------------------|----------------|-----------------|---------------|
| General sense of presence | -1.8<br>(1.14) | -0.4<br>(1.68)  | 2.6<br>(0.8)  |
| Involvement               | -0.3<br>(1.04) | -0.3<br>(0.87)  | 1.1<br>(0.9)  |
| Spatial presence          | -2.3<br>(0.72) | -0.96<br>(1.34) | 2.4<br>(0.93) |
| Realism                   | -1.8<br>(1.12) | -0.77<br>(1.15) | 0.3<br>(0.98) |

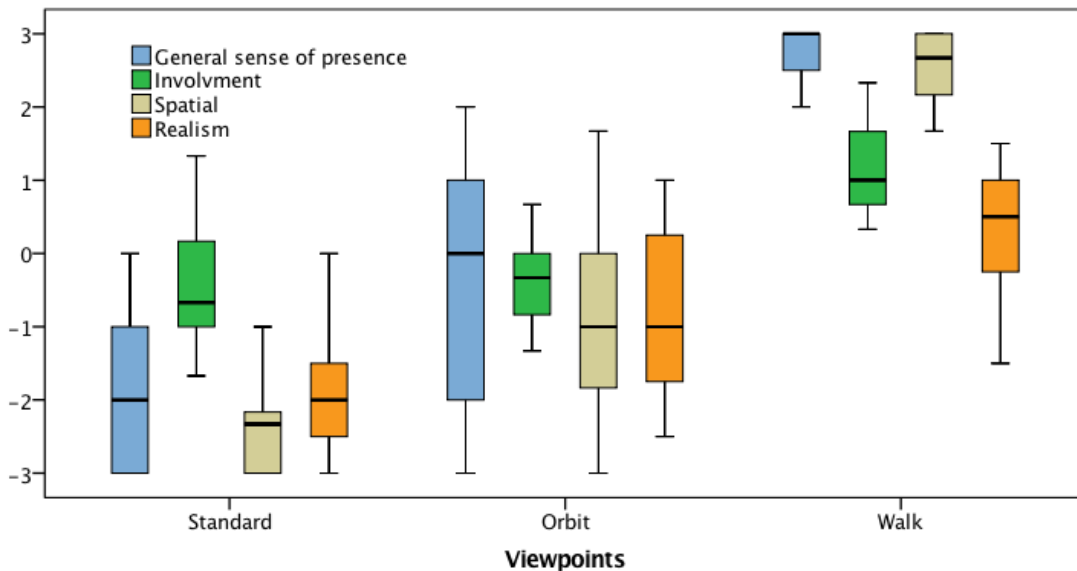


Figure 49: Boxplots representing all senses of presence categories. Box plot represents the median, interquartile (blue box), minimum, and maximum.

For the general sense of presence, the effects of the viewpoints on the clinicians' sense of presence were significant  $F(2, 42)=47.09, p<.001$ . A post hoc test shows significant differences between all the conditions: between the standard and orbit  $p<.013$ , between the standard and walk conditions  $p<.001$ , and between the orbit and walk conditions  $p=.001$ . For involvement, the effects of the viewpoints on user involvement were also significant  $F(2, 42)=11.1, p<.001$ . A post hoc test showed significant differences between standard and walk conditions  $p<.001$ , and between orbit and walk conditions  $p<.001$ . There was no significant difference between standard and orbit conditions.

For spatial presence, the effects of the observation techniques on user involvement were significant  $F(2, 42)=81.1, p<.001$ . A post hoc test showed significant differences between all the conditions: between the standard and orbit  $p=.003$ , between the standard and walk conditions  $p<.001$ , and between the orbit and walk conditions  $p=.001$ . For realism, the effects of the observation techniques on user realism were significant  $F(2, 42)=14.4, p<.001$ . A post hoc test showed significant differences between all the conditions: between the standard and orbit  $p=.031$ , between the standard and walk conditions  $p<.001$ , and between the orbit and walk conditions  $p=.031$ .

For simulator sickness, only five selected symptoms (general discomfort, difficulty concentrating, dizziness, difficulty focusing, and nausea) out of 16 (original SSQ) were measured. Each participant had to rate each symptom from 0 (none) to 4 (severe). Five clinicians felt sick in the standard condition while only 4 in both the orbit and walk conditions. The symptoms were slight (1) and did not affect the clinicians' ability to complete the study in any way.

### 5.4.6 Suitability and user experience

Clinicians were asked about the suitability of each viewpoint for use in a rehabilitation centre as an assessment tool. They were asked to rate each observation technique on a seven-point Likert-scale (1=Very Unsuitable, 7=Very Suitable). Participants rated the walk condition ( $M=6.27$ ,  $SD=0.8$ ) as the most suitable one, followed by the orbit ( $M=5.67$ ,  $SD=1.4$ ) and standard ( $M=1.73$ ,  $SD=0.7$ ) (see Figure 50). The one-way ANOVA analysis shows that there was a significant main effect between conditions  $F(2, 42)=88.4$ ,  $p<.001$ . A post hoc test showed that there was a significant main effect between standard and orbit ( $p<.001$ ) and standard and walk ( $p<.001$ ). However, there was no significant effect between orbit and walk conditions.

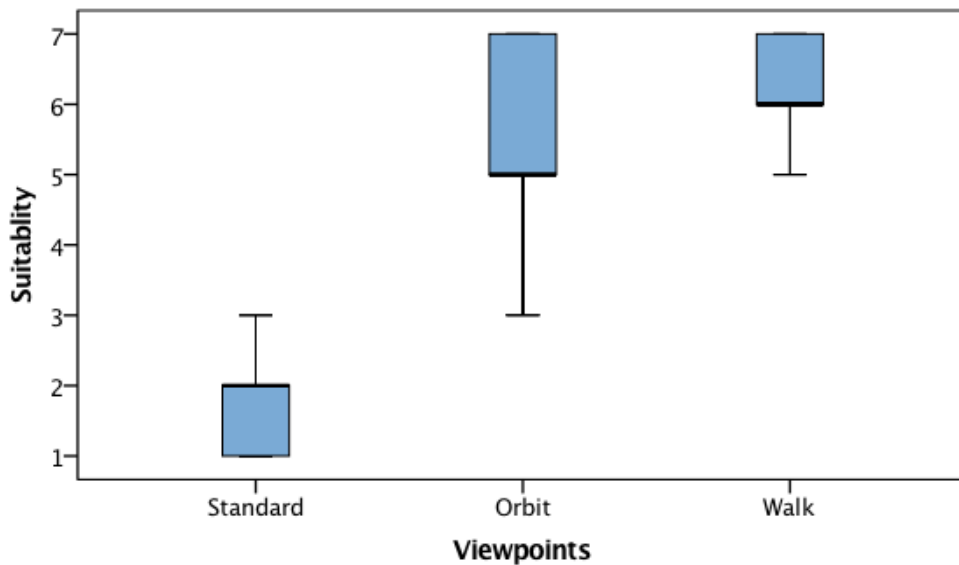


Figure 50: Suitability of the viewpoint in clinical use

For the user experience, three questions (seven-point Likert-like scale) were answered after completing all conditions. These questions were developed to gain a deeper understanding about the clinicians' experience. A Wilcoxon Signed Rank test, performed against the midpoint (4), tested if the clinicians agreed or disagreed with the statements. The first question corresponded to the controllability of the FOV regardless of what condition was used (Q1: "Do you think the

controllability of the field of view made it easier to assess in the virtual environment?”). Clinicians found it easier to evaluate the driving task while being able to control their viewpoint ( $M=6.6$ ,  $SD=0.63$ ). Wilcoxon confirmed a significant difference ( $p<.001$ ).

However, there was no significant difference when clinicians were asked about the comfort of assessing from the PWC user’s perspective ( $M=2.7$ ,  $SD=2.23$ ) (Q2: “when the field of view was static, did you feel more or less comfortable in your assessment?”). The last question (Q3: “when you were able to walk around, did you feel more or less comfortable in your assessment?”) particularly targeted the walk condition. Clinicians felt significantly ( $p<.002$ ) more comfortable ( $M=6$ ,  $SD=1.4$ ). Figure 51 shows the clinicians’ responses to questions 1, 2, and 3.

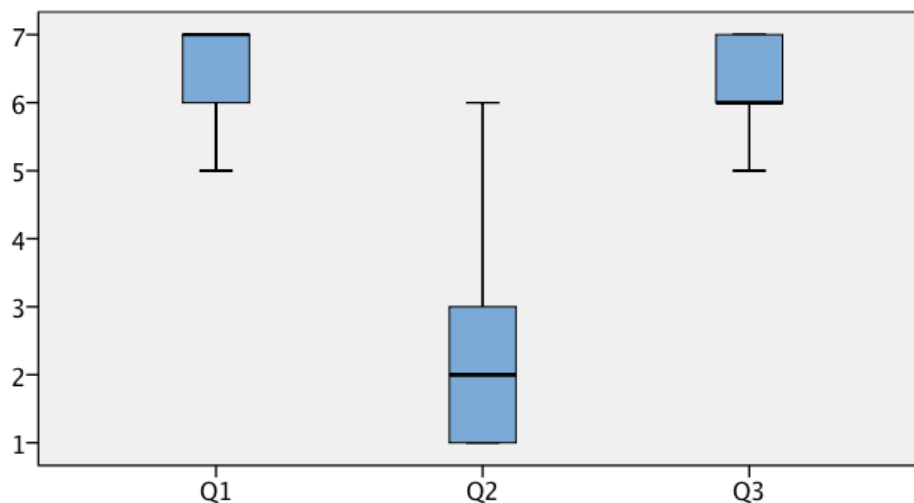


Figure 51: Clinicians’ responses to experience questions.

## 5.5 Discussion

This present study investigated virtual assessment of PWC driving tasks using three different viewpoints (egocentric, exocentric, and orbited tethered) and compared the score to a real-world standard. Ease of using each viewpoint, confidence level, sense of presence, and perceived suitability were also measured. These viewpoints are

represented as ‘walk’ (using a HMD), ‘orbit’ (using a standard mouse), and standard (no interaction with the simulator, only watching driving tasks from the PWC user’s perspective). The findings of this study suggest that the viewpoints’ main effect was strong and persistent on clinician assessment, perceived ease of use and confidence level. Although there was significant interaction between tasks and viewpoints on clinician’s perceived ease of use and confidence level, neither tasks nor interaction between tasks and viewpoints had any main effect on clinician’s judgement scores.

### 5.5.1 Assessment and correct answers

The walk condition (egocentric viewpoint) was the most effective form for virtual assessment in regard to PWC assessment when compared to the real-world score. Unlike the orbit and standard view, the difference between the judged scores and the correct ones when using the walk condition was minimal, and in some tasks was even zero. This is not surprising since such a view replicates real-world assessment and gave the clinician the freedom to behave in a natural way. The selected tasks were varied in their difficulties both from the user’s perspective (to drive) and clinician (to assess), yet they had no effect on the clinician’s judged scores. However, these tasks required different clinician interaction techniques to evaluate. For example, easier tasks such as the turn 180° and sideways manoeuvre may only require little interaction as the whole task can be seen from one fixed point of view.

The use of the orbit view in the experiment was to provide clinicians with an alternative low-cost solution to the walk condition. With the orbit technique, standard desktop, monitor, and mouse are required, whereas with the walk techniques, expensive HMD, large space, complicated setup, powerful desktop, and high-end graphic card are required. Also, clinicians were able to make significantly better judgements when using the orbit view, compared to the standard



condition. The zoom in and out feature allowed clinicians to set their desired distance from the virtual PWC and the orbit technique allowed them to change the viewpoints around the driving tasks, hence, a larger FOV was obtained. This finding provides evidence for the importance of the viewpoint perspective. The standard condition may have given the clinicians different insight into the driving tasks, as they viewed it from the perspective of a PWC user. With that said, it visually restricted the clinician's viewpoint and made the assessment more difficult.

The direct analysis of the number of correct answers between conditions further supports the analysis of the virtual assessment scores. Both the walk and orbit conditions were above the mid-point and clinicians judged significantly better than the standard condition. The number of correct answers varied in the standard condition from only from 1 to 4 correct answers. However, the orbit condition was the best with minimum correct answers of 3 and 2 in the walk condition. The orbit technique seems to provide quick access to extract the same amount of information available as the walk condition as reported by clinicians.

### 5.5.2 Perceived ease and confidence level

The viewpoints significantly affected clinicians both on how easy each system was to evaluate tasks and on their confidence level when assessing the driving tasks. The results show that the more the users perceived the system was easy to use their confidence level increased. For example, clinicians rated ease of using the standard condition at around 4 and their confidence level was also at 4. Their rating increased to 6 when they used either the orbit or the walk conditions. The significant increase of the confidence level over the standard condition shows the advantage of incorporating the clinician in the simulator as an active participant.

An interesting finding was that clinicians found it easier to assess T<sub>2</sub> (turn while moving backwards) using the orbit viewpoint, and their confidence level was also higher compared to the standard and walk viewpoints. In addition, T<sub>2</sub> was significantly perceived harder to judge compared to T<sub>3</sub> and T<sub>4</sub> (turn in space and sideways manoeuvre). Yet, tasks had no main effect on clinicians' judgement when judged score was compared to correct score. This supports the experiment design that tasks were indeed varied in difficulties.

### 5.5.3 Sense of presence

Generally, the walk condition was rated significantly across all conditions. Only the involvement aspect was not significantly different between standard and orbit conditions. Although the walk condition was rated significantly better than the orbit condition in all the sense-of-presence factors (general sense of presence, realism, spatial, involvement), this did not affect perceived ease, confidence level, and the number of correct answers. These findings suggest that even with a less immersive simulator, clinicians could still make accurate judgements. Simulator sickness, on the other hand, was low. However, there were more clinicians who felt sick in the standard condition (5) compared with only 4 in the walk and orbit conditions. Clinicians reported that with the standard viewpoint, the virtual PWC rotated on the screen, which resulted in a feeling of dizziness. This is not common, as simulator sickness is usually associated with HMDs. This could be because evaluating driving tasks from the user's perspective was something new to the clinicians; thus, it was hard for them to concentrate. This is supported by the experience question, where clinicians reported to feel less comfortable when the viewpoint was static.

### 5.5.4 Suitability and user experience

It was clear that clinicians were in favour of the walk and orbit conditions over the standard condition. In fact, the standard condition was rated very low in terms of suitability for clinical use. After the suitability rating, clinicians were asked why they would prefer one over the other. The responses can be divided into two groups: clinicians who chose the orbit viewpoint claimed low cost, easy setup, and quick change of viewpoint, whereas those who chose the walk condition claimed realistic evaluation, more immersion, and the potential for future features (such as, augmenting the user in the view). Most clinicians believed that being able to change the viewpoint made it easier for them to make an accurate decision.

## 5.6 Conclusion

This experiment demonstrates two approaches in assessing PWC driving tasks in VEs compared to the standard approach (assessment from the user's perspective) as used in Kamaraj et al. (2016) and Mahajan et al. (2013). These approaches attempt to replicate the real-world assessment that requires clinicians to view the PWC user from different angles to evaluate driving performance. The findings suggest that PWC simulators are two user systems, thus providing complementary perspectives for all involved users is essential for the assessment purpose. The HMD offers clinicians an all-encompassing view, whereas on a monitor, clinicians know that they are seeing only a particular, visually restricted view. This in itself might make the assessment more difficult.

This study had several strengths, particularly for recruiting expert clinicians to evaluate the driving tasks and receiving their critical feedback in the different viewpoints. The pre-recorded driving tasks from real expert PWC users eliminates two potential factors: 1)

variability in driving in the real and virtual world, and 2) validity of the assessment score in the VE. The randomisation of the conditions, driving tasks, and counterbalancing in each condition, made it hard for the clinician to guess the capacity score.

The following chapter (Chapter 6) will discuss the overall outcomes of this thesis. It will discuss limitations, applications, and future works in detail.

## CHAPTER 6: DISCUSSION & CONCLUSION

This chapter summarises and discusses the findings of this thesis, evaluating the contributions it makes to the fields of human-computer interaction and VE design, in particular the specific contributions to the advancement of PWC-based VEs. The studies conducted in this thesis, including the design, methods and results, will be revisited. Limitations of these studies, and potential avenues for future research, will also be discussed. Finally, the chapter will detail the clinical utility of PWC simulators for rehabilitation purposes.

### 6.1 Discussion

The principal goal of this thesis was to provide a suitable research platform for VR-based PWC applications. The importance of this thesis for advancing PWC-based VEs was highlighted in Chapter 1. It was proposed that VEs could provide a safer and cheaper assessment/training procedure compared with available solutions in the clinics. Related studies were analysed and problems with existing PWC simulators were outlined in Chapter 2. Three main issues with existing PWC simulators were identified: 1) Interaction device (which VR input devices are necessary and appropriate, and which virtual device representations can and should be implemented for PWC simulation?); 2) Simulator fidelity (how accurately can PWC users navigate in a VE?); and 3) Virtual assessment (how accurately can clinicians assess driving tasks in the VE compared to the real world?).

Review of the relevant literature revealed two key domains of PWC-based VE studies: training and assessment. The two fields share objective evaluation criteria, such as number of collisions (with objects or path boundaries), task completion time, chair trajectory, and joystick input. The simulations developed in previous studies employed either proprietary PWC joysticks or gaming joysticks;

however, no further research was conducted to evaluate the effects of these different input devices. While previous studies have shown that training in a PWC simulator has a positive transfer from the virtual to real world, PWC driving assessment is an underresearched area, with only a handful of studies incorporating clinical assessment into their simulator.

Three systems were designed, developed, and implemented to test each of the identified issues. The systems were developed with state-of-the-art software and hardware technologies and incorporated methods and techniques from computer science and computer graphic design. For each study, special consideration went into the design of the 3D models. Design challenges included the complex geometries of the PWC and the joysticks. Unity 3D was the core platform for building the simulators; the models were imported into the simulator. The simulators were developed with JavaScript and C++. APIs were necessary for the integration of immersive display hardware (Oculus Rift and HTC Vive) within Unity 3D. Chapter 5 includes a discussion of the challenges faced when tracking real PWC movement, and thoughts on how to solve these issues. The development of the simulators allowed for investigation of the identified issues.

This thesis involved extensive collaboration with field experts from the RATA South Rehabilitation Centre (Dunedin, New Zealand), the Jewish Rehabilitation Hospital (McGill University, Montreal, Canada), and the Interdisciplinary Research in Rehabilitation and Social Integration (Laval University, Quebec City, Canada). Data from three empirical studies (Chapters 3, 4, and 5) were collected and analysed with statistical hypotheses testing. Overall, evidence from the studies conducted indicated that visual representation of input devices had an impact on driving performance; immersion factors affected user perception and behaviour differently; and the clinician viewpoint influenced virtual assessment.

In the first study (Chapter 3), the effect of the visual representation of the input devices together with their real-world counterparts was investigated. In a within-subjects factorial design (2 physical joysticks x 2 virtual joysticks), 48 participants navigated a simulated PWC driving task in four conditions. The driving performance of participants was recorded in terms of wall collisions, boundary violations, and completion time; reported experiences were also measured. Potential learning effects were controlled by counterbalancing the conditions order and creating a balanced set of comparable paths that the participants traversed without interruption.

The results of the first study showed that the best performance was obtained when a virtual representation of the PWC joystick was displayed, regardless of which type of physical joystick (real PWC or gaming joystick) was used. This finding supports the results of previous studies (Powell & Powell, 2014) that changing the visual properties of virtual representations can have an impact on performance. An additional result of this study was that an inexpensive gaming joystick is adequate for use in a virtual PWC simulator, since no significant difference was found between the two physical joysticks.

The second study (Chapter 4) examined the effect of three immersion factors (display type, FOV, and self-avatar presence) on user perception, behaviour, and sense of presence while driving a simulated PWC. Behaviour was measured through embedded actions (implicit performance), perception through self-report of the perceived size/distance in the VE (explicit judgement), and sense of presence through a standard questionnaire. In a mixed-design experiment (2 avatar presence x 2 FOV x 2 display type), 72 participants engaged in a simulated PWC driving task. The participants' self-report indication (whether an action could or could not be performed) and behavioural decision-making (whether they actually passed through or went

around a particular gap) were recorded. Similar to the first study, the learning effect was controlled by randomising and counterbalancing the condition order, doorframes and gap widths within each condition, and creating a balanced set of comparable paths.

The result from the second experiment showed that all three factors affected the participants' sense of presence. While the display type significantly impacted both perceptual and behavioural measures, FOV only affected behavioural measures. This suggests that an effective PWC simulator should allow for the FOV to be changed, particularly if no HMD is used. The HMD display, in this case the Oculus Rift DK2, improved user perception and behaviour on most of the measures, especially with regard to the accuracy of detecting passable and unpassable doorframes or gaps. While the study found that this did not have a direct impact on user perception and behaviour, it did have significant interaction effects with the HMD and FOV.

In the third study (Chapter 5) the effect of three observational techniques (viewpoints) on clinician's assessment of PWC driving tasks in a VE was investigated. In addition, perceived ease of use, confidence level, and sense of presence were also examined by means of questionnaires. Four different tasks were selected from the WST with varying difficulties, and were then performed and tracked in the real world based on the WST scoring system; this resulted in 12 recorded driving tasks. In a within-subjects design, 15 expert clinicians assessed these pre-recorded driving tasks in three different conditions (walk, orbit, and standard viewpoints) using the WST capacity score system. The virtual assessment scores were then compared to real-world 'gold standard' scores.

The findings from this last study suggested that with orbit and walk conditions, clinicians could make accurate judgements with a high level of confidence. It also shows the importance of incorporating



viewpoints on clinician judgement. Furthermore, being able to walk and/or orbit around the view significantly affected the clinicians' sense of presence. This study concluded that a successful PWC simulator for driving assessment must incorporate the clinician's viewpoint into the design. The ability to change the viewpoint, in both the walk and orbit condition, improved accuracy, increased the clinician's confidence level and sense of presence, and was found to be clinically suitable. The orbit condition seems to provide an alternative approach for a cheaper and less complicated implementation, though the sense of presence was stronger in the walk condition. The ability to zoom in and out in the orbit condition gave clinicians the feeling of being able to move in the virtual space.

### 6.1.1 Contributions

The studies and findings of this thesis contribute to the field of PWC simulation, providing insight and guidance into the design and implementation of a system that can benefit both PWC users and clinicians. This thesis also investigated different means of enhancing and extending traditional clinical approaches. The nature of the identified issues are general enough to be applied to other contexts. For example, the insights from this thesis could be applied to other training/assessment systems, such as car, aeroplane, or other rehabilitation simulators that require ecologically valid simulation and transfer effects to real-world scenarios.

The development of the three simulators, including 3D modelling, design, and systems implementation, contributes to the studies as part of the apparatus and as prerequisites for the studies to take place. As a result of these experiments, the virtual assessment simulator is in the process of being transferred to clinical research, locally (RATA South Rehabilitation Clinic) and/or internationally (Jewish Rehabilitation Hospital in collaboration with McGill University, Montreal, Canada). This allows for new research directions

to be explored, bringing, in particular, virtual assessment into clinical use.

This thesis provides a number of general lessons to the field at large: Visual properties need to be carefully considered; perception and behaviour are affected differently by the levels of immersion; and ultimately, that VE can be a useful assessment tool when the clinician's viewpoint is incorporated. It was found that the representation of the input device has a significant impact on user experience and performance. Also identified was the fact that immersion factors such as display type and FOV influence user behaviour and perception. This finding could help to guide VR simulator designers to evoke targeted user behaviours and perceptions. Finally, it was discovered that embodied interaction techniques significantly affect clinician assessment by enabling more cues for the assessor. This indicates the utility of using VE as an assessment tool and the importance of incorporating the clinician's perspective (viewpoint) in such systems.

### 6.1.2 Future work

The findings in this thesis provide a testbed for many possible research directions. The limitations will be discussed together with suggestions for future directions for each of the three studies.

#### 6.1.2.1 First study (chapter 3)

The first study showed that participants perform better when the virtual PWC joystick was represented in terms of path and wall collisions, regardless of the physical joystick that was used. However, there were no significant results for task completion time and overall driving performance. Thus, future studies might consider longer session times, or repeated sessions and measures in combination with larger sample sizes. There is also the possibility that the position of the joystick within the environment (i.e., with respect to the user's

frames of reference – own body or wheelchair) played a confounding role, and future studies could explore varying positions of the joystick to address this.

Although the participants in the first study were a convenience sample, which enabled the power requirements to be met, the participants recruited randomly from the science festival may not have been sufficiently motivated, which could have impacted the study. In addition, the fact that participants were wholly unfamiliar with PWCs and the proprietary joystick controller enhanced the internal validity of the study. The question of external validity or generalisability to the population of wheelchair users remains open for further investigation. A study with real PWC users would lead to a better understanding and could be compared to the results of this study.

However, it should be recognised that even real PWC users vary in cognitive and physical ability, which would significantly impact performance. For example, a participant with a certain cognitive disorder may find it hard to even control the physical joystick, which would shift their focus from what is being displayed on the screen. Nevertheless, designing realistic virtual objects or even manipulating them is relatively simple and is worthy of consideration during VE design. As mentioned by Powell and Powell (2014), “Selecting object geometries which support accurate spatial location may help to reduce frustration and fatigue in VR”.

While in the first study only the joystick representations were investigated, there are other VE objects that could be the subject of future experiments, such as a self-avatar. The user’s body or body parts are varied in their presence and visualisation characteristics, which could potentially affect perception and performance. An interesting research area would be the study of the Proteus effect, where users change their behaviour in the VE depending on their

virtual avatar (Yee, Bailenson, & Ducheneaut, 2009). For example, would a healthy avatar representation help and encourage disabled users to perform better in the VE and, therefore, in the real world? If so, this could be a fruitful approach, especially for those who have struggled to learn to drive a PWC.

One of the limitations of the first study was that participants could look at both the virtual and physical joystick at the same time, and it is unknown whether they paid more attention to one or the other. This could be investigated more closely by tracking the user's eyes to determine how much time they spend looking directly at the virtual joystick. The visual effects could also be investigated with the use of a HMD that would eliminate such a confounding variable. In fact, an HMD would provide more cues that are absent in standard monitor displays.

Future studies could investigate whether the visual effects of the joystick in the first study were related to the visual dominance theory, a felt sense of presence in the environment, or both. However, one drawback of applying the visual dominance theory to the first study is that participants were exposed to both the virtual and physical joystick at the same time. To study such an effect, participants should be blinded from the physical joystick by a barrier or by simply using an HMD.

### 6.1.2.2 Second study (chapter 4)

In the second study, users' perception and behaviour were investigated by manipulating three immersion factors (display type, FOV, and self-avatar presence). It was found that: 1) All three factors affected user's sense of presence; 2) Display type affected both perceptual and behavioural measures; and 3) FOV only impacted behavioural measures. While the manipulated factors were mainly focused on the visual aspect, future work could identify more factors

and examine their impact on perception and behaviour. Investigation surrounding other factors may consider haptic and kinaesthetic perception, especially when a PWC platform is used. Another factor could be auditory perception, such as the sound of the PWC motor, surrounding area, or collision feedback.

The factors that were studied may have been sufficient for the selected PWC driving tasks (going through and judging the passability of gaps). More complex tasks, such as flying, car driving, or medical simulators may require the investigation of different factors. For instance, user characteristics – level of experience, cyber-sickness, or expert vs. novice users – are important factors, as indicated by Stanney, Mourant, and Kennedy (1998). Although the effect of the selected factors could be generalised to dynamic scenes, it may not be able to be generalised to static scenes, as depth perception depends on whether a scene is dynamic or static (Russell & Miles, 1993). Thus, it is important to investigate depth perception for both scenes.

The chosen scenario for the second study was specific to one task (passability). Further investigation may consider different tasks, such as selecting the right path, or choosing a safer path. Moreover, the selected task may also be unsuitable for other simulators where passability is not an issue; for instance, in flight simulators. Thus, special consideration must be given to determine which tasks will benefit the user most when using the VE. One important question would be whether the performed task enables a positive transfer of change detection to real-world scenarios.

One of the main limitations of the second study was that participants were largely university students. The sample group had good cognitive functions, were very familiar with computers and virtual games, and had likely interacted with virtual reality applications prior to the study. More significantly, they are not the main targeted user group for this particular simulation. These factors could have influenced

perception and behaviour differently from real subjects, who may even vary in their demographic characteristics, cognitive and physical capabilities. Age is another factor that affects human-VE interaction (Aykin & Aykin, 1991). Future research should consider a broader and more targeted sample, including actual PWC users.

In the second study, signal detection measures were used by means of the number of correct detections and false alarms, and the associated positive and negative predictive power measures, to calculate user perception and behaviour in the VE. These values could be useful as assessment and/or training measures in future applications. For instance, these values could determine the user's risk levels, indicating strengths and weaknesses in decision-making and judgement. Such outcomes also help to determine the user's spatial memory and navigation abilities. Future studies could also combine these measures together with the driving performance measure from the first study to provide more meaningful data for researchers and clinicians.

Future work could also compare the results of the signal detection measure to a real-world scenario by replicating the tasks to study the validity of using such measures in the VE. Signal detection could be applied to any psychological area. For example, it could be used to measure motivation through longer session times or repeated sessions. This would allow the experimenter to determine whether detection rates increase or decrease over time or session. A decrease in the detection rate would mean that the user is not detecting the stimuli signal and, therefore, losing motivation. This would be important for applications where motivation is a key factor, such as games and rehabilitation VEs.

### 6.1.2.3 Third study (chapter 5)

In the third experiment (virtual assessment), the effect of three observational techniques (walk, orbit, standard) on clinicians' assessment was investigated. The results showed that the walk and orbit condition allowed clinicians to make more accurate judgements, resulting in an increased confidence level. In this study, the assessed driving tasks were recorded to control performance variability if real users were involved. However, future research might include real PWC users and clinicians at the same time. This would allow for a direct comparison between real and virtual assessment and would also provide better understanding of the clinical use of such a system.

In this study, only four tasks out of 30 were assessed (sideways manoeuvring, turning in place, and turning while moving backwards and forwards). This was due to the experiment time frame and feasibility of implementing the tasks into the simulator. Future research could implement all the tasks presented in the WST, which may introduce some challenges with respect to interaction for some of the tasks. For example, picking up objects from the floor or moving through hinged doors. One possible solution to this issue would be the use of HMDs together with their controller acting as a hand. However, the use of HMDs by people with disabilities might be a concern, and further research should investigate the impact of cyber-sickness on impaired users.

Different assessment and/or training protocols should be implemented and tested with the inclusion of the clinician's viewpoint. Future research could involve the adaptation of the current assessment/training tool into virtual assessment. New tools for virtual assessment could eliminate danger and cost factors from reality. New tasks could be introduced to the user beyond current clinical tasks, such as driving outdoors and in the street. Virtual assessment would help clinicians to introduce tasks that are impossible to complete in

reality for safety reasons, for example, tasks that put users in great danger such as crossing the street.

Future research surrounding virtual assessment could combine current assessment measures (i.e., point scale based on clinician's observation) with objective measures that were used in the first and second experiment. The driving performance measure (e.g., completion time, number of collisions) could help clinicians to make accurate judgements instead of mere guesswork, in particular for novice clinicians. On the other hand, signal detection and predictive power measures could provide useful insights for understanding user behaviour as previously discussed. Future research could also investigate how these measures correlate with current assessment measures by directly comparing the outcomes of both measures. This could allow for the development and study of a new standardised protocol.

One of the limitations of the virtual assessment study was the restricted tracked space where the clinicians could move. Although the clinicians did not need a large space for the selected driving tasks to move around and assess, studying the possibility of walking outside of the tracked space would be important. For example, tasks that require users to go beyond the tracked space (maximum of 4 metres), such as crossing the street, would require new interaction techniques to be examined. One possible solution would be to use an HMD controller to navigate the space, or to virtually attach the clinician's camera (perspective) to the virtual PWC movement. This would give the clinician the freedom to move around the PWC regardless of where it goes.

Future investigation could consider augmented reality technology. This technology opens the possibility of allowing new tasks to be tested that could not be done in a real-world environment; an example is exposing users to unexpected moving objects while driving.



Augmented reality would also allow the clinician to observe real PWC users' reactions and facial expressions. Another subject that might be considered is how feedback could be communicated in VE between the user and clinician, especially when an HMD used. For example, instead of traditional verbal feedback, the clinician could demonstrate feedback by immediately taking over the movement of the virtual PWC, which in turn would benefit the user as they would see the demonstrated task from their perspective. Further research could target the usability of the system, as this is essential for its success in a clinical environment.

PWC assessment and training procedures go through different stages depending on the user's needs (e.g., setting, cognitive and physical evaluation, training). PWC simulators would not replace the entire procedure but would cover some of the stages or be used together with real-world evaluation. An example of this approach would be that the user gets assessed in both real and virtual environments, and the nature of the simulation would change for those who drove erratically by introducing extra guidance cues in the VE. Another application could be in the selection of the appropriate PWC for new users, where they could be assessed driving different types of virtual PWC (front, mid, rear propulsions) and their performance in each type could be examined.

## 6.2 Conclusion

PWCs are a crucial mobility solution that can change the lives of people with mobility impairments. Assessing individuals for eligibility, or teaching users how to operate PWCs, is a time-consuming, unsafe, and expensive process. VEs offer users and clinicians a preformat assessment and quantification tool that is safe and easy to use. Unfortunately, scant research has been conducted surrounding the use of PWC simulators in a clinical environment. To take advantage of

the latest technology and improve the testing experience, further research is required into the design and development of a PWC simulator.

This thesis investigated different aspects of the PWC simulator with the intention of providing a suitable research platform for the advancement of bringing PWC simulators into clinical use. A number of areas of the development and implementation of the simulator were investigated: Input devices (physical and virtual), user perception and behaviour, and the possibility of performing virtual assessment. The findings of this thesis show that the following: 1) Visual properties must be carefully selected and user driving performance is improved by representing a PWC joystick on the screen; 2) The display type significantly affected both perceptual and behavioural measures, whereas FOV only affected behavioural measures; and 3) When clinicians are a part of the simulator and provide a complementary perspective (viewpoint) that significantly improved their judgement and confidence level.

The findings from this thesis offer insight and guidance which allow future simulator design to evoke targeted user behaviour and perception. These findings could be generalised for other vehicle simulation systems, particularly towards navigational interaction in VR systems, for car, aeroplane, vessel or bicycle simulators. This thesis highlights the central importance of visualisation techniques, perception and behaviour measures, and complementary perspectives for multi-user VEs.

## REFERENCES

- Abellard, P., Randria, I., Abellard, A., Ben Khelifa, M. M., & Ramanantsizehe, P. (2010). Electric Wheelchair Navigation Simulators: why, when, how? In A. M. D. Di Paola & G. Cicirelli (Eds.), *Mechatronic Systems Applications*. InTech.
- Adelola, I., Cox, S., & Rahman. (2002). Adaptable virtual reality interface for powered wheelchair training of disabled children. In *Proceedings of The Fourth International Conference on Disability, Virtual Reality and Associated Technologies* (pp. 173–179). Veszprém, Hungary.
- Alshaer, A., Hoermann, S., & Regenbrecht, H. (2013). Influence of peripheral and stereoscopic vision on driving performance in a power wheelchair simulator system. In *2013 International Conference on Virtual Rehabilitation (ICVR)* (pp. 164–152).
- Americans with disabilities act of 1990, as amended. (n.d.). Retrieved October 24, 2012, from <http://www.ada.gov/pubs/ada.htm>
- Archambault, P., Routhier, F., Hamel, M., & Boissy, P. (2008). Analysis of movement to develop a virtual reality powered-wheelchair simulator. In *Virtual Rehabilitation, 2008* (pp. 133–138).
- Archambault, P. S., Chong, J. N. F., Sorrento, G., Routhier, F., & Boissy, P. (2011). Comparison of powered wheelchair driving

- performance in a real and in a simulated environment. In *2011 International Conference on Virtual Rehabilitation (ICVR)* (pp. 1–7).
- Archambault, P. S., Tremblay, S., Cachecho, S., Routhier, F., & Boissy, P. (2012). Driving performance in a power wheelchair simulator. *Disability and Rehabilitation. Assistive Technology*, 7(3), 226–233.
- Argelaguet, F., Kunert, A., Kulik, A., & Froehlich, B. (2010). Improving co-located collaboration with show-through techniques. In *2010 IEEE Symposium on 3D User Interfaces (3DUI)* (pp. 55–62).
- Axelsson, P., Minkel, J., Perr, A., & Yamada, D. (2002). *The Power Wheelchair Training Guide* (2nd edition). P A X Press.
- Aykin, N. M., & Aykin, T. (1991). Individual differences in human-computer interaction. *Computers & Industrial Engineering*, 20(3), 373–379.
- Barfield, W., Zeltzer, D., Sheridan, T., & Slater, M. (1995). Presence and performance within virtual environments. In W. Barfield & T. A. Furness III (Eds.), *Virtual Environments and Advanced Interface Design* (pp. 473–513). New York, NY, USA: Oxford University
- Betty J. Mohler, S. H. C.-R. (2010). The Effect of Viewing a Self-Avatar on Distance Judgments in an HMD-Based Virtual Environment. *Presence*, 19(3), 230–242.

- Blaauw, G. J. (1982). Driving Experience and Task Demands in Simulator and Instrumented Car: A Validation Study. *Human Factors*, 24(4), 473–486.
- Bowman, D., Koller, D., & Hodges, L. F. (1997). Travel in Immersive Virtual Environments: An Evaluation of Viewpoint Motion Control Techniques. In *Proceedings of the 1997 Virtual Reality Annual International Symposium (VRAIS '97)* (p. 45–). Washington, DC, USA: IEEE Computer Society.
- Bowman, D., Kruijff, E., LaViola, J., & Poupyrev, I. (2004). *3D User Interfaces: Theory and Practice*. Addison-Wesley.
- Browning, D., Cruz-Neira, C., Sandin, D., & DeFanti, T. (1994). Projection-Based Virtual Environments and Disability. In *Proceedings of the First Annual International Conference*.
- Browning, D. R., Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., & Edel, J. G. (1996). Input Interfacing to the CAVE by Persons with Disabilities. Presented at the CSUN's Annual International Conference, Carolina State University.
- Capustiac, A., Hesse, B., Schramm, D., & Banabic, D. (2011). A Human Centered Control Strategy for a Driving Simulator. *International Journal of Mechanical & Mechatronics Engineering*, 45–52.

- Chaves, E. S., Boninger, M. L., Cooper, R., Fitzgerald, S. G., Gray, D. B., & Cooper, R. A. (2004). Assessing the influence of wheelchair technology on perception of participation in spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, 85(11), 1854–1858.
- Colquhoun, H. W. (2000). *Dynamic tethering for enhanced remote control and navigation*. Ottawa: National Library of Canada.
- Cooper, R. A., Ding, D., Simpson, R., Fitzgerald, S. G., Spaeth, D. M., Guo, S., ... Boninger, M. L. (2005). Virtual reality and computer-enhanced training applied to wheeled mobility: an overview of work in Pittsburgh. *Assistive Technology: The Official Journal of RESNA*, 17(2), 159–170.
- 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.
- Cruz-Neira, C., Sandin, D. J., & DeFanti, T. A. (1993). Surround-screen Projection-based Virtual Reality: The Design and Implementation of the CAVE. In *Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques* (pp. 135–142). New York, NY, USA: ACM.
- 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.

Desbonnet, M., Cox, S., & Rahman, A. (1998). Development and evaluation of a virtual reality based training system for disabled children (pp. 177–182). Presented at the The 2nd European Conference on Disability, Virtual Reality and Associated Technologies, Skövde, Sweden: University of Reading.

Design for Access and Mobility – Buildings and Associated Facilities. (2001). New Zealand Standards.

Desmyter, J., Garvin, S., Lefèbvre, P., Stirano, F., & Vaturi, A. (2010). T1. 4 A review of safety, security accessibility and positive stimulation indicators. In *Seventh Framework Programme*.

Dicianno, B. E., Cooper, R. A., & Coltellaro, J. (2010). Joystick Control for Powered Mobility: Current State of Technology and Future Directions. *Physical Medicine and Rehabilitation Clinics of North America*, 21(1), 79–86.

Dodds, T., Mohler, B. J., de la Rosa, S., Streuber, S., & H. Bulthoff, H. (2011). Embodied interaction in immersive virtual environments with real time self-animated avatars. In *Workshop Embodied Interaction: Theory and Practice in HCI*. New York, NY, USA: ACM Press.

- Fehr, L., Langbein, W. E., & Skaar, S. B. (2000). Adequacy of power wheelchair control interfaces for persons with severe disabilities: a clinical survey. *Journal of Rehabilitation Research and Development*, 37(3), 353–360.
- Geuss, M., Stefanucci, J., Creem-Regehr, S., & Thompson, W. B. (2010). Can I Pass?: Using Affordances to Measure Perceived Size in Virtual Environments. In *Proceedings of the 7th Symposium on Applied Perception in Graphics and Visualization* (pp. 61–64). New York, NY, USA: ACM.
- Gibson, J. J. (1978). The Ecological Approach to the Visual Perception of Pictures. *Leonardo*, 11(3), 227–235.
- Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Hoboken: Taylor and Francis.
- Grant, P. M., Harrison, C. S., & Conway, B. A. (2004). Wheelchair simulation. In *Designing a more inclusive world* (pp. 101–109). Cambridge workshops on universal access and assistive technology.
- Hafid, N., & Inoue, T. (2005). Electric wheelchair simulator for rehabilitation of persons with motor disability. Presented at the Simpósio Brasileiro de Realidade Virtual, Belem, Brazil.



- Hale, K. S., & Stanney, K. M. (2014). *Handbook of Virtual Environments: Design, Implementation, and Applications* (2nd ed.). Boca Raton, FL, USA: CRC Press, Inc.
- Harrison, A., Derwent, G., Enticknap, A., Rose, F. D., & Attree, E. (2000). Application of virtual reality technology to the assessment and training of powered wheelchair users (pp. 15–22). Presented at the The 3rd international conference on disability, virtual reality and associated technologies., Alghero, Italy.
- 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 & Rehabilitation*, 24(11–12), 599–606.
- Harrison, C., Dall, P., Grant, P., Granat, M., Maver, T., & Bernard, C. (2000). Development of a wheelchair virtual reality platform for use in evaluating wheelchair access. In *Proceedings of the Third International Conference on Disability*. Alghero, Italy.
- Hasdai, A., Jessel, A. S., & Weiss, P. L. (1998). Use of a computer simulator for training children with disabilities in the operation of a powered wheelchair. *The American Journal of Occupational Therapy.: Official Publication of the American Occupational Therapy Association*, 52(3), 215–220.

- Heeter, C. (1992). Being There: The Subjective Experience of Presence. *Presence: Teleoperators and Virtual Environments*, 1(2), 262–271.
- Heineken, E., & Schulte, F. P. (2000). Acquiring Distance Knowledge In Virtual Environments. In *What Is Essential For Virtual Reality Systems To Meet Military Human Performance Goals?* (pp. 17-1-17-5). Hague, Netherland.
- Henry, D., & Furness, T. (1993). Spatial perception in virtual environments: Evaluating an architectural application. In , 1993 *IEEE Virtual Reality Annual International Symposium, 1993* (pp. 33–40).
- Holden, M. K. (2005). Virtual environments for motor rehabilitation: review. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, 8(3), 187-211-219.
- Hollands, J. G., & Lamb, M. (2011). Viewpoint tethering for remotely operated vehicles: effects on complex terrain navigation and spatial awareness. *Human Factors*, 53(2), 154–167.
- Holliday, P. J., Mihailidis, A., Rolfson, R., & Fernie, G. (2005). Understanding and measuring powered wheelchair mobility and manoeuvrability. Part I. Reach in confined spaces. *Disability and Rehabilitation*, 27(16), 939–949.

- Hou, J., Nam, Y., Peng, W., & Lee, K. M. (2012). Effects of screen size, viewing angle, and players' immersion tendencies on game experience. *Computers in Human Behavior*, 28(2), 617–623.
- Hughes, S., & Lewis, M. (2005). Attentive Navigation for Viewpoint Control in Virtual Environments. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 47(3), 630–643.
- Inman, D. P., Loge, K., Cram, A., & Peterson, M. (2011). Learning To Drive a Wheelchair in Virtual Reality. *Journal of Special Education Technology*, 26(3), 21–34.
- Johnson, S. J., Guediri, S. M., Kilkenney, C., & Clough, P. J. (2011). Development and Validation of a Virtual Reality Simulator: Human Factors Input to Interventional Radiology Training. *Human Factors*, 53(6), 612–625.
- Jonsson, A.-C., & Allwood, C. M. (2003). Stability and variability in the realism of confidence judgments over time, content domain, and gender. *Personality and Individual Differences*, 34(4), 559–574.
- Jung, J., Park, H., Hwang, D., Son, M., Beck, D., Park, J., & Park, W. (2014). A Review on Interaction Techniques in Virtual Environments. In *2014 International Conference on Industrial Engineering and Operations Management*. Bali, Indonesia.

- Kamaraj, D. C., Dicianno, B. E., Mahajan, H. P., Buhari, A. M., & Cooper, R. A. (2016). Interrater Reliability of the Power Mobility Road Test in the Virtual Reality–Based Simulator-2. *Archives of Physical Medicine and Rehabilitation*, 97(7), 1078–1084.
- Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*, 3(3), 203–220.
- Kenyon, R. V., & Ellis, S. R. (2014). Vision, Perception, and Object Manipulation in Virtual Environments. In P. L. (Tamar) Weiss, E. A. Keshner, & M. F. Levin (Eds.), *Virtual Reality for Physical and Motor Rehabilitation* (pp. 47–70). Springer New York.
- Kilkens, O. J., Dallmeijer, A. J., De Witte, L. P., Van Der Woude, L. H., & Post, M. W. (2004). The Wheelchair Circuit: Construct validity and responsiveness of a test to assess manual wheelchair mobility in persons with spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, 85(3), 424–431.
- Kilkens, O. J., Post, M. W., Dallmeijer, A. J., Seelen, H. A., & van der Woude, L. H. (2003). Wheelchair skills tests: a systematic review. *Clinical Rehabilitation*, 17(4), 418–430.
- Kirby, R. L., Ackroyd-Stolarz, S. A., Brown, M. G., Kirkland, S. A., & MacLeod, D. A. (1994). Wheelchair-related accidents caused by tips and falls among noninstitutionalized users of manually

- propelled wheelchairs in Nova Scotia. *American Journal of Physical Medicine & Rehabilitation*, 73(5), 319–330.
- Kirby, R. L., Dupuis, D. J., Macphee, A. H., Coolen, A. L., Smith, C., Best, K. L., ... Bonaparte, J. P. (2004). The wheelchair skills test (version 2.4): measurement properties. *Archives of Physical Medicine and Rehabilitation*, 85(5), 794–804.
- Kirby, R. L., Miller, W. C., Routhier, F., Demers, L., Mihailidis, A., Polgar, J. M., ... Sawatzky, B. (2015). Effectiveness of a Wheelchair Skills Training Program for Powered Wheelchair Users: A Randomized Controlled Trial. *Archives of Physical Medicine and Rehabilitation*, 96(11), 2017–2026.e3.
- Kirby, R. L., Swuste, J., Dupuis, D. J., MacLeod, D. A., & Monroe, R. (2002). The Wheelchair Skills Test: a pilot study of a new outcome measure. *Archives of Physical Medicine and Rehabilitation*, 83(1), 10–18.
- Kjeldskov, J. (2001). Combining interaction techniques and display types for virtual reality (pp. 77–83). Presented at the OZCHI: Annual Conference of the Australian Computer-Human Interaction Special Interest Group, Australia: Edith Cowan University Press.
- Koller, D. R., Mine, M. R., & Hudson, S. E. (1996). Head-tracked Orbital Viewing: An Interaction Technique for Immersive Virtual Environments. In *Proceedings of the 9th Annual ACM Symposium*

*on User Interface Software and Technology* (pp. 81–82). New York, NY, USA: ACM.

Lecuyer, A., Coquillart, S., Kheddar, A., Richard, P., & Coiffet, P. (2000). Pseudo-haptic feedback: can isometric input devices simulate force feedback? In *IEEE Virtual Reality, 2000. Proceedings* (pp. 83–90).

Lee, S.-H. (2014). Users' Satisfaction with Assistive Devices in South Korea. *Journal of Physical Therapy Science*, 26(4), 509–512.

Lim, S., & Reeves, B. (2009). Being in the Game: Effects of Avatar Choice and Point of View on Psychophysiological Responses During Play. *Media Psychology*, 12(4), 348–370.

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), 405–411.

Loeffler, C. E., & Anderson, T. (1994). What is Virtual Reality? In *The Virtual reality casebook* (pp. xii–xxv). New York: Van Nostrand.

Loomis, J. M. (1992). Presence and distal attribution: phenomenology, determinants, and assessment (Vol. 1666, pp. 590–596). Presented at the Human Vision, Visual Processing, and Digital Display III, International Society for Optics and Photonics.

- LoPresti, E. F., Koester, H. H., & Simpson, R. C. (2008). Toward automatic adjustment of pointing device configuration to accommodate physical impairment. *Disability and Rehabilitation: Assistive Technology*, 3(4), 221–235.
- 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.
- Mark, L. S. (1987). Eyeheight-scaled information about affordances: a study of sitting and stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, 13(3), 361–370.
- Massengale, S., Folden, D., McConnell, P., Stratton, L., & Whitehead, V. (2005). Effect of visual perception, visual function, cognition, and personality on power wheelchair use in adults. *Assistive Technology: The Official Journal of RESNA*, 17(2), 108–121.
- McCormick, E. P., Wickens, C. D., Banks, R., & Yeh, M. (1998). Frame of Reference Effects on Scientific Visualization Subtasks. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 40(3), 443–451.
- McCrea, P. H., Eng, J. J., & Hodgson, A. J. (2002). Biomechanics of reaching: Clinical implications for individuals with acquired brain injury. *Disability and Rehabilitation*, 24(10), 534–541.

- Mohler, B. J., Bühlhoff, H. H., Thompson, W. B., & Creem-Regehr, S. H. (2008). A Full-body Avatar Improves Egocentric Distance Judgments in an Immersive Virtual Environment. In *Proceedings of the 5th Symposium on Applied Perception in Graphics and Visualization* (p. 194–). New York, NY, USA: ACM.
- Morère, Y., Fritsch, C., Remy, S., Noordhout, B. M. de, & Bourhis, G. (2014). Powered Wheelchair Simulator: application to people with multiple sclerosis.
- Mortenson, W. B., Miller, W. C., & Auger, C. (2008). Issues for the Selection of Wheelchair-Specific Activity and Participation Outcome Measures: A Review. *Archives of Physical Medicine and Rehabilitation*, 89(6), 1177–1186.
- Motorized wheelchair. (2016, December 14). In *Wikipedia*. Retrieved from [https://en.wikipedia.org/w/index.php?title=Motorized\\_wheelchair&oldid=754751285](https://en.wikipedia.org/w/index.php?title=Motorized_wheelchair&oldid=754751285)
- Mountain, A. D., Kirby, R. L., Eskes, G. A., Smith, C., Duncan, H., MacLeod, D. A., & Thompson, K. (2010). Ability of People With Stroke to Learn Powered Wheelchair Skills: A Pilot Study. *Archives of Physical Medicine and Rehabilitation*, 91(4), 596–601.
- North, M. M., & North, S. M. (2016). A Comparative Study of Sense of Presence of Traditional Virtual Reality and Immersive



- Environments. *Australasian Journal of Information Systems*, 20(0).
- Ogle, T. (2002). *The Effects of Virtual Environments on Recall in Participants of Differing Levels of Field Dependence*. Virginia Polytechnic and State University, Blacksburg, Virginia.
- Pallavicini, F., Cipresso, P., Raspelli, S., Grassi, A., Serino, S., Vigna, C., ... Riva, G. (2013). Is virtual reality always an effective stressors for exposure treatments? some insights from a controlled trial. *BMC Psychiatry*, 13, 52.
- Phillips, B., & Zhao, H. (1993). Predictors of assistive technology abandonment. *Assistive Technology: The Official Journal of RESNA*, 5(1), 36–45.
- Pithon, T., Weiss, T., Richir, S., & Klinger, E. (2009). Wheelchair simulators: A review. *Technology and Disability*, 21(1), 1–10.
- Posner, M. I., Nissen, M. J., & Klein, R. M. (1976). Visual dominance: An information-processing account of its origins and significance. *Psychological Review*, 83(2), 157–171.
- Powell, V., & Powell, W. A. (2014). Locating objects in virtual reality – the effect of visual properties on target acquisition in unrestrained reaching. Presented at the Disability, Virtual Reality & Associated Technologies.

- Pronk, C. N., de Klerk, P. C., Schouten, A., Grashuis, J. L., Niesing, R., & Bangma, B. D. (1980). Electric wheelchair simulator as a man-machine system. *Scandinavian Journal of Rehabilitation Medicine*, 12(3), 129–135.
- Rabadi, M. H., & Vincent, A. S. (2015). Factors Predictive of Type of Powered Mobility Received by Veterans with Disability. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, 21, 1324–1332.
- Rébillat, M., Boutillon, X., Corteel, É., & Katz, B. F. G. (2012). Audio, Visual, and Audio-visual Egocentric Distance Perception by Moving Subjects in Virtual Environments. *ACM Trans. Appl. Percept.*, 9(4), 19:1–19:17.
- Regenbrecht, H., & Schubert, T. (2002). Real and Illusory Interactions Enhance Presence in Virtual Environments. *Presence: Teleoperators and Virtual Environments*, 11(4), 425–434.
- Regenbrecht, H. T., Schubert, T. W., & Friedmann, F. (1998). Measuring the Sense of Presence and its Relations to Fear of Heights in Virtual Environments. *International Journal of Human-Computer Interaction*, 10(3), 233–249.
- Riemer-Reiss, M. L., & Wacker, R. R. (2000). Factors Associated with Assistive Technology Discontinuance among Individuals with Disabilities. *The Journal of Rehabilitation*, 66(3), 44.

- Ries, B., Interrante, V., Kaeding, M., & Anderson, L. (2008). The effect of self-embodiment on distance perception in immersive virtual environments (p. 167). ACM Press.
- Rock, I. (1966). *The nature of perceptual adaptation*. Oxford, England: Basic Books.
- Rock, I., & Victory, J. (1964). Vision and touch: an experimentally created conflict between the two senses. *Science (New York, N.Y.)*, 143(3606), 594–596.
- Rodriguez, N. (2015). Development of a wheelchair simulator for children with multiple disabilities. *arXiv:1601.04436 [Cs]*, 19–21.
- Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M., Penn, P. R., & Ambihapahan, N. (2000). Training in virtual environments: transfer to real world tasks and equivalence to real task training. *Ergonomics*, 43(4), 494–511.
- Rupp, M. A., Oppold, P., & McConnell, D. S. (2015). Evaluating input device usability as a function of task difficulty in a tracking task. *Ergonomics*, 1–14.
- Russell, G., & Miles, R. (1993). Volumetric visualization of 3D data. In S. Ellis (Ed.), *Pictorial Communication In Real And Virtual Environments* (2nd ed, pp. 131–137). London: Taylor and Francis.

- Scherer, M. J., & Cushman, L. A. (2001). Measuring subjective quality of life following spinal cord injury: a validation study of the assistive technology device predisposition assessment. *Disability and Rehabilitation*, 23(9), 387–393.
- Schubert, T., Friedmann, F., & Regenbrecht, H. (1999). Decomposing the Sense of Presence: Factor Analytic Insights. In *presented at the 2nd International Workshop on Presence* (pp. 6–7).
- Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The Experience of Presence: Factor Analytic Insights. *Presence: Teleoper. Virtual Environ.*, 10(3), 266–281.
- Schuemie, M. J., van der Straaten, P., Krijn, M., & van der Mast, C. A. (2001). Research on presence in virtual reality: a survey. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, 4(2), 183–201.
- Schuler, T., Santos, L. F. dos, & Hoermann, S. (2014). Harnessing the experience of presence for virtual motor rehabilitation: towards a guideline for the development of virtual reality environments. Presented at the Disability, Virtual Reality & Associated Technologies.
- Schuler, T., Santos, L. F. dos, & Hoermann, S. (2015). Designing virtual environments for motor rehabilitation: Towards a framework for the integration of best-practice information. In

*2015 International Conference on Virtual Rehabilitation Proceedings (ICVR)* (pp. 145–146).

Schultze, U. (2010). Embodiment and presence in virtual worlds: a review. *Journal of Information Technology*, 25(4), 434–449.

Sheridan, T. B. (1992). Musings on Telepresence and Virtual Presence. *Presence: Teleoper. Virtual Environ.*, 1(1), 120–126.

Slater, M., & Wilbur, S. (1997). A Framework for Immersive Virtual Environments Five: Speculations on the Role of Presence in Virtual Environments. *Presence: Teleoper. Virtual Environ.*, 6(6), 603–616.

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.

Srinivasan, M. A., Beauregard, G. L., & Brock, D. (1996). The impact of visual information on the haptic perception of stiffness in virtual environments (Vol. 58, pp. 555–559). Presented at the ASME Winter Annual Meeting.

Stanney, K. M., Kennedy, R. S., Drexler, J. M., & Harm, D. L. (1999). Motion sickness and proprioceptive aftereffects following virtual environment exposure. *Applied Ergonomics*, 30(1), 27–38.

- Stanney, K. M., Mourant, R. R., & Kennedy, R. S. (1998). Human Factors Issues in Virtual Environments: A Review of the Literature. *Presence: Teleoperators and Virtual Environments*, 7(4), 327–351.
- Sun, H.-M., Li, S.-P., Zhu, Y.-Q., & Hsiao, B. (2015). The effect of user's perceived presence and promotion focus on usability for interacting in virtual environments. *Applied Ergonomics*, 50, 126–132.
- Swan, J. E., Stredney, D., Carlson, W., & Blostein, B. (1994). The Determination of Wheelchair User Proficiency and Environmental Accessibility through Virtual Simulation. In *Proceedings of the 2nd Annual International Conference: Virtual Reality and Persons with Disabilities* (pp. 156–161). California.
- Szalma, J. L., Hancock, P. A., Warm, J. S., Dember, W. N., & Parsons, K. S. (2006). Training for vigilance: using predictive power to evaluate feedback effectiveness. *Human Factors*, 48(4), 682–692.
- Wang, W. (2001). Dynamic Viewpoint Tethering: Controlling a Virtual Camera for Effective Navigation in Virtual Environments. In *CHI '01 Extended Abstracts on Human Factors in Computing Systems* (pp. 93–94). New York, NY, USA: ACM.
- Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: body-scaled information for affordances.

*Journal of Experimental Psychology. Human Perception and Performance*, 13(3), 371–383.

Welch, R. B. (1999). How can we determine if the sense of presence affects task performance? *Presence (Cambridge, Mass.)*, 8(5), 574–577.

Wheelchair Skills Program. (n.d.). Retrieved March 17, 2015, from <http://www.wheelchairskillsprogram.ca/eng/>

WheelSim. (2007). (Version 2.1). LifeTool.

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoper. Virtual Environ.*, 7(3), 225–240.

World Health Organization. (2011). *World Report on Disability* (p. 24). Switzerland. Retrieved from [http://www.who.int/disabilities/world\\_report/2011/report/en/](http://www.who.int/disabilities/world_report/2011/report/en/)

WST 4.2 Form for Powered Wheelchairs Operated by Their Users. (n.d.). Retrieved November 12, 2013, from <http://www.wheelchairskillsprogram.ca/eng/index.php>

Xiang, H., Chany, A.-M., & Smith, G. A. (2006). Wheelchair related injuries treated in US emergency departments. *Injury Prevention*, 12(1), 8–11.

Yee, N., Bailenson, J. N., & Ducheneaut, N. (2009). The Proteus Effect: Implications of Transformed Digital Self-Representation on Online and Offline Behavior. *Communication Research*, 36(2), 285–312.



## APPENDICES

The appendices A, B, and C are the documents used in the three studies respectively.

## Appendix A: Documents for interaction and visualisation experiment (Chapter 3)

| PWCsim Experiment: Task Discription |  |   |  |   |
|-------------------------------------|--|---|--|---|
| Virtual Joysticks                   |     |   |  |   |
| Physical Joysticks                  |    |    |  |   |
| Wheelchair                          |  |   |  |   |
| Task                                | Signs  |    |  |  |
|                                     | Task   | <p>Follow the path<br/>           Avoid collision with path and walls<br/>           Finish as fast as possible<br/>           Pay attention to the virtual joysticks</p> |  |   |



|                     |              |
|---------------------|--------------|
| Participant#        |              |
| Condition order set |              |
| Date & Time         | /7/2014 : pm |

iPWCsim Experiment

**What's the right device for controlling virtual wheels?**

**Participant Demographic Survey**

**1. Age .....**

**2. Gender** Male / Female

**3. Which is your dominant hand?**

- Left Hand
- Right Hand
- Left or Right Hand depending on task (*Cross-dominance or Mixed-handedness*)
- Left and Right hand equally for all tasks (*ambidextrous*)
- Neither - low level of dexterity (*ambilevous or ambisinister*)

**4. Have you used a joystick before the session?**

- No
- No, but know what it is all about.
- Yes.

**5. How good you think you are in using the joystick before the session?**

Haven't played it                        I am very good at it



|                     |              |
|---------------------|--------------|
| Participant#        |              |
| Condition order set |              |
| Date & Time         | /7/2014 : pm |

iPWCsim Experiment

**What's the right device for controlling virtual wheels?**

**Participant Perception Questionnaire**

Please read each statement below, and indicate how it applied to your experience using this virtual environment. There are no right or wrong answers.

**1. Overall, I felt as though I was operating the virtual joystick presented on the screen**

Strongly disagree    1    2    3    4    5    6    7    Strongly agree

**2. Overall, I felt as though I was operating the physical joystick in my hand**

Strongly disagree    1    2    3    4    5    6    7    Strongly agree

**3. Overall, I was aware of the switching between the virtual joysticks**

Strongly disagree    1    2    3    4    5    6    7    Strongly agree

**4. Overall, I was aware of the differences between the joystick on the screen and the one in my hand**

Strongly disagree    1    2    3    4    5    6    7    Strongly agree

Thank you very much for your time and participation

# Appendix B: Documents for perception and behaviour experiment (Chapter 4)

---



**Experiment Participation**  
**Department Of Psychology**  
**University Of Otago**

## EXPERIMENT APPROVAL FORM

### Experiment Details

**Code:** 2510034  
**Name:** Becoming a 'Star' Driver in an Immersive Virtual Environment  
**Credits:** 1  
**Student Level:** Stage 1  
Stage 2  
**Description:** This experiment investigates how accurately can someone drive in a virtual environment. In this experiment, participants will be driving a simulated power wheelchair through a virtual environment, using a gaming joystick. they will fill in a questionnaire between session (4 session) and they will be asked questions during the experiment. This is also a good opportunity for students to see new technologies and learn more about virtual environment  
**Location:** Annexe building, 119 Albany St (intersection of Clyde and Albany Streets, Blue building in the corner). Text me when you get there so I can open the door for you  
**# Sessions:** 4  
**Session Duration:** 8 minutes  
**Date Commences:** 01/05/2015  
**Date Finishes:** 22/05/2015  
**# Participants:** 80

### Experiment People

**Supervisor:** David O'Hare  
**Experimenters:** Abdul Alshaer (alsab548@student.otago.ac.nz, 021 078 1955)

There are at least two pages to this document. Make sure you have all the pages and the relevant signatures. Further instructions for experiment approval are overleaf.



**Experiment Participation  
Department Of Psychology  
University Of Otago**

## **EXPERIMENT APPROVAL FORM**

### **Summary Sheet Model Answers**

**Q1. The design of this experiment is:**

mixed (between and within)

**Q2. How many independent (manipulated) variables are present in the experiment?**

3 (three)

**Q3. How many dependent (measured) variables are present in the experiment?**

3 (three)

**Q4. What area of psychology does this experiment closely pertain to?**

perception

**Q5. BRIEFLY explain the main experimental question or hypothesis (in one sentence).**

How accurately can you drive in a virtual environment?

### **Experimenter Acknowledgements**

- \* I have read the current 'Guidelines for Recruiting Experiment Participants'.
- \* I agree to provide participants with adequate debriefing for my experiment.
- \* I agree to update participant attendance information on the website regularly.
- \* I acknowledge that the answers provided in the Summary Sheet Model Answers section are accurate to the best of my knowledge.

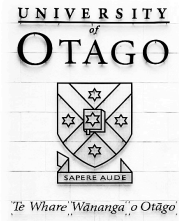
### **Approval Process**

In order for this experiment to be approved, you need to sign this form and your supervisor needs to sign this form. Once you have both signatures, take this form and a copy of your ethical approval form to the Experiment Participation Administrator at Student Enquiries in the William James building.

### **Signatures**

**Supervisor:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Experimenter:** \_\_\_\_\_ **Date:** \_\_\_\_\_



## How accurately can you drive in a virtual environment?

### Consent Form for Participants

I, \_\_\_\_\_ (please print your name)

- I have read the Information Sheet concerning this project and understand what it is about.
- My participation in the project is entirely voluntary
- I understand that I may withdraw from the experiment at any time without any disadvantage.
- All data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend may be retained in secure storage for five years, after which it will be destroyed
- The results of the project may be published and available in the library, but every attempt will be made by the researcher to preserve my anonymity.

Signature: \_\_\_\_\_

Date: \_\_/\_\_/2015



## **How accurately can you drive in a virtual environment?**

### **INFORMATION SHEET FOR PARTICIPANTS**

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you and we thank you for considering our request.

#### **What is the Aim of the Project?**

The aim of this project is to investigate how accurately you can drive a virtual power wheelchair in a virtual environment under different conditions. The result will influence our decision on how to build a more realistic PWC simulator. This project is being undertaken as part of the requirements for Abdulaziz Alshaer's PhD research.

#### **What Types of Participants are being sought?**

Participants are drawn from the Psychology Department's Stage One and Stage Two participant pool, and will be rewarded with course credit for their participation. The sample requires 80 participants. Participants need to be visually unimpaired (or corrected with lenses). Results of the study will be made available through email for any participant that wishes to receive a copy after the study's completion.

#### **What will Participants be asked to do?**

Should you agree to take part in this project, you will be asked to drive a virtual power wheelchair in a virtual environment, using a joystick. You will be asked questions during the experiment. After each condition you will be asked to fill in a sense of presence questionnaire, including questions about simulator sickness. At the end, you will be asked to fill in a comparative questionnaire. Please be aware that you may decide not to take part in the project without any disadvantage to yourself.

#### **What Data or Information will be collected and what use will be made of it?**

In this experiment, two methods will be used to collect data: subjectively, through questionnaires and objectively, through the simulator. A general demographics questionnaire will collect data such as age, sex, and dominant hand, gaming joystick experience- this is used to order data into individual sets for comparison and correlations. A sense of presence questionnaire, simulator sickness and comparative questionnaires will collect data that used for direct comparison between each condition. Objectively, other data will be recorded while performing the task in the simulator, such as, number of collisions, number of stars collected, number of right/wrong attempts, answers to judgments questions and time spent to complete the task - this is used to measure affordance perception of the virtual environment. All of the data collected will be coded to provide the best efforts at anonymity and statistically analysed for significant results to determine what type of presentation method leads to better performance.



The data collected will be securely stored in such a way that only those mentioned below will be able to gain access to it. Data obtained as a result of the research will be retained for **at least 5 years** in secure storage. Any personal information held on the participants such as contact information and demographics may be destroyed at the completion of the research even though the data derived from the research will, in most cases, be kept for much longer or possibly indefinitely. The lead researcher and his supervisor will have access to all data, in addition to additional coders of data to provide blind assessment.

The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve your anonymity.

#### **Can Participants change their mind and withdraw from the project?**

You may withdraw from participation in the project at any time and without any disadvantage to yourself.

#### **What if Participants have any Questions?**

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Abdulaziz Alshaer  
Department of Information  
Science  
a.alshaer@hotmail.com

Assoc. Prof. David O'Hare  
Department of Psychology  
ohare@psy.otago.ac.nz

Assoc. Prof. Holger Regenbrecht  
Department of Information Science  
holger.regenbrecht@otago.ac.nz

This study has been approved by the Department of Psychology. However, if you have any concerns about the ethical conduct of the research you may contact the University of Otago Human Ethics Committee through the Human Ethics Committee Administrator (ph 03 479-8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.



|                     |                 |
|---------------------|-----------------|
| Participant#        |                 |
| Condition order set |                 |
| Date & Time         | / /2015 : pm/am |

**How accurately can you drive in a virtual environment?**

**Participant Demographic Survey**

**1. Age .....**

**2. Gender** Male / Female

**3. Which is your dominant hand?**

- Left Hand
- Right Hand
- Left or Right Hand depending on task (*Cross-dominance or Mixed-handedness*)
- Left and Right hand equally for all tasks (*ambidextrous*)

**4. Have you used a gaming joystick before?**

- No
- No, but know what it is all about.
- Yes.

**5. How good you think you are in using the joystick?**

Haven't played it                        I am very good at it

**6. Do you have normal or corrected to normal (e.g. glasses, contact lenses) vision?**

- Yes
- No

If No please specify issue: \_\_\_\_\_

**7. Do you have a disability of the hand, arm, shoulder, neck, back or other health issues that could affect your performance in this experiment (e.g flu)?**

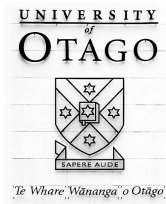
- No
- Yes

If Yes please specify: \_\_\_\_\_

**8. Have you used a head mounted display before?**

- No
- No, but know what it is all about.
- Yes.

Thank you very much for your time and participation



## **How accurately can you drive in a virtual environment?**

### **Task Description**

In this experiment, we aim to use a virtual environment to help people who are using power wheelchairs to drive more safely and accurately. Your participation in this experiment is important to achieve this goal.

Please read the following instructions carefully.

Today you will be driving a simulated power wheelchair through an artificial virtual environment, using a gaming joystick. You will experience two different modes: 1) you may/may not see an avatar sitting in the wheelchair and 2) you may/may not be able to look around in the virtual environment. There will be a start and an end point and all you need is to follow the directions (red arrows on the floor). You will be stopped automatically at stop signs (also drawn on the floor), and you will be asked a question by the experimenter. While driving through the virtual environment (a hallway) you will see pairs of poles with a gap between them, and a star in the middle of each. Your task is to collect the stars but be aware that you should avoid collisions while collecting the star. Imagine this as a real power wheelchair in real environment where you would avoid collisions and make the right decisions when navigating. It is your decision whether you choose to drive through the gap or pass around them.

#### **To summarize:**

- **At each stop sign you will see a door frame and you have to judge whether it is a passable door frame or not**
- **Your task is to collect the stars if you think you can pass through the gap where each star is**

The experimenter will now start with a “warm-up” round of the simulator so that you can make yourself familiar with the system and joystick. You should ask any questions during the warm-up session. You can take as long as you like until you feel comfortable in using the joystick and driving the virtual power wheelchair.







|                     |                 |
|---------------------|-----------------|
| Participant#        |                 |
| Condition order set |                 |
| Date & Time         | / /2014 : pm/am |

**How accurately can you drive in a virtual environment?**

**Simulator Sickness Questions**

**SYMPTOM CHECKLIST (Based in SSQ Questionnaire)**

**Instruction: please fill in this questionnaire. Circle below if any of the symptoms apply to you now.**

| SYMPTOM                  | None | Slight | Moderate | Severe |
|--------------------------|------|--------|----------|--------|
| General discomfort       | 0    | 1      | 2        | 3      |
| Difficulty concentrating | 0    | 1      | 2        | 3      |
| Dizzy                    | 0    | 1      | 2        | 3      |
| Difficulty focusing      | 0    | 1      | 2        | 3      |
| Nausea                   | 0    | 1      | 2        | 3      |

Please check that you have answered all the questions

**Please write down any additional comments you may have about your experience with this virtual environment:**





Thank you very much for your time and participation

Recording Sheet 1

| Sub | Con | Dis | Session1 |    |    |    | Session2 |    |    |    | Session3 |    |    |    | Session4 |    |    |    |
|-----|-----|-----|----------|----|----|----|----------|----|----|----|----------|----|----|----|----------|----|----|----|
|     |     |     | 76       | 60 | 64 | 72 | 64       | 72 | 60 | 76 | 60       | 76 | 72 | 64 | 72       | 64 | 76 | 60 |
| 1   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 2   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 3   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 4   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 5   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 6   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 7   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 8   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 9   |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 10  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 11  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 12  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 13  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 14  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 15  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 16  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 17  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 18  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 19  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 20  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 21  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 22  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 23  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 24  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 25  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 26  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 27  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 28  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 29  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 30  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 31  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 32  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 33  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 34  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 35  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |
| 36  |     |     |          |    |    |    |          |    |    |    |          |    |    |    |          |    |    |    |

## Appendix C: Documents for virtual assessment experiment (Chapter 5)

Effect of viewpoints and interaction techniques on the assessment of PWC driving task in a simulated based environment

**CONSENT INFORMATION**

PROJECT N°:  (administration)

APPROUVÉ PAR LE CÉR  
DES ÉTABLISSEMENTS DU CRIR  
*19 août 2016*

PROJECT TITLE :  
Effect of viewpoints and interaction techniques on the assessment of PWC driving task in a simulated based environment

INVESTIGATORS :  
Philippe Archambault, OT., PhD, McGill University  
Abdulaziz Alshaer, Information Science, Otago University, New Zealand  
Holger Regenbrecht, Information Science, Otago University, New Zealand  
David O'Hare, Psychology, Otago University, New Zealand

INTRODUCTION :  
We are inviting you to participate in a research project. 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.

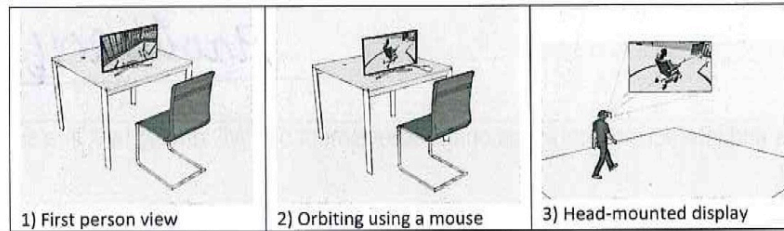
NATURE AND OBJECTIVES OF THE STUDY :  
Virtual reality wheelchair simulators can aid with the assessment and training of potential users in a safe and controlled environment. However, assessing how a client drives a wheelchair in a simulator remains problematic. Indeed, clinicians might find it hard to estimate certain parameters they would determine by observation during real world assessment. The objectives of the study are to understand how to assess power wheelchair skills while the client is driving in a virtual reality

Approved by the IRB of CRIR on xx xxx 2016

1



simulator and to find the best method to achieve this goal. Specifically, we want to compare three viewpoints for the assessment: 1) a first person view, where clinicians observe from the client's perspective; 2) direct manipulation of the viewpoint (orbiting around the virtual power wheelchair); and 3) embodied interaction, or allowing the clinician to move freely in the virtual space. These viewpoints are illustrated in the figure below. We also wish to compare the assessment in the virtual environment with assessment in the real world.



**NATURE OF PARTICIPATION :**

You will be asked to view and evaluate virtual clients while they perform four different driving tasks in the simulator. You will evaluate each driving tasks on a 0 to 2 scale. You will repeat these evaluations of wheelchair driving for each viewpoint (first-person perspective, orbiting using the mouse, head-mounted display). After you have completed the evaluations for one viewpoint, you will be asked to complete a short questionnaire on your experience. Finally, you will be asked to evaluate videos of clients performing wheelchair the same driving tasks in the real world. The experiment will last no more than 60 minutes, and can be completed in one or two sessions, at your convenience.

**POTENTIAL ADVANTAGES AND POSSIBLE INCONVENIENTS OF YOUR PARTICIPATION:**

You may not personally benefit from your participation to this research project. However, the results arising from this study will make a contribution to the knowledge, in particular with respect to physical rehabilitation.

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 stop the experiment if required.

**VOLUNTARY PARTICIPATION AND RIGHT OF THE PARTICIPANT:**

It is understood that participation in the research project described above is completely voluntary and you are, at any time, free to end your participation without having to justify your decision, nor to suffer prejudices of any kind. 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. If you elect to withdraw from the project, the data collected will be retained unless you tell us otherwise.

**COMPENSATION:**

After the interview, a meal or a snack will be provided. Upon presentation of receipts, your transportation costs, if any, will be reimbursed. The maximum amount reimbursed is 50\$.

**CONFIDENTIALITY AND DIFFUSION OF STUDY RESULTS :**

All personal information gathered during the study will be coded in order to ensure its confidentiality. Only the members of the research team will have access to it. This includes the researchers from Otago University, New Zealand, who are part of the research team. However, for quality control of the research project, your research dossier may be accessed by a person mandated by the Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), who adheres to a policy of confidentiality, or by the Ethics Department of the Ministry of Health and Social Services. These data will be kept under lock and key at the Jewish Rehabilitation Hospital by the principal investigator for a period of five years following the end of the study, after which they will be destroyed. In the event that the results of this study are presented or published, no identifying information will be included.

**RESPONSIBILITY CLAUSE::**

By agreeing to participate in this study, you do not relinquish any of your rights nor release the researchers, sponsor or institutions involved in this study of their legal and professional obligations.

**QUESTIONS ABOUT THE STUDY :**

We will answer any questions you may have about the research project and or your implication in it. Please communicate with the research team at 514-360-3513 or Philippe Archambault ([philippe.archambault@mcgill.ca](mailto:philippe.archambault@mcgill.ca)), principal investigator on this project who can be reached at either of those two numbers: 450 688-9550 ext. 4832 (lab) or 514 398-7323 (office). If you have questions about your rights and remedies regarding your participation in this study, please contact Me Anik Nolet, Coordinator of the Research Ethics Board for member institutions of CRIR: at [514-527-4527](tel:514-527-4527) ext. 2649 or by email to: [anolet.crir@ssss.gouv.qc.ca](mailto:anolet.crir@ssss.gouv.qc.ca). You can also contact the Service Quality and Complaints Commissioner – CIUSSS Laval at [450 - 668-1010](tel:450-668-1010) ext. 23628 and by email to [plaintes.csssl@ssss.gouv.qc.ca](mailto:plaintes.csssl@ssss.gouv.qc.ca). For these questions you can also contact the Local Complaints Commissioner of your institution.

Effect of viewpoints and interaction techniques on the assessment of PWC driving task in a simulated based environment



CONSENT

Project N°: CRIR-1152-0516

Project title:

Effect of viewpoints and interaction techniques on the assessment of PWC driving task in a simulated based environment

Researchers:

Philippe Archambault, Abdulaziz Alshaer, Holger Regenbrecht, David O'Hare

The project, the nature and the degree of my participation and the possible inconveniences and risks of the project as listed in the 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.

This project might give investigators the opportunity to follow up and propose another study. If this is the case, I authorize the project investigators to contact me again and invite me to participate in a subsequent study:

- no
- yes, for a period of one year\*
- yes, for a period of two years\*
- yes, for a period of three years\*

\* Note that if you select one of these three cases, your personal details will be kept by the principal investigator for the chosen period.

Effect of viewpoints and interaction techniques on the assessment of PWC driving task in a simulated based environment

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 be retained 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.

\_\_\_\_\_  
Participant's name

\_\_\_\_\_  
Telephone number

X

\_\_\_\_\_  
\_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_  
Participant's signature Date

Signed in \_\_\_\_\_, on \_\_\_\_\_

SECTION TO BE COMPLETED BY THE INVESTIGATOR

I, the undersigned, \_\_\_\_\_, certify

- (a) having explained to the research participant the terms of this form;
- (b) having answered all the questions he/she has asked in this regard;
- (c) having clearly indicated that he/she remains free, at any time, to end his/her participation in the above described research study;
- (d) that I will give him/her a signed and dated copy of this form.

\_\_\_\_\_  
(principal investigator) \_\_\_\_\_ (date)

**Scale for Scoring Skill Capacity Objectively (WST)**

| Score   | Capacity criteria   |
|---|---|
| <b>Pass<br/>(Score of 2):</b>                     | Task independently and safely accomplished without any difficulty. The skill may be performed in any manner. The focus is on meeting the task requirements, not the method used.  |
| <b>Pass with<br/>difficulty<br/>(Score of 1):</b> | If the evaluation criteria are met, but the subject experienced some difficulty worthy of note (e.g. excessive time or effort required, inefficient method used, ergonomically unsound method used, poor technique that may or may not lead to overuse injury at a later time, minor injury)  |
| <b>Fail<br/>(Score of 0):</b>                     | Task incomplete or unsafe.<br><br>If there are limitations of the space within which the skill is to be performed and the wheelchair wheels or the subject's feet in contact with the ground extend beyond those limits. Feet on footrests or wheelchair parts not in contact with the ground are usually permitted to extend beyond the limits, to simplify testing. |



|                  |                 |
|------------------|-----------------|
| Participant#     |                 |
| Conditions order |                 |
| Date & Time      | / /2016 : pm/am |

**Assessment of PWC Driving Tasks in a Virtual Environment**  
**Évaluation de tâches de conduite en fauteuil roulant motorisé dans un environnement virtuel**

**Participant Demographic Survey**  
**Questionnaire démographique**

1. Age (Âge) .....
2. Gender Male / Female      Sexe      Homme/Femme
3. Occupation (Profession) .....
4. Years of experience (Nombre d'années d'expérience) .....
  
1. **Have you done WST assessment before?**  
Avez-vous déjà évalué des habiletés en fauteuil roulant avec le WST?
  - Yes (Oui)
  - No (Non)
  
2. **Years of experience in training or assessing wheelchair skills**  
 Années d'expérience en lien avec l'entraînement et l'évaluation des habiletés en fauteuil roulant  
 .....
  
3. **Do you have normal or corrected to normal (e.g. glasses, contact lenses) vision?**  
Avez vous une vision normale ou corrigée à la normale (verres de contact, lunettes)?
  - Yes (Oui)
  - No (Non)

If No please specify issue: \_\_\_\_\_  
 Si vous avez répondu non, veuillez préciser:
  
4. **Do you have a disability of the hand, arm, shoulder, neck, back or other health issues that could affect your performance in this experiment (e.g flu)?**  
Avez-vous une limitation physique (main, bras, épaule, cou, dos) ou d'autres problèmes de santé qui pourraient influencer votre performance lors de l'étude (par exemple une grippe)
  - No (Non)
  - Yes (Oui)
  
5. **Have you used a head mounted display before?**  
Avez-vous déjà utilisé un casque de réalité virtuelle?
  - No (Non)
  - No, but know what it is all about (Non, mais je connais bien ces casques)
  - Yes (Oui)



|                  |                 |
|------------------|-----------------|
| Participant#     |                 |
| Conditions order |                 |
| Date & Time      | / /2016 : pm/am |

**Assessment of PWC Driving Tasks in a Virtual Environment**

**Comparative Questionnaire  
Questionnaire comparatif**

Please read each statement below, and indicate how it applied to your experience using this virtual environment. There are no right or wrong answers.

Veillez lire chaque énoncé et indiquer comment cela se rapporte à votre expérience dans l'environnement virtuel. Il n'y a pas de bonnes ou de mauvaises réponses.

**1. Do you think the controllability of the field of view made it easier to assess in the virtual environment?**

**Pensez-vous que le contrôle du champ de vision facilite l'évaluation dans l'environnement virtuel?**

|                             |   |   |   |   |   |                          |
|-----------------------------|---|---|---|---|---|--------------------------|
| 1                           | 2 | 3 | 4 | 5 | 6 | 7                        |
| Harder<br>Plus<br>difficile |   |   |   |   |   | Easier<br>Plus<br>facile |

**2. When the field of view was static, did you feel more or less comfortable in your assessment?**

**Lorsque le champ de vision était fixe, vous sentiez-vous plus ou moins en confiance pour évaluer la tâche?**

|  |   |   |   |   |   |   |
|--|---|---|---|---|---|---|
| 1  | 2 | 3 | 4 | 5 | 6 | 7   |
| less<br>comfortable<br>Moins en<br>confiance |   |   |   |   |   | more<br>comfortable<br>Plus en<br>confiance |

**3. When you were able to walk around, did you feel more or less comfortable in your assessment?**

**Lorsque vous pouviez vous promener dans l'environnement virtuel, vous sentiez-vous plus ou moins en confiance pour évaluer la tâche?**

|  |   |   |   |   |   |   |
|--|---|---|---|---|---|---|
| 1  | 2 | 3 | 4 | 5 | 6 | 7   |
| less<br>comfortable<br>Moins en<br>confiance |   |   |   |   |   | more<br>comfortable<br>Plus en<br>confiance |



4. For each of the following interface, how suitable it is for clinical assessment?  
Veillez indiquer pour chacune des interfaces suivantes si elle est appropriée pour l'évaluation clinique des tâches en fauteuil roulant motorisé

**A) Standard interface**  
**Interface standard**

|                                      |   |   |   |   |   |                                  |
|--------------------------------------|---|---|---|---|---|----------------------------------|
| 1                                    | 2 | 3 | 4 | 5 | 6 | 7                                |
| Very unsuitable<br>Très inappropriée |   |   |   |   |   | Very suitable<br>Très appropriée |

**B) Mouse orbiting**  
**Manipulation de l'environnement avec la souris**

|                                      |   |   |   |   |   |                                  |
|--------------------------------------|---|---|---|---|---|----------------------------------|
| 1                                    | 2 | 3 | 4 | 5 | 6 | 7                                |
| Very unsuitable<br>Très inappropriée |   |   |   |   |   | Very suitable<br>Très appropriée |

**C) Walking around**  
**Pouvoir se promener dans l'environnement virtuel**

|                                      |   |   |   |   |   |                                  |
|--------------------------------------|---|---|---|---|---|----------------------------------|
| 1                                    | 2 | 3 | 4 | 5 | 6 | 7                                |
| Very unsuitable<br>Très inappropriée |   |   |   |   |   | Very suitable<br>Très appropriée |

Thank you very much for your time and participation  
Merci beaucoup pour votre participation



|              |                 |
|--------------|-----------------|
| Participant# |                 |
| Condition    |                 |
| Date & Time  | / /2016 : pm/am |

## Assessment of PWC Driving Tasks in a Virtual Environment

### IPQ Questionnaire

Please read each statement below, and indicate how it applied to your experience using this virtual environment. There are no right or wrong answers.

Veillez lire chaque énoncé et indiquer comment cela se rapporte à votre expérience dans l'environnement virtuel. Il n'y a pas de bonnes ou de mauvaises réponses.

**1. In the computer-generated world I had a sense of "being there".**

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

|                    |    |    |   |   |   |                 |
|--------------------|----|----|---|---|---|-----------------|
| -3                 | -2 | -1 | 0 | 1 | 2 | 3               |
| not at all         |    |    |   |   |   | very much       |
| <u>Pas du tout</u> |    |    |   |   |   | <u>Beaucoup</u> |

**2. I was not aware of my real environment.**

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

|                             |    |    |   |   |   |                             |
|-----------------------------|----|----|---|---|---|-----------------------------|
| -3                          | -2 | -1 | 0 | 1 | 2 | 3                           |
| Fully disagree              |    |    |   |   |   | fully agree                 |
| <u>Pas du tout d'accord</u> |    |    |   |   |   | <u>Tout à fait d'accord</u> |

**3. I still paid attention to the real environment.**

**Je faisais toujours attention à l'environnement réel.**

|                             |    |    |   |   |   |                             |
|-----------------------------|----|----|---|---|---|-----------------------------|
| -3                          | -2 | -1 | 0 | 1 | 2 | 3                           |
| Fully disagree              |    |    |   |   |   | fully agree                 |
| <u>Pas du tout d'accord</u> |    |    |   |   |   | <u>Tout à fait d'accord</u> |

**4. I was completely captivated by the virtual world.**

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

|                             |    |    |   |   |   |                             |
|-----------------------------|----|----|---|---|---|-----------------------------|
| -3                          | -2 | -1 | 0 | 1 | 2 | 3                           |
| Fully disagree              |    |    |   |   |   | fully agree                 |
| <u>Pas du tout d'accord</u> |    |    |   |   |   | <u>Tout à fait d'accord</u> |

**5. Somehow I felt that the virtual world surrounded me.**

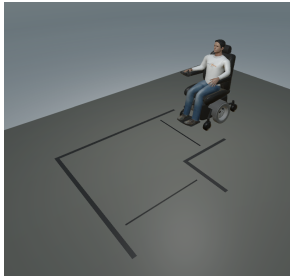
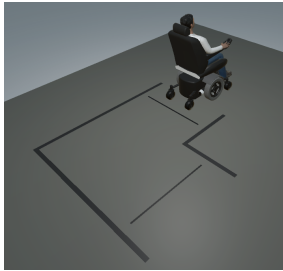
**D'une certaine façon, j'ai eu l'impression que le monde virtuel m'entourait.**


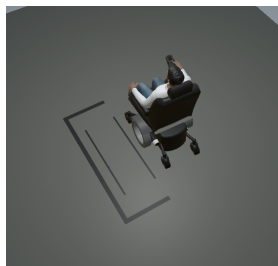
|                             |    |    |   |   |   |                             |
|-----------------------------|----|----|---|---|---|-----------------------------|
| -3                          | -2 | -1 | 0 | 1 | 2 | 3                           |
| Fully disagree              |    |    |   |   |   | fully agree                 |
| <u>Pas du tout d'accord</u> |    |    |   |   |   | <u>Tout à fait d'accord</u> |

Conditions Order and Assessment Recording Sheet

|                          |                           |
|--------------------------|---------------------------|
| A: Turns 90 forwards L&R | B: Turns 90 backwards L&R |
| C: Turn in Place 180 L&R | D: Maneuvers sideways L&R |

|        |                |                |                |                |                |                |                |                |                |                |                |                |
|--------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1      | Standard       |                |                |                | Orbiting       |                |                |                | Walking        |                |                |                |
|        | A <sub>0</sub> | D <sub>2</sub> | B <sub>1</sub> | C <sub>0</sub> | C <sub>1</sub> | B <sub>2</sub> | D <sub>0</sub> | A <sub>1</sub> | D <sub>1</sub> | C <sub>2</sub> | A <sub>2</sub> | B <sub>0</sub> |
| Score  |                |                |                |                |                |                |                |                |                |                |                |                |
| Ease   |                |                |                |                |                |                |                |                |                |                |                |                |
| Conf   |                |                |                |                |                |                |                |                |                |                |                |                |
| Collis |                |                |                |                |                |                |                |                |                |                |                |                |
| 2      | Walking        |                |                |                | Standard       |                |                |                | Orbiting       |                |                |                |
|        | A <sub>0</sub> | D <sub>2</sub> | B <sub>1</sub> | C <sub>0</sub> | C <sub>1</sub> | B <sub>2</sub> | D <sub>0</sub> | A <sub>1</sub> | D <sub>1</sub> | C <sub>2</sub> | A <sub>2</sub> | B <sub>0</sub> |
| Score  |                |                |                |                |                |                |                |                |                |                |                |                |
| Ease   |                |                |                |                |                |                |                |                |                |                |                |                |
| Conf   |                |                |                |                |                |                |                |                |                |                |                |                |
| Collis |                |                |                |                |                |                |                |                |                |                |                |                |
| 3      | Orbiting       |                |                |                | Walking        |                |                |                | Standard       |                |                |                |
|        | A <sub>0</sub> | D <sub>2</sub> | B <sub>1</sub> | C <sub>0</sub> | C <sub>1</sub> | B <sub>2</sub> | D <sub>0</sub> | A <sub>1</sub> | D <sub>1</sub> | C <sub>2</sub> | A <sub>2</sub> | B <sub>0</sub> |
| Score  |                |                |                |                |                |                |                |                |                |                |                |                |
| Ease   |                |                |                |                |                |                |                |                |                |                |                |                |
| Conf   |                |                |                |                |                |                |                |                |                |                |                |                |
| Collis |                |                |                |                |                |                |                |                |                |                |                |                |
| 4      | Standard       |                |                |                | Orbiting       |                |                |                | Walking        |                |                |                |
|        | A <sub>0</sub> | D <sub>2</sub> | B <sub>1</sub> | C <sub>0</sub> | C <sub>1</sub> | B <sub>2</sub> | D <sub>0</sub> | A <sub>1</sub> | D <sub>1</sub> | C <sub>2</sub> | A <sub>2</sub> | B <sub>0</sub> |
| Score  |                |                |                |                |                |                |                |                |                |                |                |                |
| Ease   |                |                |                |                |                |                |                |                |                |                |                |                |
| Conf   |                |                |                |                |                |                |                |                |                |                |                |                |
| Collis |                |                |                |                |                |                |                |                |                |                |                |                |
| 5      | Walking        |                |                |                | Standard       |                |                |                | Orbiting       |                |                |                |
|        | A <sub>0</sub> | D <sub>2</sub> | B <sub>1</sub> | C <sub>0</sub> | C <sub>1</sub> | B <sub>2</sub> | D <sub>0</sub> | A <sub>1</sub> | D <sub>1</sub> | C <sub>2</sub> | A <sub>2</sub> | B <sub>0</sub> |
| Score  |                |                |                |                |                |                |                |                |                |                |                |                |
| Ease   |                |                |                |                |                |                |                |                |                |                |                |                |
| Conf   |                |                |                |                |                |                |                |                |                |                |                |                |
| Collis |                |                |                |                |                |                |                |                |                |                |                |                |
| 6      | Orbiting       |                |                |                | Walking        |                |                |                | Standard       |                |                |                |
|        | A <sub>0</sub> | D <sub>2</sub> | B <sub>1</sub> | C <sub>0</sub> | C <sub>1</sub> | B <sub>2</sub> | D <sub>0</sub> | A <sub>1</sub> | D <sub>1</sub> | C <sub>2</sub> | A <sub>2</sub> | B <sub>0</sub> |
| Score  |                |                |                |                |                |                |                |                |                |                |                |                |
| Ease   |                |                |                |                |                |                |                |                |                |                |                |                |
| Conf   |                |                |                |                |                |                |                |                |                |                |                |                |
| Collis |                |                |                |                |                |                |                |                |                |                |                |                |

| Task                     | Turns while moving forwards   | Turns while moving backwards   |
|--------------------------|---|--|
| <b>Description</b>       | <p>The subject turns the wheelchair 90° to the left and right around a corner while moving forwards.</p>   | <p>The subject turns the wheelchair 90° to the left and right around a corner while moving backwards.</p>  |
| <b>Capacity criteria</b> | <p>A “pass” should be awarded if:</p> <ul style="list-style-type: none"> <li>• The subject safely completes the task.</li> <li>• The endpoint is when the wheelchair is around the corner, 90° from its original orientation and with the leading wheel axles at least 0.5 m from the corner. Subjects who stop short of this distance may be prompted, without penalty, to continue.</li> <li>• If lines are used to define the lateral limits, to simplify scoring, it is permissible for parts of the wheelchair user or wheelchair (e.g. a foot on a footrest) to extend beyond the lines, as long as the wheels or feet on the floor stay within the prescribed limits.</li> <li>• Subject may touch the tape but not extending beyond the line</li> </ul> |  |

| Task                     | Turns in place (180°)   | Maneuvers sideways (0.5 m)   |
|--------------------------|---|--|
| <b>Description</b>       | <p>The subject turns the wheelchair around 180° to the left and right to face in the opposite direction, while remaining within a square space with 1.5 m sides.</p>   | <p>The subject maneuvers the wheelchair 0.5 m sideways to the left and right parallel to an object (e.g. bed or wall).</p>   |
| <b>Capacity criteria</b> | <p>A “pass” should be awarded if:</p> <ul style="list-style-type: none"> <li>• The subject turns at least 160° in each direction.</li> <li>• All parts of the wheelchair and subject that touch the ground must remain within the square. However, to simplify scoring, it is permissible for parts of the wheelchair user’s body or wheelchair (e.g. a foot on a footrest) to extend beyond the lines, as long as the feet and wheels on the floor stay within the prescribed limits.</li> <li>• Subject may touch the tape but not extending beyond the line</li> </ul> | <p>A “pass” should be awarded if:</p> <ul style="list-style-type: none"> <li>• The most lateral aspect of the wheelchair is moved to within 10 cm of the target. The wheelchair may touch the lateral barrier.</li> <li>• On completion, the fore-aft axis of the wheelchair must not be at an angle of &gt;20 degrees from the wall.</li> <li>• The parts of the wheelchair or subject in contact with the ground must stay within the 1.5 m forward-backward limits, but other parts of the wheelchair or subject (e.g. feet on footrests) may extend beyond these limits</li> <li>• Subject may touch the tape but not extending beyond the line</li> </ul> |