Usability of a Virtual Reality Simulator for Manual Wheelchairs

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Abstract

Individuals with reduced mobility often require assistance for getting around. Small task such as going from the couch to the kitchen or bigger tasks such as going to grocery store for necessities, require a significant amount of planning. Manual wheelchair (MW) is one of several alternatives. As for any other movement repeated hundreds of time a day, the proper use of a MW is of great importance in order to avoid, reduce, and prevent the risk of injury. It requires proper technique, knowledge and practice due to the complexity of the task. Given the risks involved with MW use, it is important to be able to gain the maneuvering and navigational skills in safe and controlled training environment. Training in a virtual reality (VR) setting allows for safe simulation of MW driving in a wide range of otherwise risky environments. In addition, it has been reported that the learned skills in a VR setting, can translate to real world scenarios, therefore allowing for skills improvement.

The purpose of this thesis was to contribute evidence towards validating the usability and fidelity potential to which wheelchair skill training can be positively influenced by using a VR simulator, which provides realistic haptic feedback that mimics gravitational and inertial forces experienced during real propulsion.

The first objective of this study was to validate the usability of the MiWe simulator by clinicians and expert MW users to, eventually, help improve wheelchair skills.

The second objective was to determine whether or not haptic feedback would affect the overall experience by comparing the current study to a similar previous study done without haptic feedback. This thesis contains the results of an experiment that investigated the sense

of presence, overall experience and ease of use of the experience. Sense of presence was broken down in four component that can be defined as level of involvement, experienced realism, spatial presence and overall presence. As for ease of use, it can be defined as level of ease faced when learning to operate and interact with the system, as well as the systems flexibility. Lastly, overall experience was assessed by a questionnaire and feedback on a multitude of factors such as comfort, control and level of difficulty experience.

Our first hypothesis was that among clinicians and MW users, we would measure a positive view on ease of use and sense of presence during the MiWe simulator experience, and that there would be no difference between both groups. We were able to confirm this hypothesis with the results of the questionnaires and semi-structured interview.

As for our second hypothesis, we hypothesized that the newer version of the simulator, which includes haptic feedback, would provide a more positive overall experience in comparison to our previous version with no haptic feedback. We were able to confirm that the inclusion of haptic feedback had a positive impact on overall experience.

For this mixed method study, six MW users, as well as five expert clinicians in the field of wheeled mobility were recruited. They experienced a thirty minutes session in the McGill Wheelchair Simulator (MiWe) simulator. MW driving performance was assessed in MW users at baseline. After the experience in the MiWe simulator, three questionnaires were administered measuring sense of presence, ease of use and overall experience, as well as a semi-structured interview, to further investigate the overall experience.

In terms of semi-structured interviews, the emerging themes were centered around technology adoption and branched into clinical usability and user experience. These findings intend to help rehabilitation professionals, who provide mobility-related services, to guide, alter and tailor their future mobility interventions according to their clients' needs.

To conclude, we were able to determine that among clinicians and MW users alike, there was a positive view on usability and sense of presence during the MiWe simulator experience, and that the addition of haptic feedback contributed significantly to the overall experience. The impact of our findings intends to help rehabilitation professionals, who provide mobility-related services, to guide, alter and tailor their future mobility interventions according to their clients' needs.

Résumé

Les personnes à mobilité réduite ont souvent besoin d'aide pour se déplacer. Les petites tâches telles que passer du canapé à la cuisine ou des tâches plus importantes telles que se rendre à l'épicerie pour les nécessités nécessitent une planification importante. Le fauteuil roulant manuel (MW) est l'une des nombreuses alternatives. Comme pour tout autre mouvement répété des centaines de fois par jour, la bonne utilisation d'un MW est d'une grande importance pour éviter, réduire et prévenir les risques de blessures. Cela nécessite une technique, des connaissances et une pratique appropriées en raison de la complexité de la tâche. Compte tenu des risques liés à l'utilisation des MW, il est important de pouvoir acquérir les compétences de manœuvre et de navigation dans un environnement d'entraînement sûr et contrôlé. La formation dans un cadre de réalité virtuelle (VR) permet de simuler en toute sécurité la conduite en MW dans un large éventail d'environnements autrement risqués. En outre, il a été rapporté que les compétences acquises dans un cadre de réalité virtuelle peuvent se traduire par des scénarios du monde réel, permettant ainsi une amélioration des compétences.

Le but de cette thèse était de fournir des preuves pour valider le potentiel d'utilisabilité et de fidélité auquel la formation des compétences en fauteuil roulant peut être influencée positivement en utilisant un simulateur de réalité virtuelle.

Le premier objectif de cette étude était de valider l'utilisabilité du simulateur MiWe par des cliniciens et des utilisateurs experts de MW pour, éventuellement, aider à améliorer les compétences en fauteuil roulant.

Le deuxième objectif était de déterminer si le retour haptique affectera ou non l'expérience globale en comparant l'étude actuelle à une étude précédente similaire réalisée sans retour haptique. Cette thèse contient les résultats d'une expérience qui a étudié le sentiment de la présence, l'expérience globale et la facilité d'utilisation de l'expérience. Le sentiment de présence a été divisé en quatre composantes qui peuvent être définies comme le niveau d'implication, le réalisme expérimenté, la présence spatiale et la présence globale. Quant à la facilité d'utilisation, elle peut être définie comme le niveau de facilité rencontré lors de l'apprentissage du fonctionnement et de l'interaction avec le système, ainsi que de la flexibilité des systèmes. Enfin, l'expérience globale a été évaluée par un questionnaire et un retour d'expérience sur une multitude de facteurs tels que le confort, le contrôle et le niveau de difficulté.

Pour cette étude à méthode mixte, six utilisateurs de MW, ainsi que cinq cliniciens experts dans le domaine de la mobilité à roues ont été recrutés. Ils ont vécu une session de trente minutes dans le simulateur de McGill Wheelchair Simulator (MiWe). Les performances de conduite en MW ont été évaluées chez les utilisateurs de MW au départ. Après l'expérience dans le simulateur MiWe, trois questionnaires ont été administrés mesurant le sentiment de présence, la facilité d'utilisation et l'expérience globale, ainsi qu'une interview semi-structurée, pour approfondir l'expérience globale.

En termes d'entretiens semi-structurés, les thèmes émergents étaient centrés sur l'adoption de la technologie et se sont ramifiés dans l'utilisabilité clinique et l'expérience utilisateur. Ces résultats visaient à aider les professionnels de la réadaptation, qui fournissent des services liés à la mobilité, à guider, modifier et adapter leurs futures interventions de mobilité en fonction des besoins de leurs clients.

Pour conclure, nous avons pu déterminer que parmi les cliniciens et les utilisateurs de MW, il y avait une vision positive de la convivialité et du sentiment de présence pendant l'expérience du simulateur MiWe, et que l'utilisation de la rétroaction haptique a contribué de manière significative à l'expérience globale. L'impact de nos résultats vise à aider les professionnels de la réadaptation, qui fournissent des services liés à la mobilité, à guider, modifier et adapter leurs futures interventions de mobilité en fonction des besoins de leurs clients.

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Preface and contributions of authors

The contents of this thesis constitute original material written in its entirety by Fadi Chaar.

This thesis consists of one manuscript to be submitted for publication. The manuscript is an experiment investigating the usability of virtual reality simulator for MW training. The experiment and data analysis and the writing of the manuscript were conducted by Fadi Chaar, with support from Philippe Archambault.

Abbreviations

MiWe: McGill Wheelchair Simulator

MW: Manual wheelchair

RE: Real environment

TAM: Technology acceptance model

VE: Virtual environment

VR: Virtual reality

WST: Wheelchair Skills Test

WST-Q: Wheelchair Skills Test – Questionnaire

Chapter 1: Introduction and Background

1.1 - Use of mobility devices

There are approximately 290 000 wheelchair users in Canada, including all pathologies and wheelchairs types [1]. This represent approximately 1% of the Canadian population with similar numbers reflected worldwide [1]. A bit more than 200 000 of those previously mentioned are manual wheelchair (MW) users [1]. As the population ages, there is a projected increase in the number of wheelchair users, due to the majority of users being 65 years of age and older [1]. Approximately 70.8% of senior wheelchair users are women [1]. This observation may be due to the higher prevalence of chronic diseases in women, which may help explain this disproportion in sex [45].

An individual needing a manual wheelchair will likely be using it for several weeks, months, years, or the remainder of their lives, for all their activities [2], making it a necessary means to maintain independent mobility, as well as social participation [3].

1.2– Quality of life and Proper Skill Training

Independent mobility or social participation are not guaranteed for manual wheelchair users due to a multitude of factors such as the difficulties faced when maneuvering through their home and community environments [4]. This requires the necessary skills to overcome obstacles such as curbs, ramps and rough terrain [4]. This is of great importance, as level of independence is a determinant of quality of life (QoL). The World Health Organization defines quality of life as being “an individual’s perception of their position in life the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns" [5]. QoL can be assessed based on the following facets: physical health, psychologically, level of independence, social relations, environment and spirituality/religion/personal beliefs [5]. A study conducted by Oyster et al. has demonstrated that the time spent propelling the wheelchair is associated with improved QoL [6], and that proper wheelchair skill training leads to more independent wheelchair use in new wheelchair users [7].

In addition, as high as 60% of Canadian MW users tend to depend on other people for mobility assistance [8]. This is associated with a reduced sense of independence, and a greater sense of depression [9], both negatively affecting QoL for wheelchair users [8]. Multiple studies have found a positive association between wheelchair skills and independent mobility, functioning and social participation in wheelchair users [7] [10]. This demonstrates the importance of proper wheelchair skill training.

A study conducted by Smith et al., named the following categories as being the most frequently reported factors associated with participation: accessibility, skills with wheelchair use, pain, finances and education [39]

In addition, we investigated the factors influencing participation in social and community activities for wheelchair users. A study conducted in our lab where experienced MW users were asked to identify context-specific tasks that were challenging for them when learning to operate a MW. The results included entering a doorframe, manoeuvring onto and off-of a sidewalk, overcoming cracks in the road, and performing wheelies.

1.3 – Wheelchair Skills Training Program

One widely used standardized training program for people in MW is the Wheelchair Skills Training Program (WSTP). The WSTP (version 5.0 as of June 2018) is a series of 33 MW skills graded from 0 "Not possible" to 3 "Yes, very well". These skills span different difficulty levels and include: basic skills (applying the brakes, moving the armrests), wheelchair maneuvering and daily living skills (turns in place, turns while moving), obstacle-negotiating skills (opening/travelling through a door), and advanced skills (propulsion over an irregular surface, and achieving and maintaining a wheelie)[11]. A systematic review and meta-analysis of 13 randomized controlled trials on a total of 581 participants conducted by Keeler et al, concluded that using the WSTP as the intervention, increased Wheelchair Skills Test (WST) total capacity scores by 21.2% relative to baseline [12]. Another study conducted by Ben Mortenson et al., also concluded that these same skills were an important predictor of life-space mobility and frequency of participation in social activities [9]. There is a clear link associated with skill training and an overall improvement of QoL [9]. Nonetheless, clinicians have yet to implement the WSTP as their main tool in wheelchair training for a multitude of reasons.

For clinicians, the most common perceived barriers for providing MW training were lack of time, lack of resources, cost and uncertainty of how to implement the tool into practice [13]. The most recurrent theme of all was lack of time. Clinicians found a great challenge incorporating the validated wheelchair training program into their practice, due to the short stay of patients in their care. They were faced with prioritizing the patients many complex needs, therefore addressing the most urgent matters first, with wheelchair skill training not being an immediate priority [13].

As for MW users, when asked about the training they received by healthcare professionals, the MW users stated that training typically consisted of a self-learning process. Many reported not receiving any formal training at all [42]. Corrections were provided in the case of a blatant misuse and improper technique. Very few reported being taught basic skills such as turns, going forward and backwards, and going up and down inclined planes. Even fewer reported more complex skills training, such as performing a wheelie.

This emphasizes the need of being able to perform complex skills as it may enhance mobility and participation in meaningful activities that require use of a MW.

1.4 – Solution: Virtual Reality Simulation

With the availability of virtual reality (VR), the use of computer-based rehabilitation interventions has greatly increased [14]. VR has presented itself as a promising modality to bridge the gap in MW training. It could possibly help resolve the issues of **lack of time and lack of standardization** brought forth by the clinicians. This technology offers many advantages such as its ability to recreate different real-world environments without the hassle of physical constraints, in a safe and controlled manner [15]. This is of great importance, as the **context-specific tasks identified as challenging** by the MW users can be recreated in a virtual environment and modified as needed. In addition to providing a reproducible and safe environment, VR also provides a consistent environment with the potential for infinite repetitions, making it unique [16], with the ability to capture objective measurements as well as providing real time feedback [17]. The use of VR has also demonstrated greater patient compliance, enthusiasm, enjoyment and improved confidence when placed in similar real-world environments [16]. A review on sensorimotor training in VR conducted by Adamovich et al. reinforces these advantages in stroke rehabilitation. They conclude that the possibility of modulating VR training difficulty to a patient's skill level provides a motivational advantage that would not be seen in regular therapy, which encourages longer engagement in the exercises [18]. VR has also been used in a wide variety of scenarios with a multitude of applications from gaming to education. For our interest, we will look at its ability to be used as a training tool for MW skills, focusing on its ability to facilitate the transfer of learned skills to real life and motor skills training. VR has been used in the medical field to help train the motor skills required to perform a surgical procedure [19]; in which case the skill transfer from VR to the real world has been validated [20].

VR has also successfully been used in driving simulation of vehicles such as cars, planes [21] and power wheelchairs [15, 19, 22-25]. As for MW's, there are few conclusive studies that exist in which VR is used as an addition to regular therapy, in regard to MW skills training. Most conclusive studies for MW users and VR, utilize the "gaming" aspect of VR addressing cardiovascular health. A study conducted by O'Connor et al., looked at the use of VR as a physical training system, soliciting an improvement in cardiovascular health [26]. They developed a training station that consisted of two dynamometers on top of which a manual wheelchair was placed and a VR simulator was used to recreate different environments [26]. This study reported that the use of a "video game like system" had a positive effect on motivation of the MW users to use VR as a training tool. Another study conducted by Blouin et al., where subjects trained on a MW simulator demonstrated an improvement in propulsion pattern [27]. This system used the help of haptic feedback in order to modulate the force applied on the wheels, in order gain a more efficient propulsion pattern [27]. Both studies looked at participants with spinal cord injury, limiting their generalizability. In addition, the study conducted by Blouin et al. used a single standard wheelchair for all participants, which may have led to a less comfortable experience, once again limiting the generalizability, as well as making the skill transfer more difficult to reproduce on the users respective WC.

The tool we will be using in this study is the McGill immersive wheelchair simulator (MiWe). The simulator addresses the previously listed limitations, allowing people with different pathologies to use their own wheelchair for skill acquisition. We wish to address the concerns brought forth by clinicians regarding lack of time and standardization by allowing the MW user familiar with the system to improve their skills, all the while identifying the more challenging tasks that need more work. This may augment regular therapy, acting as an aid to clinicians who find a constraint in the time they have with patients.

1.5 – Intervention: the MiWe simulator

This simulator consists of a platform that replicates the forces and chair dynamics experienced when using a MW in the real world, as well as a computer and monitor on which the virtual scenario can be displayed (Figure 1). It is a videogame like system that is comprised of hardware and software components, which enables it to be used as an intervention tool. The hardware consists in an adjustable platform, able to accommodate different types of MW (Figure 2). Propulsion of the wheels controls the VR MW, and haptic feedback provided to the wheels mimics the effects of inertia and gravity, as well as collisions (e.g. when going uphill, a resistance is applied on the wheels so that the user needs to exert ore force, whereas when going downhill an ease in propulsion is experienced).

The software content of the miWe simulator is based on an “infinite sidewalk” scenario, where the MW user is faced with different obstacles that mimic real-world obstacles to overcome. The environment represents a city setting where cars are driving on the road, and virtual characters are walking on the sidewalk. The obstacles encountered by the participants are: 1) moving pedestrians 2) static pedestrians 3) static objects of varying size such as benches and fire hydrants 4) slopes 5) times road crossings. Each of these obstacles require a specific set of skills to be overcome. The slopes, for example, require the participant to generate more force when propelling in anticipation of the uphill experience, which will in turn require less force when going down. These obstacles were created based on interviews with health care professionals, as well as expert MW users which has provided the preliminary work needed to determine the challenges faced by MW [42].

1.6 – Technology acceptance model and VR simulator

We used the technology acceptance model (TAM) to help guide the important variables to assess in this research. It is based on the premise that, in order to adopt a new technology, we first have to accept it. According to the TAM, acceptance is an attitude towards a technology, and it is influenced leading to behavior [37]. Indeed, the main factors impacting the motivation of using a new technology are perceived usefulness, perceived ease of use and attitude towards use [37]. In this thesis, we have grouped these three factors under the term *usability*.

We also did a literature for both manual and powered wheelchair simulators [17-19, 25, 27-29] to make sure we didn't overlook any other factors that may impact usability. We found that fidelity was also a very important factor to consider. *Fidelity* can be defined as the grouping of level of immersion and haptic feedback (both of which include sense of presence). Realism is also an important factor but is closely related to both immersion and haptic feedback, and it will not be considered as a separate concept [17, 25].

1.6.1– Usability

Usability is a concept that addresses the human-technology interaction, more specifically, the ability of the intended user to effectively use the tool [30]. It can be defined as the perspective of ease to learn that a technology can provide, ease of remembrance of a task, or how a task can be subjectively pleasing [30]. As explained by the TAM, usability can be influenced by perceived usefulness, perceived ease of use and attitude towards use.

1.6.2– Immersion

Immersion can be defined as the user's sense of presence and can be divided into three categories: non-immersive, semi-immersive or fully immersive [17]. Level of immersion can be enhanced by providing the user with the ability to change the field of view, improving sense of presence and navigation skills [25]. Since we are using a 2D monitor and platform, this type of immersion falls into the non-immersive category. This could help overcoming immersion sickness, a phenomenon impacting the usability of VR in rehab.

1.6.3– Haptic Feedback

As for haptic feedback, its role is to increase sensory fidelity of VR, thus creating a communication with the user via stimuli [31]. Sensory fidelity can be defined as how close to reality the experience is. The platform of miWe simulator is stationary; therefore, no tilt will be provided by the hardware when going up or down a hill. The use of haptic feedback will provide the compensation needed to ensure that the physical effort of propelling a wheelchair in the virtual world is matched [32]. Features such as slopes, different floor surfaces, collisions, all help improve the sense of reality when matched with the effort of propulsion, which is vital to making the VR simulator immersive [32]. As previously mentioned, immersion and haptic feedback are both concept that are required in order to have a sense of realism. Realism can be defined as level of consistency of the virtual environment with real world experience [17, 25].

1.7- Rationale and Objectives

In light of the information presented above, this study exploredways of filling in the gaps in MW skill training as perceived by clinicians and MW users. Thus, the aim of this study was to contribute evidence towards validating the usability and fidelity potential to which wheelchair skill training can be positively influenced by using a VR simulator.

The first objective of this study was to validate the usability of the MiWe simulator by clinicians and expert MW users to, eventually, help improve wheelchair skills.

The second objective was to determine whether or not haptic feedback will affect the overall experience by comparing the current study to a similar previous study done without haptic feedback.

Chapter 2: Manuscript

Usability of a Virtual Reality Manual Wheelchair Simulator

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2.1 – Abstract

Introduction. Individuals with reduced mobility often require assistance for getting around. Simple task such as going from the couch to the kitchen or more complex tasks such as going to grocery store, require a significant amount of planning and repetition. As for any other movement repeated hundreds of time a day, the proper use of a MW is of great importance in order to avoid, reduce, and prevent the risk of injury. It requires proper technique, knowledge and practice due to the complexity of the task. Given the risks involved with MW use, it is important to be able to gain these skills in safe and controlled training environment, all while being effective. Training in a virtual reality (VR) setting allows for safe simulation of MW driving in a wide range of otherwise risky environments. In addition, it has been reported that the learned skills in a VR setting, can translate to real world scenarios, therefore allowing for skills improvement. The purpose of this study was to contribute evidence towards validating the usability and fidelity potential to which wheelchair skill training can be positively influenced by using a VR simulator. The first objective of this study was to validate the usability of the MiWe simulator by clinicians and expert MW users. The second objective was to determine whether or not the addition of haptic feedback to the simulator, which mimics gravitational and inertial forces, would positively affect the overall user's experience.

Methods. This mixed method study investigated the sense of presence, overall experience and ease of use of the experience in six MW users, as well as five expert clinicians in the field of wheeled mobility.

Results. Both clinicians and MW users reported a positive perception of usefulness, sense of presence, and immersion during the MiWe simulator experience. In addition, adding haptic feedback to the simulator significantly enhanced fidelity of the overall experience, compared to the no-feedback condition.

Discussion. The impact of our findings intends to help rehabilitation professionals, who provide mobility-related services, to guide, alter and tailor their future mobility interventions according to their clients' needs.

2.1.2 - Introduction

There are approximately 290 000 wheelchair users in Canada, including all pathologies and wheelchairs types, with 200 000 being manual wheelchair (MW) users [1]. This represents approximately 1% of the Canadian population with similar numbers reflected worldwide. An individual needing a MW will likely be using it for several weeks, months, years, or the remainder of their lives, for many of their activities [2]. Proper MW skills will need to be mastered in order to be able to maintain independence, as independence is an important determinant of quality of life (QoL). As for any other movement repeated hundreds of time a day, the proper use of a MW is of great importance in order to avoid, reduce, and prevent the risk of injury. It requires proper technique, knowledge and practice due to the complexity of the task. Given the risks involved with MW use, it is important to be able to gain these skills in a safe and controlled training environment.

It has been reported that as high as 60% of Canadian MW users tend to depend on other people for mobility assistance [8]. This is associated with a reduced sense of independence, and a greater degree of depression [9], both negatively affecting QoL for wheelchair users [8]. Therefore, helping improve MW skills is of great importance. There is, indeed, a clear link associated between MW skill training and an overall improvement of QoL [40]. For example, a study conducted by Oyster et al. has demonstrated that proper wheelchair skill training, as well as increased time spent propelling a MW, leads to a greater degree of independence and improved QoL [6-7]. This leads to less dependence on caretakers, which in turn leads to an increased sense of QoL and social reintegration [40].

Nonetheless, clinicians have yet to implement standardized training programs for MW users. According to a national survey of practice in Canadian rehab centers, basic MW skill training (e.g. wheel-locks) was consistently part of clinical practice with 45 of 68 respondent teaching it, while advanced skill training (e.g. curb-cuts) was rare with only 8 of 68 respondents teaching it, for reasons such as lack of time lack of resources, cost and uncertainty of how to implement such programs into practice [13,43].

The use of VR has presented itself as a promising modality to bridge the gap in MW training. It could possibly help resolve the issues of time, resources and cost brought forth by the clinicians. This technology offers many advantages such as its ability to recreate different real-world environments without the hassle of physical constraints, in a safe and controlled manner [15]. This is of great importance, as we can recreate context-specific tasks identified as challenging by the MW users in a virtual environment and modify them as needed. In addition to providing a reproducible and safe environment, VR can also provide a consistent environment with the potential for infinite repetitions, making it unique [16], with the ability to capture objective measurements as well as providing real time feedback [17]. The use of VR has also demonstrated greater patient compliance, enthusiasm, enjoyment and improved confidence when placed in similar real-world environments in comparison to regular therapy. [16].

VR has been successfully used in driving simulation of vehicles such as cars, planes [21] and power wheelchairs [15, 19, 22-25]. As for MW's, there are few conclusive studies that exist in which VR is used as an addition to regular therapy, in regard to mobility training. Although studies on MW users and VR are few and far between, the one that are conclusive utilize the "gaming" aspect of VR addressing cardiovascular health. For example, O'Connor et al. looked at the use of VR as a physical training system for MW users, eliciting an improvement in cardiovascular health [26]. They developed a training station that consisted of two dynamometers on top of which a manual wheelchair was placed and a VR simulator was used to recreate different environments [26]. Nonetheless, there are currently few studies in the literature looking at helping MW users learn how to use a MW with the help of VR.

This has led us to create the McGill immersive wheelchair simulator (miWe). It consists of a platform, with motors that replicate the forces and dynamics experienced when using a MW in the real world, as well as a computer and monitor on which the virtual scenario can be displayed (Figure 1). The simulator allows people with different pathologies to use their own wheelchair for skill acquisition, integrating a fun and motivating gaming aspect. The miWe is unique in its low build cost and compact size (size of a small desk). The miWe was designed to help address the concerns brought forth by clinicians regarding lack of time and standardization in MW skill training, all the while keeping the MW user top of mind. The software content of the miWe simulator is based on an "infinite sidewalk" scenario, where the MW user is faced with different obstacles to overcome (benches, slopes and cross-slopes, moving pedestrians, street crossing, etc.). This scenario was designed to allow users to experience the outside world, without being exposed to the risk of injury due to lack of experience.

In a preliminary study, there was an assessment of the MiWe simulator in sixteen healthy adults using two display conditions: a head-mounted display (HMD) and a computer monitor [42]. The evaluation of task performance, cybersickness, presence and overall experience in

VR were compared between the two display conditions. Results showed that the HMD condition was rated as significantly higher in terms of sense of presence and VR experience but provoked more intense symptoms of cybersickness [42]. Further many participants of the earlier study indicated that propulsion in the simulator was not realistic, with too much friction and no ability to perceive slopes or collisions. A new version of the MiWe simulator was conceived, which added force/haptic feedback to the wheels, in order to mimic gravitational and inertial forces experienced during real MW propulsion. And due to the increased symptoms of cybersickness experienced with an HMD, with small gains in MW performance, we decided to use a computer monitor in this new MiWe version.

As part of the MiWe's continued development, we needed to validate its content to make sure it is useful and usable, to help improve MW skills. Clinicians and MW users will find a tool to be useful if it fits their needs, and allows them to reach their goals, all while being easy to operate. The easier and more useful the tool is, the more motivated the participant would be, which encourages longer engagement [18]. Another important concept in VR research is the sense of presence, defined as the subjective feeling of being "in" the virtual environment. Sense of presence is related to motivation while engaged in the activity, as well as realism. A high sense of presence is related to compliance in the practice of an activity and to better transfer of skills are to the real-world environment, provided that the activity is also realistic [44].

This project was designed to answer the following research question: what is the usability of virtual reality simulator, and its potential influence on manual wheelchair skills training, according to clinicians and expert wheelchair users? Our first hypothesis was that among clinicians and MW users, we would measure a positive view on usability and sense of presence, during the MiWe simulator experience, and that there would be no difference between clinicians and MW users. Our second hypothesis was that the current version of the miWe simulator, which includes haptic feedback, would provide more realism in comparison to the previous version with no haptic feedback, therefore, increasing the sense of presence [42].

2.2 - Methods

2.2.1– Study design

A mixed method design was conducted, combining an observational cross-sectional study with semi-structured interviews**.**

2.2.2– Participants

All participants provided informed consent, as approved by the ethics committee of the Interdisciplinary Research Centre in Rehabilitation (CRIR, Canada). Eleven participants were recruited for this study of which six were MW users and five were clinicians. The study took place at the Jewish Rehabilitation Hospital, Laval, Canada, over the course of six months.

To participate in the interviews, both clinicians and MW users had to be between 18 and 75 years of age, able to follow directions in either French or English and with no significant visual impairments, uncorrected by eyeglasses. Clinicians were included if they were experts in the field of wheeled mobility, defined as having a minimum of 5 years providing care to people in MW. As for the MW users, they were included if they had a minimum of 3 years of MW use. They were excluded if they had upper limb impairments; if they were unable to transfer independently from their WC to the simulator's WC (for reasons of safety and practicality); and if they had cognitive impairments, defined as a score lower than 3 on the Mini-Cog assessment. The Mini-Cog is a simple to use test which consist of a clock-drawing task, an animal naming task, and a three-item recall task [33]. This test was chosen due to its reliability and validity.

2.2.3– Task design

The participants were placed on the miWe platform to experience the infinite sidewalk simulation. The hardware consists of a platform replicating the forces and chair dynamics experienced when using a MW in the real world, as well as a computer and monitor on which the virtual scenario can be displayed [46]. It is able to accommodate different types of MW. Movement of the wheels controls the virtual MW, and haptic feedback mimics inertia. gravity and collisions felt in the real environment.

The software content of the miWe simulator is based on an “infinite sidewalk” scenario. The task consisted of navigating on an infinite sidewalk and facing different obstacles. The obstacles encountered by the participants were: 1) moving pedestrians 2) static pedestrians 3) static objects of varying size 4) slopes 5) times road crossings (Fig. 1.a-1. d). The order at which they presented themselves was randomized and each participant experienced every obstacle 5 times for a total of approximately 30 minutes on the platform.

Following the experimental task, participants answered questionnaires on sense of presence and ease of use. They also participated in a short interview on the same topics. A complete experimental session is illustrated in Figure 3.

Figure 1.a. Static and moving pedestrians

Figure 1.b. Static objects of varying size

Figure 1.c. Slopes

Figure 1.d. Timed road crossing

As illustrated in figure 1. a,b,c, and d, we can see the different obstacles in the MiWe infinite sidewalk experience.

Figure 2.a. View of full set up

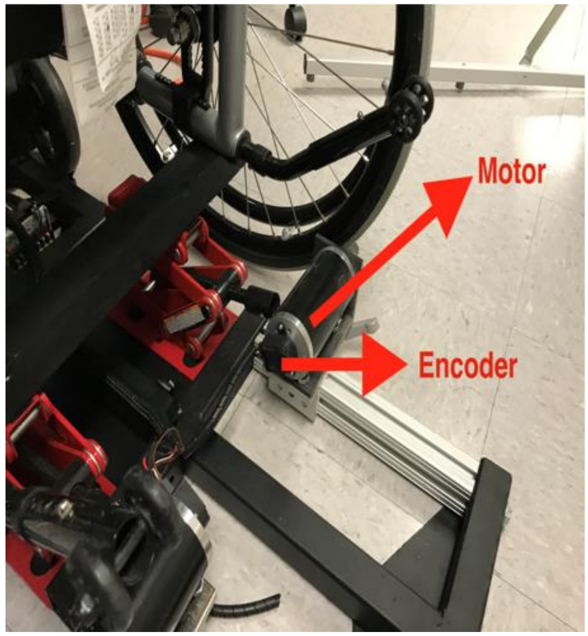

Figure 2.b. View of motor and encoder

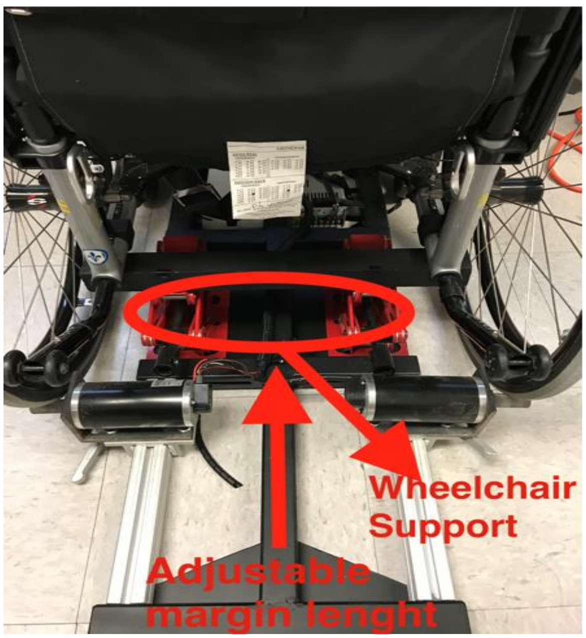

Figure 2.c. View of wheelchair support and adjustable platform

As illustrated in figure 2. a,b, and c., we can see the different views of the MiWe platform.

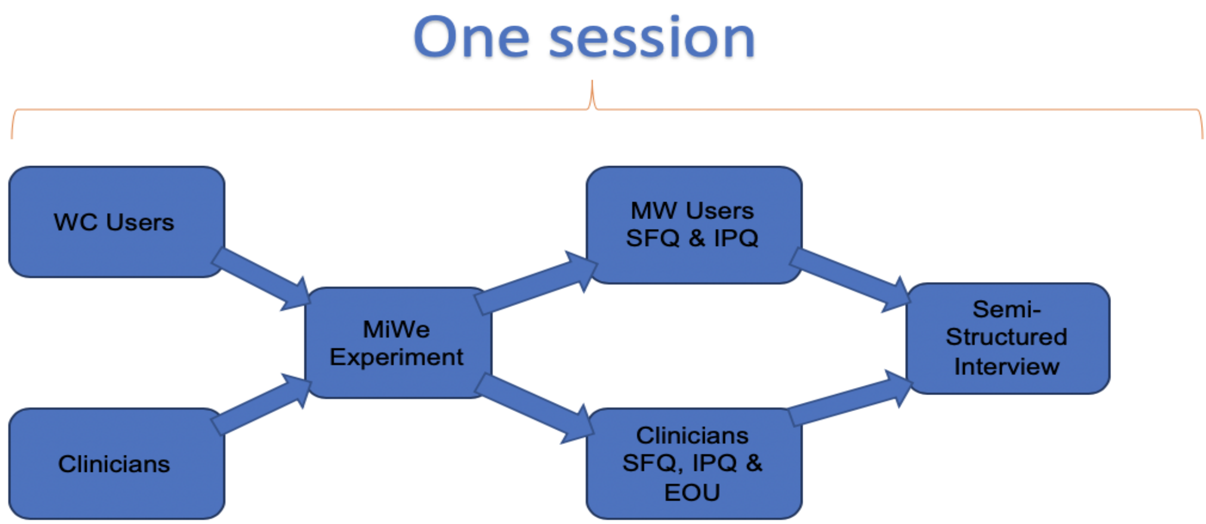

Figure 3: A global overview of a full session.

2.3-Quantitative Measures

Immediately after completing the miWe task, the participants completed a series of questionnaires and participated in a semi-structured interview. The MW users answered the

short feedback

questionnaire (SFQ) and the iGroup-presence questionnaire (IPQ) (Appendix 1-2). The clinicians, in addition, were given the perceived usability and ease of use questionnaire (EOU) (Appendix 3). Both groups then participated in an individual, semi-structured interview, guided by their answers in the pre-administered questionnaires.

The SFQ is a 10-item questionnaire, scored on a five-point scale (eg. 1= Not at all and 5= A lot), that inquiries about the participant's level of enjoyment, immersion, success, control, conform, overall difficulty and whether the feedback from the computer was clear and understandable (Kizony et al., 2006). It was chosen for its good internal consistency, construct validity, and its ability to efficiently get feedback from the participants VR experience [28]. This questionnaire contains ten questions ranging from the feeling of enjoyment, to the level of discomfort, all scored on a five-point scale.

The IPQ is an outcome measuring the experienced sense of presence in a virtual environment. It consists of a 14-item questionnaire, scored on a seven-point scale (eg. -3= fully disagree, 0= neutral and 3= fully agree), that inquiries about the participant’s level of involvement, experienced realism, spatial presence and general presence [38]. It was chosen for its good validity and reliability in terms of presence measured in a virtual environment [38].

The EUQ is a two-part questionnaire looking at ease of use of the technology as well as perceived usability of the technology. It assesses the lack of difficulty brought upon with the use of a technology, as the easier a technology is to use, the more likely it will be accepted and used [37].The EUQ administered in this study was made to be specific to the use of the miWe simulator. This questionnaire was only administered to clinicians as it relates more specifically to their practice. It contains twelve questions scored on a seven-point scale.

2.4-Qualitative Assessment

All participants had a one-on-one semi-structured interview conducted by the first author in order to describe their experience with the miWe simulator and VR tasks, as well as the degree to which the miWe could be used as a training tool. The one-on-one interview were administered immediately after the questionnaires by the first author. Participants were asked to describe what they enjoyed the most and least about the simulator and why, the level of similarity of each activity with their real-world MW experience, and overall comments on their experience. In addition, their answers from the questionnaires were used to guide the interview with additional questions. The initial time allotted for the interview had a time limit of 30 minutes. These were recorded by audio for transcription purposes. For more information about the questions asked, refer to Appendix 4.

2.5-Data analysis

2.5.1 -Quantitative analysis

For our first hypothesis, we expected to record a positive result on ease of use, sense of presence, perceived usefulness, as well as overall feedback from clinicians and MW users using the miWe simulator and that we wouldn't see a difference between both groups. We first computed descriptive statistics (mean and standard) for the SFQ, IPQ and EOU (clinicians only) and considered a result to indicate a positive opinion when the average response was above neutral.

To compare the responses of clinicians and MW users for the SFQ, we conducted a Mann Whitney U test. This testing method was chosen as the response option were non-parametric. Although it is not on a continuous scale, the answers were in a categorical ordinal scale. For the IPQ we conducted a one-way ANOVA comparing the responses of clinicians and MW users.

For our second hypothesis, we hypothesized that the newer version of the miWe would provide a greater sense of presence when comparing it to the previous study without haptic feedback, due to the inclusion of the haptic feedback. For this hypothesis, we only investigated the IPQ. We conducted a separate analysis for each of the IPQ's subscales, comparing the following three groups: WC users (n=6), Clinicians (n=5), Participants of the previous study without haptic feedback (n=16), (post-hoc/one-way ANOVA, with correction for unequal groups).

2.5.2-Qualitative analysis

After carefully listening to the recordings, all interview conducted were transcribed verbatim by author FC; all aspects of the conversations, including any changes in intonation, pauses and incomplete sentences, as these aspects can convey important emotional significance.

Common topics, concepts, feelings and recurring phrases from the interviews were initially coded line by line by author FC. They were then reviewed by the second author (PSA), who was able to agree with, disagree with, and/or question the codes established by the first coder in addition to adding new codes that the later may have missed. After being able to highlight and agree on the emerging themes, several meetings were held to discuss and determine the subsequent themes for both the data gathered from the MW users and clinicians. A deductive analysis was used to analyze the transcribed data. Data from clinicians and MW users were analyzed together as the same major themes were recurrent between all participants. The emerging themes were combined and categorized, as illustrated in the results. We used pre-established questionnaires in order to help guide the semi-structured interview.

2.6- Results

2.6.1- Demographics

Table 1 summarizes the demographic characteristics of the 5 (n = 5) expect clinicians who participated in this study. 3 (n = 3) participants were between 28 to 32 years of age and 2 (n = 2) participant were aged 38 and 42.

Demographic variables		Value
Age	Mean	33.8
	Median	32
Gender	Male	4
	Female	1
Years of experience in wheeled mobility	Mean	7.2
	Median	7

Table 1: Demographic data of expert clinicians (n = 5).

Table 2 summarizes the demographic characteristics of the 6 (n = 6) MW user who participated in this study. 6 (n = 6) participants were between 51 and 62 years of age.

Demographic variables		Value
Age	Mean	56.3
	Median	55
Gender	Male	5
	Female	1

Table 2: Demographic data of MW users (n = 6).

Table 3 summarizes the demographic characteristics of the 16 (n = 16) naïve adults who participated in the previous study without haptic feedback. 15 (n = 15) participants were between 21 and 26 years of age and 1 (n = 1) participant was 63 years of age.

Demographic variables		Value
Age	Mean	25.4
	Median	24
Gender	Male	9
	Female	7

Table 3: Demographic data of naïve adults who participated in the previous study without haptic feedback (n = 16).

2.6.2– Quantitative Results

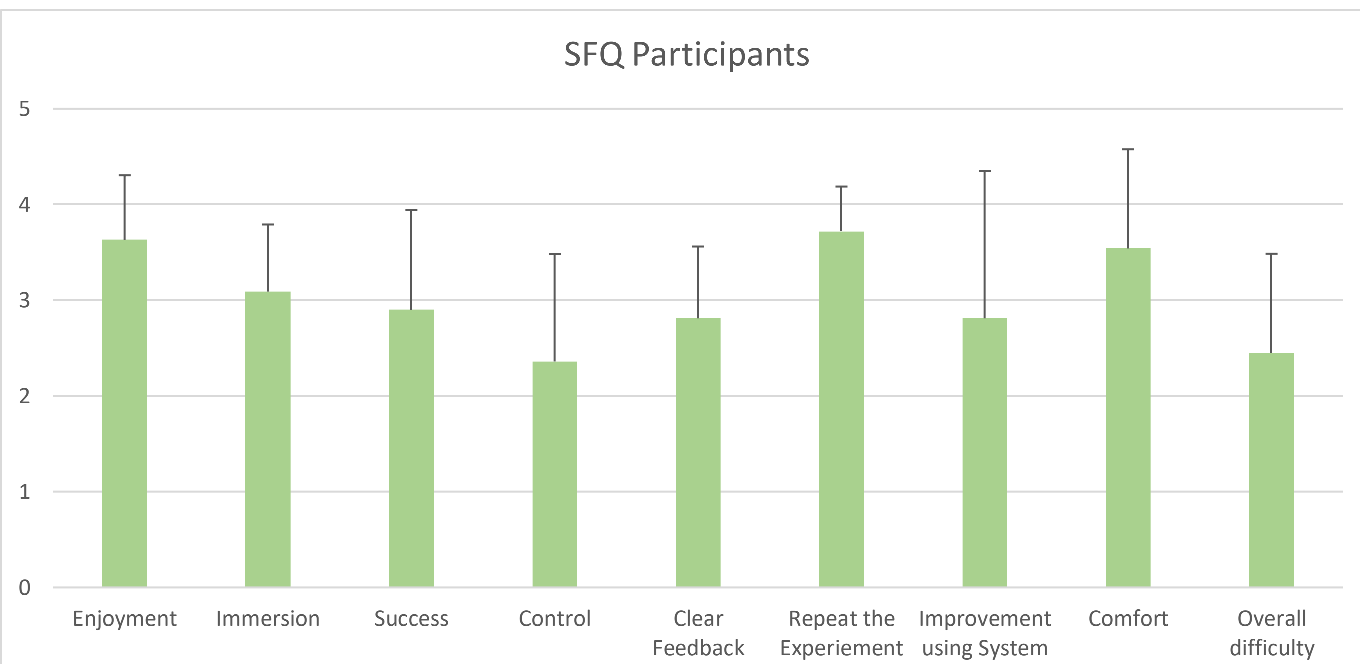

Figure 4: Results for overall feedback of all participants in the study. Error bars represent the standard deviation.

When looking at the SFQ for all participants, we can see that there was an overall positive miWe experience in terms of feedback. Most participants expressed enjoyment, comfort and a willingness to redo the experiment. The most positive feedback was the willingness to repeat the experiment. In contrast the sense of control was the least positive one.

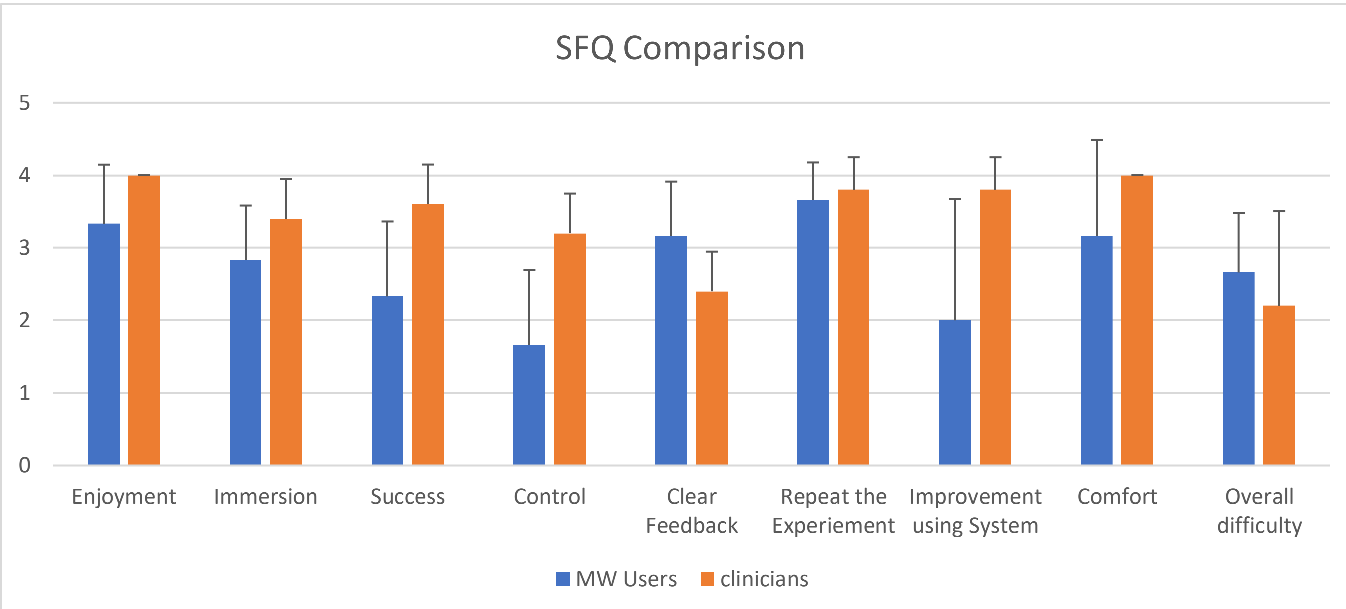

Figure 5: Results for overall feedback for all participants, separated by manual wheelchair users and clinicians. Error bars represent the standard deviation.

After comparing answers of clinicians and MW users on the SFQ, we only saw a significant difference in one question, related to the feeling of control during the miWe experience (appendix 1). There was no significant difference between clinicians and MW users on any of the other SFQ questions.

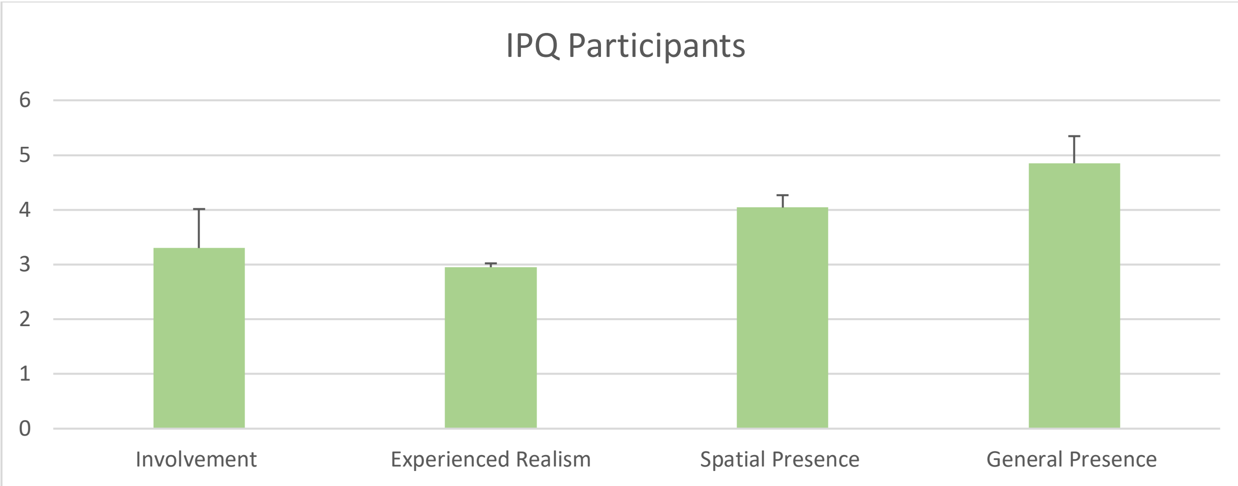

Figure 6: Average IPQ score for each category for all participants of this study. Error bars indicate standard deviation.

IPQ scores for all participants showed that they felt present in the simulated environment. The lowest score is seen to be 3 (on a maximum of 5) in the Experienced Realism. Involvement (score of 3.25), spatial presence (score of 4.1) and general presence (score of 4.82) were all above a score of 3 (neutral).

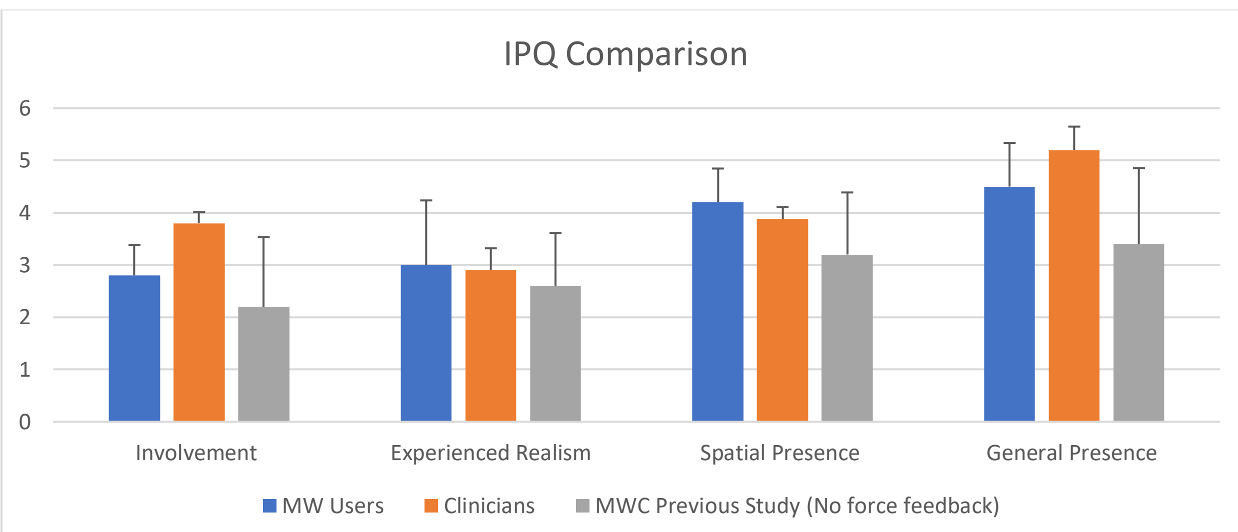

Figure 7: Average IPQ score for each category for all participants, separated by clinicians and MW users. Error bars indicate standard deviation. MW users n=6, Clinicians n=5, and MWC Previous Study (No force feedback) n=16.

IPQ group comparison scores are presented in Figure 7. The biggest difference between both groups was the level of involvement, showing the MW users felt a below average level of involvement with a score of 2.8, in comparison with the clinicians with a score of 3.8. However, none of the observed differences were significant.

In terms of involvement and experienced realism, there was no difference between the three groups (clinicians, MW users and participants from previous study). However, there was a significant group

effect

found in terms of spatial presence (F= 9.05 and p= 0.001) and general presence (F= 4.96 and p= 0.016).

When looking at the post-hoc test for the spatial presence we found that there was no significant difference between the MW users and the clinicians. Nonetheless, there was a significant difference between the MW users of our study and the MW users of the previous study without haptic feedback (mean difference of 1.56 Std. error of 0.46 and a p = 0.003). There was also a significant difference in the level of spatial presence between the clinicians and the MW users without feedback (mean difference of 1.24 Std. error of 0.44 and a p = 0.03)

When looking at the post-hoc test for general presence, there was also a significant difference between the clinicians and the MW users without haptic feedback (mean difference of 1.83 std. error of 0.63, with p= 0.02).

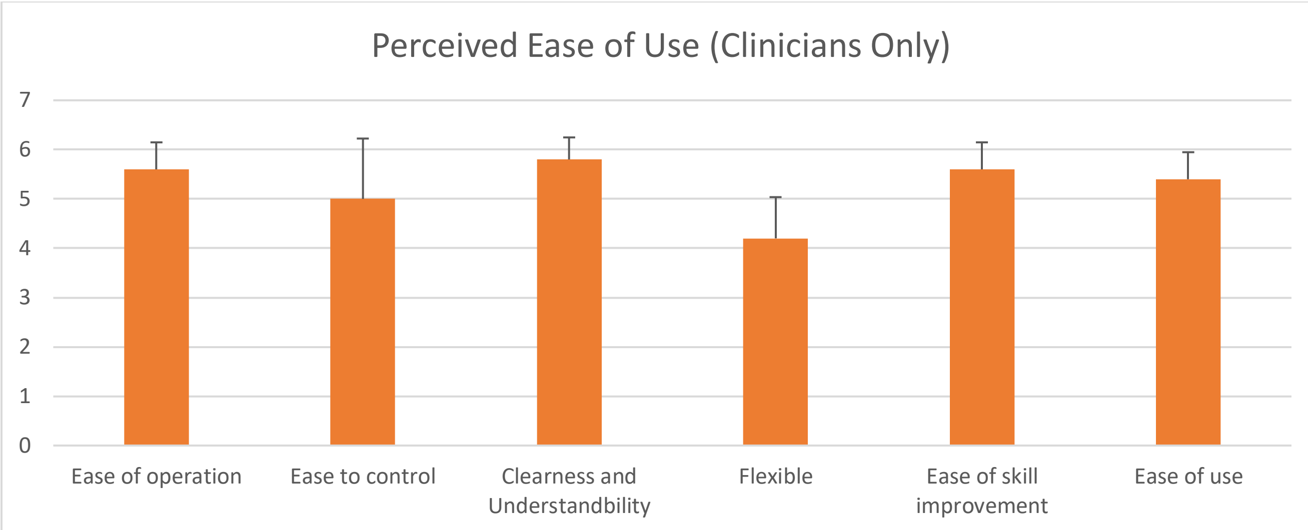

Figure 8: Perceived Ease of Use scores for clinicians. Error bars indicate standard deviation

In terms of perceived ease of use clinicians reported an overall ease of use with the miWe system, as shown by the high scores across the different subcategories of the EOU (Figure 8). The highest score was seen in the "Clearness and Understandability" category (5.8/6). With the lowest score being in the flexibility of use category (4.2/6), while still being above neutral, which is represented by the number 3 in this graph.

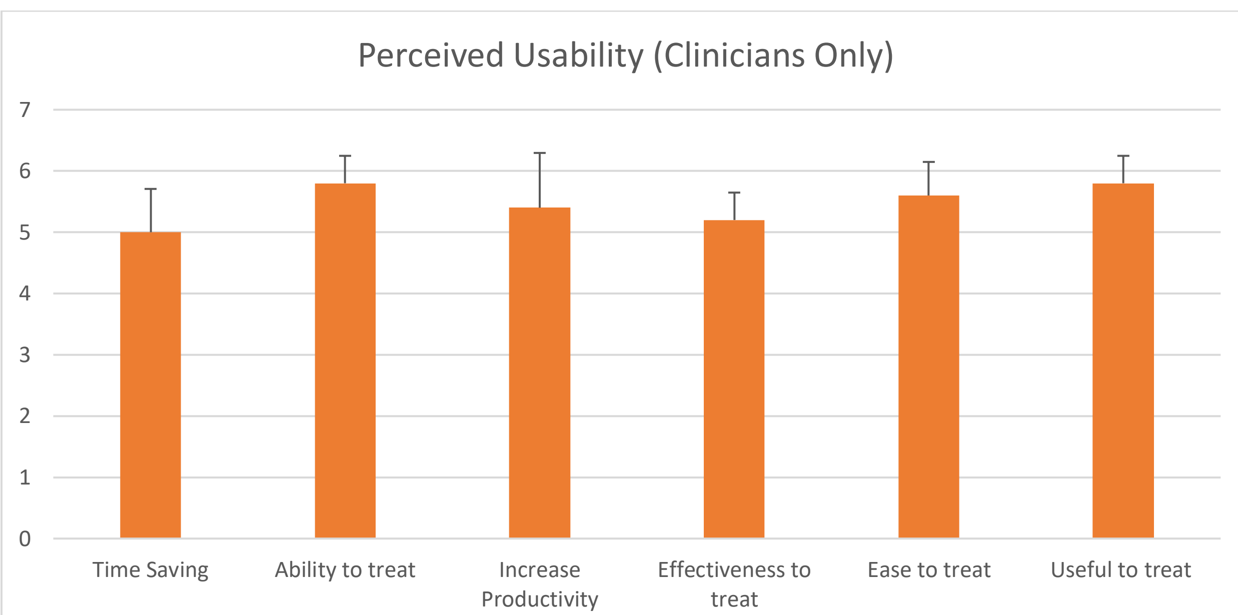

Figure 9: Perceived Usability scores for clinicians. Error bars indicate standard deviation

As seen in figure 9, the perceived usability in terms of potential clinical use, we saw a high result across all sections. The highest scores were seen in two sections: “Ability to treat” and “Useful to treat”, with a result of 5.8/6. The lowest score is seen in the “Time Saving” category, with a score of 5/6, which is two point above neutral, represented by the number 3 in this graph.

2.6.3 Qualitative results

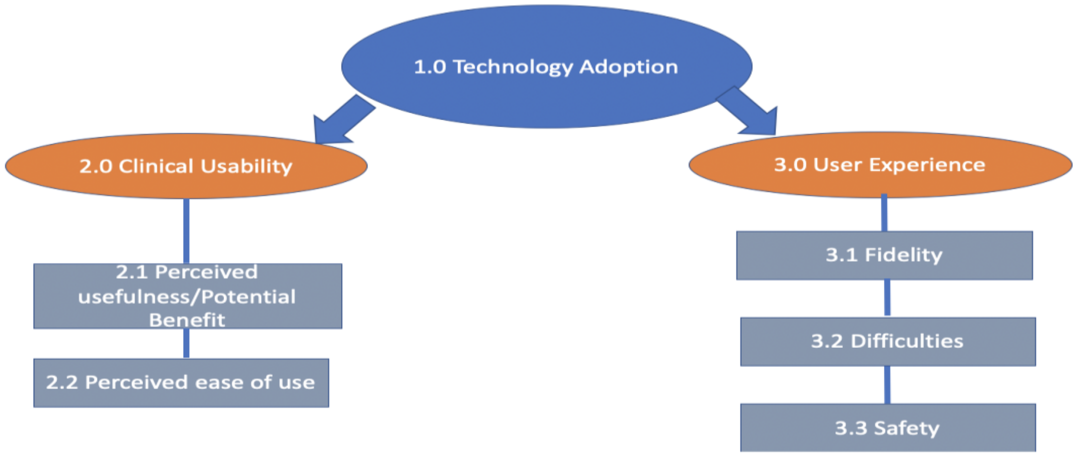

Figure 10: Visual representation of the identified themes.

1.0 Technology adoption

Technology adoption was the significant theme that emerged in all interviews during the data analysis and was made the central emerging theme. This theme refers to all the elements and factors involved in the steps needed to validate the adoption of a new technology.

2.0 Clinical Usability

Clinical usability was a significant theme that emerged in all interview transcripts during the data analysis. This theme ties in with technology adoption and refers to all the elements and factors involved needed to make a technology usable in a clinical setting. There were two sub-themes that emerged, potential benefits and ease of use.

2.1 Perceived usefulness/Potential Benefits:

This theme can be described in terms of potential benefits, as observed by the different participants. This includes both clinical and practical aspects of the miWe.

The data analysis revealed that these factors encompass the participants' ability to forecast a potential use for this system in terms of developing skills related to MW mobility. When asked about its potential benefits, a clinician said: *"this would be a great training tool for new MW users. It would allow the user to develop reflexes in terms of obstacles faced. Knowing to increase speed when facing a slope, and the more you practice, the more you can gage the amount of effort needed."* A manual wheelchair user added: "*it would be a great system; I didn't get much training myself. It would help me learn how to use my energy. I would feel more confident before going outside by myself.* "

All participants greatly appreciated the idea that a new user could possibly learn how to gauge the necessary amount of energy and skills required to do regular tasks such as going to grocery store, as they would be face with a lot of obstacles to get there.

A MW user mentioned he really enjoyed the precision required to maneuver in small spaces such as a sidewalk as it would help the new MW users gain a lot of important skills.

Other interesting comments were in regard to its compact size and space saving benefits. Facilities need be equipped with space and a wide range of equipment including slopes, sidewalks, different surfaces to be able to conduct the current standardized training program for people in MW, such as the Wheelchair Skills Training Program (WSTP). When they don't have such equipment and space, they resort to more creative ways of helping users practice these essential skills. A clinician mentioned: *"I see it reducing the need to go outside and to use the clinics hallways which would help me out a lot.".*

Another idea was its ability to help clinicians free up some time and focus on different aspect of training. The system can be modified in terms of number of faced obstacles, the types of obstacles, the time spent using the machine, and it saves the number of collisions. This allows the clinician to have someone practice on the machine, while they focus on other aspects of MW training such as arc length, possibly making each session more beneficial in terms of learning. *"I would definitely see a place for this tool in the hospital, it would be a great addition that would allow me to focus on other aspects of learning while the user is on the machine practicing."*

2.2 Perceived ease of use:

This is defined as the level of ease experienced by clinicians and MW users when faced with learning to operate and interact with the systems. In addition, this includes the flexibility of the system. As mentioned by Davis (1989) in his paper looking at ease of use of new technology, the easier the perception of use, the more readily the technology will be adopted and adhered to [37]. A MW user commented: *"at the beginning, I found it a bit difficult, it didn't feel natural, the traction wasn't the same as the real world, but after 10-15 minutes, I understood what was needed of me"*

When asking the participants on their thoughts about being able to use the machine by themselves, both clinicians and MW users agreed that it was easy to set up and use. A clinician mentioned: "*it didn't require many steps, it seems to be able to accommodate different wheelchair sizes [...], once the wheelchair was secured, it seemed like a pretty smooth process".*

3.0 User Experience:

User experience is a significant theme that emerged in all interview transcripts during the data analysis. This theme refers to all the elements and factors that improve or hinder user experience. Such factors encompass the participants' level of immersion, difficulties faced, and safety.

3.1 Fidelity:

In this section we combined several different concepts as they were frequently used interchangeably by participants when discussing level of immersion. The concepts are the following: level of immersion, level of coherence and level of realism.

These themes can be defined according to the following criteria's: awareness of environment while navigating in the virtual world, level of realism of the virtual world, how consistent the virtual world was to the real world and how present they felt in the virtual world. In addition, this section includes all elements that could be improved to increase the level of immersion.

When asked about the feeling of immersion, a MW user responded: *"I felt immersed, I wasn't completely disconnected with the real world, but this demanded my full attention. I felt like I was going to fall off of the sidewalk if I didn't push properly before getting to the slope."*

In terms of coherence and level of realism, participants had mixed reviews. In terms of what was enjoyed, a clinician mentioned: *"I like the fact there are people that we have to avoid and* *side slopes that require specific propulsion strategies and street crossing where you actually had to press a button to cross and you were timed. The cars were also a nice feature."*

In terms of features that weren't so coherent with the real world and weren't enjoyed by participants, there were several. The most commonly brought up feature was the pedestrian obstacle. Both clinicians and participants didn't enjoy the fact that the avatars didn't have a pre-set direction they would follow. *"The avatar would be walking straight, and all of sudden would turn around and stop in front of you. This was very frustrating."* A MW user added that *"in real life, you are able to verbally warn them and make eye contact with people".*

Another interesting comment that was made by a MW user was in terms of their ability to use their feet to help propel themselves: *"This is not the same, because in the real world, I would use my legs to get around at the same time. Here we are limited to only arms."*

In terms of features that would help increase the level of immersion, coherence and realism, several aspects were brought up. These features can be classified under haptic feedback. As for haptic feedback, its role is to increase sensory fidelity of VR, thus creating a communication with the user via stimuli [31]. A clinician mentioned that *"adding vibrations, sounds, frontal and lateral inclines, would increase the sense of realism in the virtual world, this would help me feel more immersed. "*Other comments such as being able to feel the cracks in the streets would also be an interesting feature.

3.2 Difficulties:

Difficulties is defined as all issues faced with the system or while using the system related to the participant experience. Every participant had a unique experience and faced different difficulties with the system.

Some issues faced where technical in terms of the machine itself. The system would sometimes crash, lag or just freeze. This in turn had an effect on the overall experience.

Different aspect such as shoulder pain, were also brought up during the interview. One participant said: "*30 minutes of rolling is very hard on the shoulders; I would usually be with someone or take easier routes if I was alone*".

Another aspect that was brought up by several participants was inertia. This is defined as the resistance to movement required to move the WC. It was at times experienced as too low or too high, which made it difficult to use the machine properly. *"The level of traction* [inertia] *didn't feel natural. At times I felt like it was too easy, at other it was too hard. It was more difficult going up a slope in this environment then it is in real life. But coming down is harder to control and I always hit the wall. "*This gave some participants a sense of lack of control.

3.3 Safety:

For the purpose of our study, safety is defined in terms of level of safety experience while using the miWe as a training tool in an outside environment. The data analysis revealed that there was an increased sense of safety felt when using the miWe system in comparison with the thought of conducting the same experiment on a real sidewalk. The sense of safety is multifaceted as it was brought up by both clinicians and MW users.

When asked about safety a clinician mentioned that *"this is great (the experience). If I was to reproduce this environment in the real world it would be extremely risky. Cars, falls, obstacles, all this is integrated while being inside."*

The level of skill required to be able to overcome a side slope on a sidewalk, while moving cars steps away, is not adequate for new MW users. This would cause a new MW user a lot of anxiety and would be unsafe. A MW user expressed: *"I would have avoided the slopes and side slopes if they were that close to the moving vehicles out of fear of falling. This would help me build my confidence. I feel I can make mistakes without injuring myself. "*

2.7- Discussion

The purpose of this study was to contribute evidence towards validating the usability and fidelity potential to which wheelchair skill training can be positively influenced by using a VR simulator. Due to the limited amount of studies that take this standpoint in the literature, we have also decided to use expert clinicians to validate the usability and fidelity potential of the MiWe simulator, making this study the first of its kind. We had two hypotheses to help guide this study and any future study of the kind. Our first hypothesis was supported with the results of the questionnaires and semi-structured interview. Indeed, when looking at the at the results from the IPQ and SFQ, which were administered to both clinicians and MW users, supported that the MiWe would be perceived as usable, which is considered as a response above neutral. Another important finding is that there wasn't any significant difference between the two groups.

The EOU was only administered to clinicians, as we wanted to gain a better understanding of their perceived ease of use and level of clinical usefulness of the miWe. The results show that the results were once again positive. As mentioned by Davis (1989), the easier the perception of use, the more readily a technology will be adopted and adhered to.

The quantitative results were confirmed by the interviews, where participants reported perceiving a sense of presence and immersion. This was seen in both groups, along with a positive sense of safety. Participants expressed a great sense of safety and increased confidence when using the miWe stating they felt the benefits of "practicing on a sidewalk, without the risk of have an accident on the road". Clinicians expressed a very similar feeling, but for different reasons, stating that the miWe would be a great clinical tool as it would help in “[*r]educing the need to go outside and to use the clinic’s hallways”.* Consistent with hypothesis, there was also a subjective appreciation for the miWe system and potential use for it in terms of clinical tool for new MW users, referring to its potential of freeing up some time and helping MW users focus on different aspect of training such as propulsion technique and possibly making each session more beneficial in terms of learning.

As for our second hypothesis, we hypothesized that the newer version of the simulator, which includes haptic feedback, enhances fidelity of the MiWe simulator in comparison to our previous version with no haptic feedback. Haptic feedback, plays a very important role in increasing sensory fidelity of VR, thus creating a communication with the user via stimuli [31]. The use of haptic feedback ensured that the physical effort of propelling a wheelchair in the virtual world was realistic, i.e., comparable to that of a real MW [32]. Features such as slopes, different floor surfaces, collisions, all help improve the sense of realism when matched with the effort of propulsion, which is vital to making the VR simulator immersive [32]. Immersion, realism and haptic feedback all contribute to a higher sense of realism.

When comparing the MW users of our study with haptic feedback to the MW users of the previous study without haptic feedback, there was a significant difference in terms of spatial presence with haptic feedback experiencing a higher. There was also a significant difference between the clinicians and the previous study’s participants (no haptic feedback) in terms of general presence (mean difference of 1.83 std. Error of 0.63, with P= 0.023). This shows the importance of haptic feedback in order to enhance sense of presence and fidelity of the MiWe.

These results are also reflected in the interviews by both clinicians and MW users. They mentioned experiencing an above average sense of spatial and general presence. Nonetheless, both groups also mentioned that they would have enjoyed more feedback in the form of sounds and realistic vibrations, such as "feeling the cracks in the sidewalk". This highlights the idea that more haptic feedback leads to a more present experience. This type of sensory feedback can provide crucial information regarding the ground surface such as slope, the surrounding environment and much more, all of which can even affect the users' emotions [41].

This study sheds light on how we can better the MW training process for new MW users. A possibility for a future would be adding different real time feedback in terms of where and when the collision was done, arc length and body positioning. This would possibly help the MW user improve in real time and help the clinician determine what needs to be focused on during future sessions.

2.7.1- Study Limitations

In this study, we analyzed the experience of MW users and clinicians after using the miWe system. The results may not be generalizable because the interviews focused on individual experiences. Nevertheless, the personal experiences of individuals can help the healthcare system understand how to better teach new MW user's important skills for their day to day life, as well as equip them with a tool that might change the way teaching is done.

Moreover, some interview content may have been impacted by the problem we faced with inertial force required to propel the MW and the fact that the platform of miWe simulator is stationary; therefore, no tilt was provided by the hardware when going up or down a hill. We made adjustments to the inertial force required to propel the wheelchair, which may have affected the realism of the simulation, impacting our study.

In addition, we had a low number of participants with a total of eleven, five MW users and six clinicians.

Finally, the problems faced by the systems might have caused participant to have a lower sense of presence and hindered the ability to feel fully immersed. At several occasions, the system either lagged or froze.

2.8- Conclusion

In conclusion, we were able to evaluate the usability and fidelity of the MiWe simulator, by both clinicians and MW users. This study's results intend to help validation the miWe as a tool that can one day be used by rehabilitation professionals involved in the learning of use of MW. This study gave us a better understanding on the current way MW users are being taught how to use a MW, as well as shedding light on an alternative method.

Chapter 3: Thesis summary and conclusions

The manuscripts of this thesis presented the results of our study exploring ways of filling in the gaps in MW skill training as perceived by clinicians and MW users. Thus, the aim of this study is to contribute evidence towards validating the usability and fidelity potential to which wheelchair skill training can be positively influenced by using a VR simulator.

We found that both clinicians and MW users had a positive experience using the miWe, validating its content in terms of usability. There was no significant difference between both groups. This was also seen during the interviews of both groups.

Our second hypothesis was that the current version of the MiWe simulator, which includes haptic feedback, would provide more fidelity in comparison to the previous version with no haptic feedback, therefore, increasing the sense of presence. Since there was no significant difference between clinicians and MW users in our study, they were considered to be a single group, while MW users of the previous study were considered to be a second group. Group differences were found when looking at sense of presence. We were able to determine that when included, haptic feedback had a significant different in the improvement of sense of general and spatial presence. The effect of haptic feedback was found to be as hypothesized. However, it is important to note that the previous study was conducted on healthy controls rather than expert MW users, which might be a limitation. As for the semi structured interviews, there was also an several mentions of enjoyment of the haptic feedback. Several participants also mentioned experiencing an above average sense of spatial and general presence. Nonetheless, both groups also mentioned that they would have enjoyed more feedback in the form of sounds and realistic vibrations, such as "feeling the cracks in the sidewalk".

This highlights the idea that more haptic feedback leads to a more present experience.

Two important limitations of the study were the low number of participants and the fact that we made adjustments to the inertial force required to propel the wheelchair. We had a total of 11 participants from which 6 were clinicians and 5 expert MW users. In addition, adjustments were made due to issues finding the proper propulsion resistance. Therefore, the results of this study may not be generalizable to the wider population.

Nonetheless the results of this study allow us to move one step closer to finding a proper way of enabling new MW users to learn how to use a MW in a safe, and more accessible way.

While trying to find the right inertial resistance for the MW, and interesting idea was brought forth by a MW user: the lack of resistance could help new users be more alert and work on their reflex. A future research study could look at the impact of reflex training in helping new MW users learn how to use a WC. Reflex training would include helping new MW users learn how to brake, when to cross a street, how to avoid collision with pedestrian, how much effort it takes to go uphill and control to go downhill…. I believe this would help new users get familiar with the effort necessary to navigate using a MW in the real world.

In summary, we were able to establish usability and fidelity of the miWe simulator in terms of usability immersion and haptic feedback. The study makes contributions to the fields of VR learning and rehabilitation. This was the first instance of validation of a VR simulator by MW users and clinicians, in the purpose of helping new users learn how to navigate. Virtual reality training combined with regular therapy is a novel way to train MW users safely and effectively. MiWe training would consist of a group setting, were one therapist could oversee the performance of several MW user at once. This would be done in conjunction with regular therapy at the initial stages of MW skill training. After the MW users gets familiar with the machine, they would be able to use it by themselves, and all performance information such as time and number of collisions would be relayed to the therapist to view at a later time.

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APPENDIX

1. SFQ

Short Feedback Questionnaire- modified (SFQ-M)

Name:______________________________ Date:________________

Name of Scenario:______________________ Experience #:__________

Please circle the number that best reflects your response:					
Part 1:	Not at all				A lot
1. Did you enjoy the task?	1	2	3	4	5
2. Did you feel as if you were inside the task/environment?	1	2	3	4	5
3. Did you succeed in the task?	1	2	3	4	5
4. Did you feel in control of the situation?	1	2	3	4	5
5. Did the environment seem realistic to you?	1	2	3	4	5
6. How clear was the feedback that was given by the computer?	1	2	3	4	5
7. Would you want to repeat this experience?	1	2	3	4	5
8. Do you think you would be able to improve using this system?	1	2	3	4	5
9. Did you feel any discomfort during the experience?	1	2	3	4	5
Part 2:	Very easy				Very difficult
10. How difficult was the task for you?	1	2	3	4	5

If you felt any discomfort please specify:____________________________________

____

2. IPQ

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

extremely aware — not aware at all

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

0 = moderately aware

64/inv1/0

How real did the virtual world seem to you?

completely real — not real at all

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

48/real1/1

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

fully disagree — fully agree

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

31/sp4/2

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

not consistent — very consistent

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

0 = moderately consistent

7/real2/3

How real did the virtual world seem to you?

about as real as an imagined world — indistinguishable from the real world

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

59/real3/4

I did not feel present in the virtual space.

did not feel	-3	-2	-1	0	+1	+2	+3	felt present	28/s

I was not aware of my real environment.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	37/in

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

not at all	-3	-2	-1	0	+1	+2	+3	very much	62/

Somehow I felt that the virtual world surrounded me.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	44/s

I felt present in the virtual space.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	33/s

I still paid attention to the real environment.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	40/inv

The virtual world seemed more realistic than the real world.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	47/real4/11

I felt like I was just perceiving pictures.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	30/sp2/12

I was completely captivated by the virtual world.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree	38/inv4/13

3. EOU

Using the VR Training System would enable me to accomplish tasks more quickly.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

Using the VR Training System would improve my ability to treat patients.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

Using the VR Training System would increase my productivity.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

Using the VR Training System would enhance my effectiveness to treat patients.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

Using the VR Training System would make it easier to treat patients.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

I would find the VR Training System useful to treat patients.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

Perceived Ease of Use

Learning to operate the VR Training System would be easy for me.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

I would find it easy to get the VR Training System to do what I want.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

My interaction with the VR Training System would be clear and understandable.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

I would find the VR Training System to be flexible to interact with.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

It would be easy for me to become skilful at using the VR Training System.

likely								unlikely
	Extremely	quite	slightly	neither	slightly	quite	extremely	

I would find the VR Training System easy to use.

likely								unlikely