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Wheelchair Training Program for New Manual Wheelchair Users

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by

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List of Abbreviations

ANOVA, repeated measures analysis of variance

CPG, Clinical Practice Guidelines for the Preservation of Upper Limb Function Following Spinal Cord Injury

DC, decay coefficient

ICF, International Classification of Functioning, Disability and Health

MCS, motor control signal

MFS, motor feedback signal

NSCISC, National Spinal Cord Injury Statistical Center

PC, push coefficient

PS, previous signal

SCI, spinal cord injury

VMC, video motion capture

WHO, World Health Organization

WMS, WheelMill System

WPT, Wheelchair Propulsion Test

WST, Wheelchair Skills Test

WSTP, Wheelchair Skills Training Program

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Dedicated to David B. Gray, PhD, my first research mentor and good friend.

ABSTRACT OF THE DISSERTATION

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Manual wheelchairs are commonly used for everyday mobility among people with lower limb impairments, including persons with spinal cord injury (SCI). Manual wheelchair users often experience pain and chronic overuse injuries in their upper extremities, limiting their mobility and their ability to complete daily activities. The repetitive trauma of propelling a wheelchair may be a contributing factor to upper extremity pain and injury. The anatomy of the upper extremities is not designed for the number of repetitions and the amount of force involved in everyday wheelchair propulsion. Research has been conducted to identify recommendations for decreasing the number of repetitions and the amount of force involved with manual wheelchair propulsion; however, training on how to use a wheelchair, specifically propulsion training, is often not implemented during rehabilitation. Important steps in identifying strategies for teaching wheelchair propulsion and skills include exploring devices for training, understanding health care professional and wheelchair user perspectives of wheelchair training, and training based on motor learning approaches. Therefore, the overall goal of this project was to further explore methodology for training of new manual wheelchair users. To this end, we conducted three studies (Chapters 2–4).

In study 1 (Chapter 2), we tested a wheelchair dynamometer roller system, the WheelMill System (WMS), on its use in simulating different surfaces (i.e., overground and ramps) and assessing propulsion variables that can be used for training new wheelchair users. We identified that the WMS has the ability to accurately simulate flat overground movement; however, the

accuracy of the WMS was poor in simulation of ramps. Modifications to the software model and the addition of visual feedback may improve the accuracy of the simulation of ramps. The WMS was accurate in the quantification of biomechanical propulsion variables.

In study 2 (Chapter 3), we identified perspectives of health care professionals and manual wheelchair users to assist in prioritizing the focus of wheelchair skills training of new manual wheelchair users. During focus groups, health care professionals and manual wheelchair users discussed if and how wheelchair propulsion biomechanics were taught and important skills that should be included in training. Results indicate that propulsion biomechanics were introduced but not addressed in detail. Important training components discussed include propulsion techniques, transfers in an out of the wheelchair, providing maintenance to the wheelchair, and navigating barriers such as curbs, ramps, and rough terrain. Health care professionals and manual wheelchair users identified many of the same skills as important but ranked them in a different order.

In study 3 (Chapter 4), we piloted a wheelchair training program implementing aspects of motor learning for new manual wheelchair users and measured the impact of this program on wheelchair propulsion biomechanics and overall wheelchair skills. Post-training wheelchair biomechanics changed, as well as propulsion performance overground. Wheelchair skills did not change significantly post-training. Wheelchair training has the potential for change; however, there are many challenges associated with implementing training programs for new manual wheelchair users.

Together, these results contribute knowledge to evidence-based approaches to teaching new manual wheelchair users with SCI how to efficiently and effectively use their wheelchairs. Specifically, we obtained information about technology for simulating and assessing manual wheelchair propulsion, perspectives of stakeholders with regard to the manual wheelchair training process, and methodology for training new manual wheelchair users.

Chapter 1: Introduction

1.1 Manual Wheelchair Users

In the United States, approximately 6.8 million (3.51%) of the non-institutionalized general population age 18 and older use an assistive device for mobility (Kaye, Kang, & LaPlante, 2000; Kaye, Kang, & LaPlante, 2002; LaPlante & Kaye, 2010; Russell, Hendershot, LaClere, Howie, & Adler, 1997). The third most common device reported for mobility is the manual wheelchair (1.42 million users; Kaye et al., 2000; LaPlante & Kaye, 2010). People with various disabilities including spinal cord injury (SCI), multiple sclerosis, stroke, and cerebral palsy use manual wheelchairs for mobility (Kaye et al., 2000; LaPlante & Kaye, 2010).

1.1.1 Spinal Cord Injury

According to the National Spinal Cord Injury Statistical Center (NSCISC), nearly 276,000 people in the United States live with an SCI, and there are approximately 12,500 new injuries per year (DeVivo, 2012; NSCISC, 2013). Of those injured, 41% are paraplegics and 59% are tetraplegics. The incidence of SCI typically occurs at a relatively young age and, with advances in health care, more people are saved after injury, and people with SCI are living longer (DeVivo, 2012). The population of people with SCI is relatively small compared to the number of people with other health conditions such as cancer, stroke, and heart disease; however, associated annual health care utilization costs for people with SCI are overwhelming (Sadowsky & Margherita, 1999; Selvarajah et al., 2014). Persons with SCI use the health care system more often than the general population (this includes more physician and hospital visits), and they are more likely to experience other health conditions (Dryden et al., 2004; Selvarajah et al., 2014). The goal of clinicians and researchers who are focused on spinal cord injury is to decrease the negative impact of impairments and enhance participation in major life activities (Simpson, Eng, Hsieh, & Wolfe, 2012). The focus of rehabilitation for persons with SCI has been broadening from a traditional medical management to a model that includes an emphasis on community participation (Gomara-Toldra, Sliwinski, & Dijkers, 2014).

Persons with SCI require support and resources to live independently; this includes having independent mobility. Independent mobility has been identified by persons with spinal cord injury as a primary concern post injury as well as an ongoing concern post rehabilitation (Cox, Amsters, & Pershouse; Estores, 2003). The most common type of mobility device most persons with paraplegia and some with tetraplegia use for everyday mobility is a manual wheelchair (NSCISC, 2013). This is especially true for persons who are newly injured with approximately 61% of persons with a new injury using a manual wheelchair over other wheeled mobility devices (NSCISC, 2013).

1.1.2 Manual Wheelchair Use and Wheelchair Propulsion

Manual wheelchairs may enhance the mobility of persons with SCI, helping them engage in major life activities by increasing independence, providing more choices of activities, and improving satisfaction with participation in many areas. Despite this, many manual wheelchair users still experience activity limitations (Kaye et al., 2002; LaPlante & Kaye, 2010). Manual wheelchair users must be able to perform wheelchair skills to maneuver around their home and community environments independently (Kilkens, Dallmeijer, De Witte, van der Woude, & Post, 2004). Strong manual wheelchair skill performance by people with SCI is positively associated with participation in major life activities (Kilkens, Post, Dallmeijer, van Asbeck, & van der Woude, 2005; Öztürk & Ucsular, 2011).

An important skill related to moving the wheelchair is propulsion. Wheelchair propulsion using both upper extremities is the primary means of maneuvering a manual wheelchair for persons with SCI. A propulsion cycle is divided into a push phase and a recovery phase. The push phase is when the hand is in contact with the wheel and pushes in a forward motion. Recovery phase is the period in which the hand is not directly engaged with the pushrim. Four types of propulsion patterns (i.e., arc propulsion, single loop over propulsion, double looping over propulsion, and semicircular) have been classified (Boninger, Cooper, Baldwin, Shimada, & Koontz, 1999; Boninger et al., 2005). Each of these patterns varies according to the trajectory of the hand when the hand is in the recovery period. The variability in the propulsion techniques and skill of manual wheelchair users may be due in part to the level of injury and in part as a result of little or no manual wheelchair training (Coolen et al., 2004).

While wheelchair propulsion is an essential skill for maneuvering a manual wheelchair, the repetitive trauma of wheelchair propulsion is linked to secondary health conditions (e.g., pain, fatigue, and chronic overuse injuries). Ergonomic literature documents that a high amount of force and a high number of repetitions for a single activity increases a person's risk for a repetitive use injury (Bernard, Cohen, Fine, Gjessing, & McGlothlin, 1997; Kohn, 1998). According to the evidence found in the wheelchair biomechanics literature, wheelchair propulsion far exceeds those limits, with an average of one push per second during propulsion and peak propulsive forces as high as 110 N (Boninger, Cooper, Robertson, & Rudy, 1997; Hoover et al., 2003; Koontz et al., 2006). The average wheelchair user exceeds in 16 minutes the number of repetitions a factory worker in a high-cycle task would complete in an eight-hour day (Bernard et al., 1997; Koontz et al., 2006).

1.1.3 Chronic Overuse Injuries and Wheelchair Propulsion

Research suggests that repetitive trauma from propelling a wheelchair may be responsible for pain and chronic overuse injuries (Akbar et al., 2010; Boninger, Baldwin, Cooper, Koontz, & Chan, 2000; Collinger, Impink, Ozawa, & Boninger, 2010; Davidoff, Werner, & Waring, 1991; Finley, Rasch, Keyser, & Rodgers, 2004; Gellman, Chandler, Petrasek, Sie, Adkins, & Waters, 1988; Koontz et al., 2005; Mercer et al., 2006). Pain and injury may impact manual wheelchair users' desire or ability to perform daily activities that aggravate that pain. As such, people who experience pain as a result of overuse injuries may limit activities such as performing transfers, propelling the wheelchair, and other major life activities (Richter & Axelson, 2005; Robertson, Boninger, Cooper, & Shimada, 1996). Chronic overuse injuries in manual wheelchair users most commonly occur in the shoulder but can also occur in the elbow or wrist joints. Common chronic overuse injuries in manual wheelchair users include rotator cuff injuries, carpal tunnel syndrome, and median nerve damage (Akbar et al., 2010; Boninger et al., 1999; Gellman et al., 1988). Elbow tendonitis is also a common overuse injury due to a flexion–extension pattern, which assists the hand in pushing the wheelchair pushrim (Robertson, Boninger, Cooper, & Shimada, 1996).

Not only can the act of wheelchair propulsion lead to overuse injuries, but methods of propulsion can lead to different outcomes with respect to injury. For example, wheelchair users who push with a faster cadence and have a shorter recovery period have more median nerve damage than those who push with a slower cadence and have a longer recovery period (Boninger et al., 1999). Poor wheelchair propulsion techniques include a high push frequency, short push length (also referred to as push angle), and the use of the arc propulsion pattern, (i.e., a pattern that is short, forceful, and one in which the hand does not go down toward the wheel axle during recovery) as the main propulsion stroke (Boninger et al., 2005).

The wheelchair literature contains substantial information regarding wheelchair propulsion mechanics, techniques, and skills and suggests that propulsion mechanics may be changeable through training (Fay et al., 2004; Mercer et al., 2006). Research suggests that important components of training in propulsion are: decreasing push frequency (or cadence), using a semicircular propulsion pattern (i.e., a pattern in which the hand drops below the pushrim toward the axle during the recovery phase), and increasing push length (Boninger et al., 2005). The Clinical Practice Guidelines for the Preservation of Upper Limb Function Following Spinal Cord Injury (CPG) provide recommendations related to this research that emphasize minimizing force and frequency of pushes and using long strokes during propulsion (Boninger et al., 2005; Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005; Sawatzky, DiGiovine, Berner, Roesler, & Katte, 2015). The semicircular pattern follows these guidelines and is the recommended pattern for reducing chronic overuse injuries (Boninger et al., 2002). The goal of the guidelines is to promote a more efficient propulsion pattern, or a motion that requires fewer pushes on the pushrim but uses more of the pushrim to retain the same speed (Boninger et al., 2002). Increased propulsion efficiency minimizes unnecessary upper extremity use during propulsion and may lead to a reduction in chronic injuries of the upper extremities.

1.2 Wheelchair Training Devices

Researchers and clinicians commonly conduct manual wheelchair research and training using a wheelchair simulation device. Using devices to simulate a propulsion environment eliminates the problem of limited lab or clinic space and simplifies data collection methods by placing the participant and the wheelchair in a relatively stationary location. Many simulated propulsion systems have been used and, to this point, it is still unclear which offers the most realistic environment in which generalizations can be made to propulsion overground and in the environment (Kwarciak et al., 2011; Stephens & Engsberg, 2010). Each type of system has strengths and weaknesses; factors include cost, space, and adjustability. The use of different systems makes it difficult to compare data across studies (DiGiovine et al., 2001). However, having different device options enables clinicians and researchers to select appropriate devices for specific studies or interventions.

The selection of equipment is related to the availability of resources and the specific purpose of the study or clinical intervention. Common equipment used in manual wheelchair research and clinical interventions include belted treadmills, rollers, and ergometers. Motor-driven belted treadmill systems use either one or two belts and require aspects of steering and propulsion at the same time (de Groot, De Bruin, Noomen, & van der Woude, 2008; Richter, Rodriguez, Woods, & Axelson, 2007; Samuelsson, Tropp, Nylander, & Gerdle, 2004; Vegter, Lamoth, de Groot, Veeger, & van der Woude, 2014). Belted treadmills allow the simulation of different ramps by changing the angle of the belted surface; however, they are hard to use for the study of rolling resistance of different surface materials (Vegter, Lamoth, de Groot, Veeger, & van der Woude, 2014). Roller systems (sometimes referred to as dynamometers) consist of either one roller or two rollers running parallel to each other and a platform to secure the front wheelchair casters (Mercer et al., 2006). Many roller systems do not require aspects of steering, nor do they have features that allow the slope to be changed. The ergometer system uses components of a treadmill and a bicycle and typically has a laboratory wheelchair attached to the system (Rodgers, Keyser, Rasch, Gorman, & Russell, 2001). The literature contains information about a variety of ergometer systems including systems using hand crank devices and other systems that are similar to dynamometers (de Groot, Veeger, Hollander, & van der Woude, 2002; Newsman et al., 1999; Niesing et al., 1990). Variables related to manual wheelchair propulsion, such as force, are not always able to be assessed with some of the equipment described above. Often, additional instruments such as force-sensing wheels (e.g., the SmartWheel and the OptiPush) are needed (Cooper, 2009; Guo, Kwarciak, Rodriguez, Sarkar, & Richter, 2011).

The propulsion experience varies for the wheelchair user depending on the type of simulation device used. The use of belted and roller testing surfaces creates a simulated propulsion environment that might not be realistic (Mercer et al., 2006; Stephens & Engsberg, 2010; van der Woude, Veeger, Dallmeijer, Janssen, & Rozendaal, 2001). Researchers often assume that methods and conclusions transfer directly to environmental conditions such as ramps and different resistive surfaces (e.g., tile, carpet, and gravel). Several research studies using treadmills and dynamometers reported setting the resistance comparable to rolling over a tile surface (Boninger et al., 2002; DiGiovine et al., 2001). However, many studies do not report how or whether the testing devices were calibrated to match surfaces commonly traversed by wheelchair users. Some devices offer a comparable experience of an individual's actual propulsion pattern in the environment, and some may not (Koontz, Worobey, Rice, Collinger, & Boninger, 2012; Kwarciak et al, 2011; Stephens & Engsberg, 2010). Few of these devices simulate real-life conditions such as changes in surface and speed encountered by manual wheelchair users during everyday activities (Kwarciak et al., 2011). Available devices are limited in their ability to be adjusted to simulate several different surfaces (e.g., flat overground surface, up and down slopes, and cross slopes) by changing the resistance and the position of the wheelchair.

1.3 Manual Wheelchair Training

Effective training of wheelchair skills in rehabilitation and community settings is imperative to increasing participation by people with mobility limitations (Carpenter, Forwell, Jongbloed, & Backman, 2007; Routhier, Vincent, Desrosiers, & Nadeau, 2003). Training may make an enormous impact on the incidence of pain and chronic overuse injuries and on a person's independence (Kilkens, Post, Dallmeijer, Seelen, & van der Woude, 2003; Kilkens et al., 2004). However, few rehabilitation programs focus on training manual wheelchair propulsion and skills, despite the evidence suggesting that training may improve independence, freedom of movement, and quality of life (MacPhee et al, 2004).The time allowed for initial rehabilitation under current health care insurance policies is brief (approximately 36 days) and, often, insufficient training is given to wheelchair users for how to use and propel their wheelchairs efficiently (Kendall, Ungerer, & Dorsett, 2003; NSCISC, 2013). Therefore, manual wheelchair users in rehabilitation do not always develop their wheelchair skills (Fliess-Douer, Vanlandewijck, Manor, & van der Woude, 2010). When training is offered, the training is inconsistent in content and duration. Currently, wheelchair training during rehabilitation tends to be based on clinician intuition and not on tested training protocols (McNevin, Wulf, & Carlson, 2000). Guidelines, recommendations and validated protocols (Axelson, Chesney, Minkel, & Perr, 1996; Kirby et al., 2004; Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005) have been developed, but health care professionals often report not implementing them into rehabilitation practices due to limited time, funding constraints, and lack of knowledge (Best, Miller, & Routhier, 2014; Isaacson, 2011; Mitchell, Jin, Kim, Giesbrecht, & Miller, 2014).

Different approaches to improving propulsion mechanics have been researched, including exercise programs, educational programs, and instructional programs based on visual and verbal feedback (de Groot, Veeger, Hollander, & van der Woude, 2005; Degroot, Hollingsworth, Morgan, Morris, & Gray, 2009; I. Rice, Pohlig, Gallagher, & Boninger, 2013; L. Rice, Smith, Kelleher, Greenwald, & Boninger, 2014; Zwinkels, Verschuren, Janssen, Ketelaar, & Takken, 2014). Exercise interventions are typically composed of strength and aerobic training, with no specific instruction on propulsion techniques (de Groot, De Bruin, Noomen, & van der Woude, 2008; Rodgers et al., 2001). Educational programs describe the characteristics of a desired format using verbal explanation, written explanation, and/or videos and photographs, but direct instruction is not used (L. Rice et al., 2014). A few studies have used components of motor learning, such as providing visual feedback. The visual feedback was often provided through customized computer software programs using different variables (e.g., push force and speed) to allow manual wheelchair users to self-evaluate their performance (Kotajarvi, Basford, An, Morrow, & Kaufman, 2006; I. Rice, Gagnon, Gallagher, & Boninger, 2010). Each of these approaches has had varying results related to wheelchair propulsion biomechanics (Degroot et al., 2009; Kotajarvi et al., 2006; I. Rice et al., 2013).

In general, few studies have explored training methods implementing motor learning concepts important to skill acquisition, performance, and retention for manual wheelchair propulsion (I. Rice et al., 2010). Even fewer studies have concentrated on training new manual wheelchair users. Literature on training interventions and their effectiveness is limited and difficult to translate to the clinical setting and to new manual wheelchair users.

1.4 Motor Learning

Manual wheelchair propulsion is a complex skill that requires long-term training. Motor learning of such a new complex skill involves many repetitions and training sessions to become a task that can be performed implicitly without much thought and with little error (Baddeley &

Longman, 1978; Karni, 1996; Kitago & Krakauer, 2013; Korman, Raz, Flash & Karni, 2003). Much of the research on motor learning that is available has used simple laboratory tasks that often lack the complexity of many real-life skills and have little in common with the types of functional skills addressed in rehabilitation (Shea & Wulf, 1999; Wulf, Höß, & Prinz, 1998). In real-life settings, motor skills, such as manual wheelchair propulsion, consist of various movements that have to be coordinated and require the control of multiple degrees of freedom (McNevin et al., 2000). Therefore, understanding motor learning may assist in providing relevant interventions in rehabilitation to enhance the efficiency of propulsion for manual wheelchair users (I. Rice et al., 2010; I. Rice et al., 2013).

1.4.1 Repetition-Based Training

In both animal and human studies, the reported amount of movement (or number of repetitions) required to acquire a skill varies (Lang et al., 2009). In neurorehabilitation literature, recommendations for turning a movement into a learned skill range from 300–800 repetitions per rehabilitation session (Birkenmeier, Prager, & Lang, 2010; Kimberley, Samargia, Moore, Shakya, & Lang, 2010; Lang et al., 2009). Manual wheelchair research does not contain detailed information regarding the number of practice repetitions; rather, studies focus more on the number of sessions overall and the number of sessions per week related to practice. Clinicians have reported that approximately one to four hours are spent addressing basic wheelchair skills—including wheelchair propulsion— during rehabilitation (Best et al., 2014). For persons with stroke and traumatic brain injury in rehabilitation, fewer than 200 practice repetitions per session are reported (Kimberley et al., 2010). Insufficient wheelchair propulsion repetitions to promote a biomechanically efficient and effective propulsion pattern are being provided during rehabilitation in most instances. To understand the amount of training necessary and the impact of training, additional research in manual wheelchair propulsion training methods that implement motor learning concepts is needed.

1.5 Mixed Methods Approach

Three approaches are used in research studies: quantitative, qualitative, and mixed methods approaches. Quantitative research tests hypotheses and examines relationships among variables. However, knowledge produced from quantitative studies may be abstract and too general for application to specific contexts and individuals. Qualitative data through methods such as stakeholder interviews allows researchers to explore and understand meaning related to individuals and groups (Hammell, 2001). However, the knowledge produced may not generalize to other people or other settings. A mixed methods approach combines the best aspects of both approaches and addresses the shortcomings of each; it involves collecting both quantitative and qualitative data and integrating the two forms of data to inform research design or interpret findings (Johnson & Onwuegbuzie, 2004). A mixed methods approach is now being used across disciplines including health sciences. *NIH Best Practices for Mixed Methods Research in the Health Sciences* acknowledges the value of using both qualitative and quantitative data in a mixed methods design (Creswell, Klassen, Plano, Clark, & Smith, 2011). Mixed methods may provide a more complete understanding of a research problem or question than either qualitative or quantitative research alone (Creswell, 2013).

1.6 International Classification of Function Disability and Health

A mixed methods approach commonly integrates conceptual frameworks as a basis for clarifying research aims. The World Health Organization (WHO) International Classification of Functioning, Disability and Health (ICF) is a conceptual framework developed to provide a common language for communication among health care professionals and persons receiving rehabilitation services (WHO, 2011). The ICF incorporates the medical model and the social model of disability, recognizing the complex interactions between intrinsic person factors, such as body structures and function, and contextual factors, such as the environment and social policy. The ICF is composed of four sub-classifications: Body Functions, Body Structure, Activities and Participation, and Environment. The ICF describes a person's capacity for functioning, as well as his or her actual performance (World Health Organization, 2001). The ICF has embraced the importance of measuring, assessing, and classifying disability in context (Gray & Hendershot, 2000). The inclusion of a performance in context (participation) may bring attention to the interactions of physical and social environmental factors that restrict or facilitate the participation of people in their home and community activities instead of simply focusing on simple movements and personal care activities (Verbrugge & Jette, 1994; Wright, 1983). Thus, environmental factors have become an essential feature of the ICF system for classifying participation. The changing scientific models and public policies regarding people with disabilities provide impetus for the evolution of research to capture body structure, body function, and participation of people with disabilities in the context of their environment (Bickenbach, 1993; Gray & Hendershot, 2000).

1.7 Summary

The literature on training interventions is limited and often difficult to translate to new manual wheelchair users. Training introduced at the time a person receives his or her wheelchair has the potential to decrease or delay the incidence of overuse injuries and pain and improve overall wheelchair skills and propulsion efficiency, resulting in increased participation. Providing an appropriate and realistic environment for the training is an important component of the training program's success. Through a mixed methods approach, this project may contribute evidence related to training approaches and a simulation device for training. The project goals are to test the usability of a device for training and assessing the propulsion biomechanics of new manual wheelchair users with SCI (study 1), identify important components for a manual wheelchair training program from the perspectives of health care professionals and manual wheelchair users (study 2), and to pilot-test a motor learning–based wheelchair training program (study 3).

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<u>Chapter 2: The Testing of an Instrumented Wheelchair Propulsion Testing and Training Device</u>

This chapter has been submitted and revised:

Morgan, K. A., Engsberg, J. R., & Klaesner, J. (Under Revision). The testing of an instrumented wheelchair propulsion testing and training device. *Assistive Technology*.

Abstract

Purpose: Researchers and clinicians often look for devices that can be used to simulate wheelchair propulsion in different environments for implementing interventions and conducting assessments. Common devices used are belted treadmills, dynamometers (roller systems), and wheelchair ergometers. The WheelMill System (WMS), a motor-driven roller system, has been developed to match the experience of rolling overground and pushing up and down graded slopes. The purpose of this research was to determine the accuracy of the WMS to simulate surfaces in the environment and to assess propulsion variables.

Methods: SmartWheel and WMS data were collected with 13 manual wheelchair users pushing their wheelchairs overground and up two different sloped ramps. The participants then pushed their wheelchairs on the WMS at different resistance settings.

Results: Participants pushed at a faster cadence and with more force when pushing overground and on the ramps than on the WMS. The force profiles of the participants were closer overground compared to the WMS than on the ramps compared to the WMS. During the push phase, the WMS assessed forces similar to those collected with the SmartWheel.

Conclusions: The WMS has the ability to simulate different environments and assess propulsion variables, and it adds to the equipment available to clinicians and researchers. These results will assist in enhancing the WMS software models for simulating the resistance of common surfaces encountered by manual wheelchair users.

2.1 Introduction

Persons who use manual wheelchairs encounter different surfaces as they move through the environment, including smooth, flat surfaces, resistive surfaces (e.g., carpet), and graded slopes (Kasemsuppakorn, Karimi, Ding, & Ojeda, 2014; Routhier, Vincent, Desrosiers, & Nadeau, 2003). Propulsion on different surfaces may impact upper extremity injury and participation in life activities (Hurd, Morrow, Kaufman, & An, 2009). Investigating manual wheelchair propulsion techniques over these surfaces in the natural environment would be ideal; however, the natural environment provides challenges for collecting data and implementing interventions. For example, using accurate data collection procedures (such as video motion capture) can be difficult outside of a laboratory (Hurd, Morrow, Kaufman, & An, 2008). Therefore, devices are commonly used for manual wheelchair propulsion assessment and training purposes in both research and clinical settings. Using devices to simulate an environment eliminates the problem of limited lab or clinic space and simplifies data collection.

Many devices have been used and tested by researchers, but it is still unclear which offers the most realistic simulation of propulsion in the environment (Kwarciak, Turner, Guo, & Richter, 2011; Stephens & Engsberg, 2010). Each type of system has strengths and weaknesses (cost, space, and adjustability), and the use of different systems makes it difficult to compare data from study to study (DiGiovine, Cooper, & Boninger, 2001). However, having different device options allows clinicians and researchers to select the most appropriate device(s) for specific studies or interventions.

Common equipment used in manual wheelchair research and clinical interventions includes belted treadmills, rollers, and ergometers. Belted treadmills provide movement variability and require the user to engage in aspects of steering and propulsion at the same time

(Vegter, Lamoth, de Groot, Veeger, & van der Woude, 2013). In addition, changing the angle of the belted surface can allow for the simulation of different ramps. A belted treadmill is, however, difficult to use for the study of rolling resistance on different surface materials (van der Woude, Geurts, Winkelman, & Veeger, 2003). Roller systems, sometimes referred to as dynamometers, are simple to use but have been found to not emulate overground propulsion (Koontz, Worobey, Rice, Collinger, & Boninger, 2012; Stephens & Engsberg, 2010). The ergometer system typically uses a standard laboratory wheelchair but has instrumentation to collect propulsion variables (de Groot, Veeger, Hollander, & van der Woude, 2002; Mercer et al., 2006; Newsman et al., 1999). The selection of a device is related to the availability of resources and the specific purpose of the study or clinical intervention.

Belted treadmills, rollers, and ergometers that are commonly used vary in the propulsion experiences for the wheelchair user. Some devices offer a comparable experience to an individual's actual propulsion pattern in the environment, and some may not (Koontz et al., 2012; Kwarciak et al., 2011; Mason, Lenton, Leicht, & Goosey-Tolfrey, 2014; Stephens & Engsberg, 2010). However, few of these devices simulate the real-life conditions (e.g., changes in surface and speed) encountered by manual wheelchair users during their participation in everyday life activities (Kwarciak et al., 2011; Mason et al., 2014). In addition, it is often not possible to assess variables related to manual wheelchair propulsion, such as force, with some of these devices. Often, additional instruments such as force-sensing wheels are needed (Cooper, 2009; Guo, Kwarciak, Rodriguez, Sarkar, & Richter, 2011). The WheelMill System (WMS) is a unique, motor-driven, computer-controlled dynamometer roller system that was developed to simulate environmental situations (e.g., overground and ramps) and to quantify propulsion variables (e.g., cadence, peak force, and average force; Klaesner, Morgan, & Gray, 2014). The purpose of this research was to: (1) evaluate the accuracy of the WMS for simulating propulsion over actual surfaces (smooth, flat, overground surfaces and graded slopes such as ramps), including the determination of the coefficients for the software model controlling the WMS, and (2) assess the accuracy of the quantification of propulsion variables. We hypothesized that the WMS propulsion variables would be comparable to those experienced on overground surfaces and up graded slopes. In addition, we hypothesized that the WMS would accurately measure propulsion forces.

2.2 Methods

2.2.1 Participants

Thirteen participants (ten men, three women; aged 37.8 ± 11.5) with a spinal cord injury (SCI) or related neurologic condition that requires the use of a manual wheelchair were recruited from a local Independent Living Center (Table 2.1). Participants were screened to ensure that they met the following inclusion criteria: could actively self-propel their own manual wheelchairs, used their manual wheelchairs for at least 75% of activities throughout the day, had used a wheelchair for at least one year, were between the ages of 18 and 60, understood spoken English at a sixth grade level or higher, and were able to provide informed consent. The participants also had to have 24-inch wheels on their wheelchairs to accommodate the 24-inch SmartWheel. Potential participants were excluded from the study if they used power assist wheels or maneuvered the wheelchair with their lower extremities or with only one arm. Participants were compensated for their time and effort. The project protocol was approved by an institutional review board.

Table 2.1 Participant demographics

	N	%
Gender		
Male	10	76.9
Female	3	23.1
Race		
White	10	76.9
African American	2	15.4
Other	1	7.7
Diagnosis		
SCI	12	92.3
Other	1	7.7
Level of Injury		
Paraplegic	5	38.5
Quadriplegic	8	61.5
Complete vs. Incomplete		
Complete	7	53.8
Incomplete	5	38.5
N/A	1	7.7
Side Dominance		
Right	11	84.6
Left	2	15.4

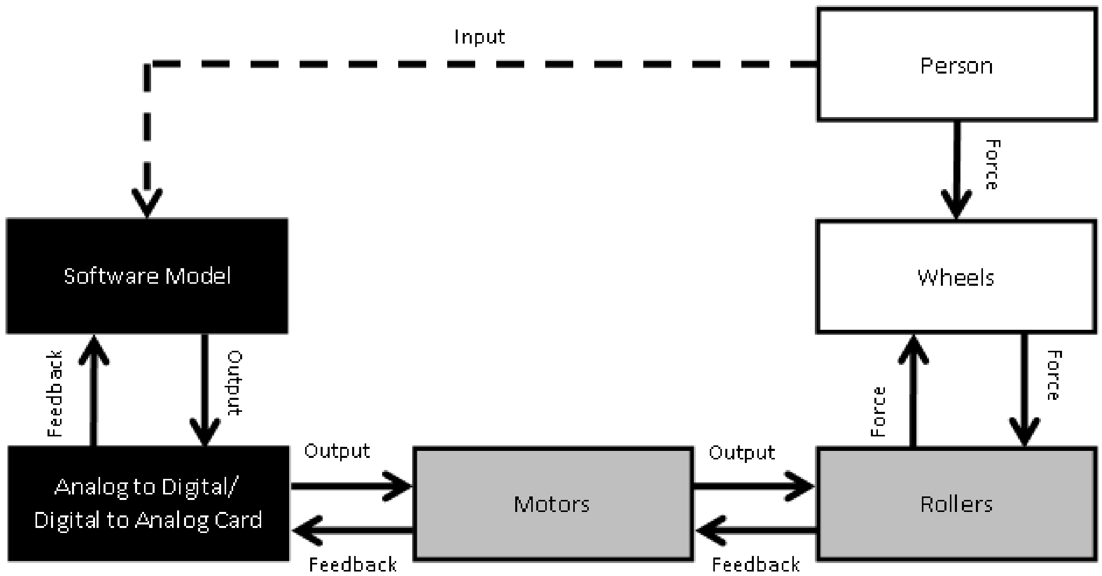
Note. SCI = spinal cord injury.

2.2.2 Equipment

SmartWheel. Kinetic data were collected using an instrumented manual wheelchair wheel with pushrim force and torque sensors, referred to as the SmartWheel (Three Rivers Holdings, LLC, Mesa, AZ). The SmartWheel is a force- and moment-sensing wheel that replaces one of the wheels of the user’s wheelchair during testing (Asato, Cooper, Robertson, & Ster, 1993). The SmartWheel measures the force applied to the pushrim by the hand during propulsion. The SmartWheel has been used to assess propulsion among wheelchair users, much in the way that force plates during gait analysis are used to assess an individual’s foot–ground forces during ambulation (DiGiovine, Koontz, & Boninger, 2006). A high-speed Wi-Fi link and onboard memory enable data collection from 500 feet. The data sampling frequency was 240 Hz. The SmartWheel was used to measure the force applied to the pushrim as well as cadence (push frequency) and push angle. The SmartWheel has been used extensively in manual wheelchair research and, for the purposes of this study, was considered to be the "gold standard" for assessing wheelchair propulsion forces (Cooper, 2009).

WheelMill System (WMS). The WMS is a computer-controlled roller dynamometer system that has the potential to simulate different environmental conditions through the adjustment of the platform to place the wheelchair in different positions and to provide realistic resistance on the rollers (Klaesner et al., 2014). The system consists of four motor-driven aluminum rollers, a front pan that holds the casters, and two independent motors (Kollmorgen AKM41 servomotor and S200 servo drive) that are used to control the rollers. The WMS is controlled by software written in Microsoft Visual C (Microsoft Visual Studios, 2005). The software uses an analog-to-digital/digital-to-analog system (NI USB-6229) to collect data from the motors and to change the roller torque applied by the motors, which changes the resistance and speed of the rollers. The analog-to-digital/digital-to-analog system measures speed with an optical device, measures camber and cross slope angles with goniometers, and controls the motors to change the slope. The software interface displays information such as speed, slope, and distance the person has pushed. The interface also allows the user to change the degree of the slope and cross slope; change the parameters controlling the motors (described below) for the left and right rollers, changing resistances; and save this information to a data file.

The speed at which the wheels roll is dependent upon the force applied on the pushrims of the wheels by the person using the WMS (Figure 2.1). To move the rollers, the force the person creates has to be greater than the resistive force of the rollers on the wheels. The motors sense torque placed upon the rollers, and this information is used to control the speed of the rollers.



Note. Person and his or her wheelchair (white boxes), the physical structure of the WMS (gray boxes), and the computer system operating the WMS motors (black boxes).
Figure 2.1 Interaction of WMS components to control speed

The speed of the rollers can be varied by software models that simulate different surfaces or slopes. This is accomplished by increasing or decreasing the resistance supplied by the motors. Inertial effects are minimal when at a steady state. The movement for each pair of rollers is controlled independently. The variables that are used to control the motors' speed and resistance are listed in Table 2.2. The voltage that is outputted to the motors by the digital-to-analog controller is referred to as the motor control signal (MCS). This signal controls the torque that the motors apply to the rollers and is updated 50 times per second. The MCS signal is calculated using Equation 2.1. The previous signal (PS) variable is the MCS voltage from Equation 2.1. The motor feedback signal (MFS) is a voltage that is a feedback signal from the motors and is the difference between the torque that the motor applies to the rollers and what the rollers apply back to motors. This voltage increases when the wheelchair user applies force to the pushrims. Two dimensionless coefficients (push coefficient [PC] and decay coefficient [DC]) are used to adjust the voltage applied to the motors and can be changed to allow for variation among users, different wheel chairs, modeled slopes, and simulated surface types.

Table 2.2 WMS motor control equation variables

Variable	**Definition**
Motor Control Signal (MCS)	The voltage output by the digital to analog converter (DAC) to the motor, which controls the speed of the rollers.
Previous Signal (PS)	The previous voltage output sent to the motor by the DAC.
Push Coefficient (PC)	Coefficient that controls the efficiency of the "push" to change the speed of the rollers; it may be related to the weight on the rollers and wheelchair configuration. This is a dimensionless variable.
Motor Feedback Signal (MFS)	A voltage signal from the motor to the analog-to-digital converter (ADC) that indicates how much torque is resisting or assisting the current movement of the rollers.
Decay Coefficient (DC)	Coefficient that controls the decrease in speed of the rollers due to the effects of friction (or other forces resisting the movement, such as gravity, an upslope, or air resistance). This is a dimensionless variable.

$$MCS = \{PS + PC[\Delta\,(MFS)]\} * DC \qquad \text{(Equation 2.1)}$$

The PC represents how efficiently the push is converted into roller speed and is related to the type (e.g., lightweight) and setup (e.g., axle position) of the wheelchair. The two PC values used for testing, 10 and 25, were chosen through experience using the WMS. The value 10 represents a typical “low” value that would be used for a less efficient wheelchair (e.g., heavier frame with rearward axle position), and 25 is a typical “high” value for the PC variable that would be used by a more aggressive wheelchair setup (e.g., lightweight frame and forward axle position). The DC controls how quickly the speed of the roller decreases, which affects the glide, or distance the wheels continue to roll, of the wheelchair after a push and can be adjusted to reflect different types of surfaces and slopes as well as differences in wheelchair weights and centers of gravity. The values for the DC typically can range from about 0.4, which would be very difficult, to 1.0 or greater, which would allow the rollers to spin continuously without any additional push by the user. We selected these PC and DC values to encompass a wide range of pushing experiences as previously identified with three pilot participants (Klaesner et al., 2014). The data in this paper may provide further information that may be used to refine this software model by providing a systematic means of determining the PC and DC values to better simulate multiple surfaces for different users.

2.2.3 Setting

All testing was completed at a community-based research facility. The facility houses the WMS and contains two ramps with different slopes (1:20 and 1:12) and a flat surface 40 meters long.

2.2.4 Data Collection Procedures

Outcome variables. The SmartWheel has the ability to generate numerous variables that describe a person's propulsion mechanics. Five of these variables (cadence, speed, peak tangential force, average tangential force, and push angle) were selected for this project and are deemed clinically relevant and frequently used in propulsion research to analyze propulsion mechanics (Boninger et al.,2002; Cowan, Boninger, Sawatzky, Mazover, & Cooper, 2008; Kwarciak et al., 2011). The WMS was able to collect data for three of the five propulsion variables (cadence, peak tangential force, and average tangential force). Once the participant reached a steady state (after three initial start-up pushes), three to five consecutive pushes were averaged for each variable. Cadence (push frequency) is defined as the number of times per second the pushrim is contacted (in contacts per second). Speed is the average speed (in meters per second) across the pushes. The most relevant force for wheelchair propulsion is the tangential force to the pushrim (Niesing et al., 1990); therefore, this is the force that was used for analysis. Peak tangential force is the average of the greatest amount of force, measured in Newtons, of each of the three-to-five pushes. Average force, measured in Newtons, is the overall tangential force applied to the pushrim during the push phase averaged across the three-to-five pushes. Push angle is defined as the distance traveled by the hand on the pushrim from the point of contact to the point of release. Push angle is measured as the angle (in degrees) between the points at which the hand contacts the pushrim and then leaves the pushrim (Cowan, Nash, Collinger, Koontz, & Boninger, 2009).

Actual surface: overground and ramps. The SmartWheel was placed on the participant's dominant side to measure the force occurring during propulsion on an overground surface and on the upgraded slopes. Participants were asked to roll across a smooth, flat, overground surface for 40 meters and up the slopes of a low-grade (1:20, or about 2.9°) ramp and a high-grade (1:12, or about 4.8°) ramp at a self-selected comfortable pace. The slopes of 1:20 and 1:12 were selected because these are the specifications of slopes recommended for ramps in public spaces (U.S. Department of Justice, 2010). Three trials were completed on each surface. A laptop computer with SmartWheel software was used to capture the data for each trial. Data collection of cadence, speed, peak tangential force, average force, and push angle was initiated as the participant began the propulsion motion, prior to the first propulsion stroke. Participants began from a stationary position and accelerated to a self-selected comfortable speed. Data collection was stopped when the participant reached the end of the surface (e.g., for the ramp, until the participant reached the platform).

Simulation on WMS. The participant was placed on the WMS with straps and wheel guides to keep the wheelchair secure (Figure 2.2). The SmartWheel remained on the dominant side of the person's wheelchair. The participant was instructed to push at a self-selected comfortable pace for two minutes to become acclimated to the WMS. The participant was then asked to propel the wheelchair on the WMS for 10 seconds for each PC and DC setting as outlined in Table 2.3. Changing the DC varied the resistance and glide that the wheelchair user experienced, and changing the PC altered how efficiently the user's pushes overcame the resistance. The participant pushed the wheelchair for 12 different settings, consisting of a combination of six DCs and two PCs (see Table 2.3) to represent the expected range of simulated pushing experiences. The settings were tested from hardest (most resistance, least amount of glide) to easiest (least amount of resistance, greatest amount of glide). For each set of coefficients, the variables were collected by the SmartWheel and the WMS. DC values of 1.0 or greater were not tested with some individuals because the rollers would turn on their own without the user pushing on the pushrims of the wheelchair.

Figure 2.2 Participant on the WMS

Table 2.3 WMS settings

WMS Setting	Decay Coefficient	Push Coefficient	Level of Resistance	Overground Best Match	Low Ramp Best Match	High Ramp Best Match
1	.6	15	Hardest	0	10	12
2	.6	25	↓	0	2	1
3	.7	15		0	1	0
4	.7	25		0	0	0
5	.8	15		0	0	0
6	.8	25		0	0	0
7	.9	15		0	0	0
8	.9	25		4	0	0
9	1.0	15		4	0	0
10	1.0	25		2	0	0
11	1.1	15		1	0	0
12	1.1	25	Easiest	1	0	0

Note. Numbers in Overground, Low Ramp and High Ramp Best Match columns represent the number of participants who had their best match at that setting.

Data processing. Custom MATLAB scripts and Microsoft Excel spreadsheets were developed to extract data from existing software (SmartWheel and WMS) and minimize manual data processing (The MathWorks, Inc., 2010; Microsoft, 2011). Data were identified across five variables for three pushes on the ramps to five pushes on overground and for each set of WMS coefficient values. Data were trimmed to include only the pushes made when the participant had achieved a steady state (after the initial three pushes). The start-up pushes were not included in the analysis; after push four, three to five consecutive pushes were averaged for each variable. These data represent the propulsion force of each participant across the different pushing experiences (overground, two graded [low and high] ramps, and 12 WMS settings).

Actual surface comparisons to the WMS settings. To identify best fits of the WMS settings for each of the three surfaces (overground, low-grade, and high-grade ramps), three to five pushes were overlaid using the peak forces as the guide. The force profile for the five pushes was averaged to produce one representative push for each WMS setting and for each trial overground and on the ramps. Forces (of the one average push) for the overground and ramp trials were compared to data for each of the WMS settings. The difference of force readings at each time sample was calculated. Through this process, the values that produced the output closest to the actual surface were identified for each person for flat surfaces and ramps. The WMS setting with the smallest force difference compared to the overground surface and ramps was selected as the best fit. These coefficients (see Table 2.3) were used for comparisons of all five propulsion variables collected by the SmartWheel on the actual surface and on the WMS.

Assessing wheelchair propulsion variables: WMS compared to SmartWheel. To examine the accuracy of the WMS for assessing propulsion variables (cadence, peak force, and average force), the data collected from one trial representing the overground surface from all 13 participants using both the SmartWheel and the WMS were processed and compared. The WMS does not measure the force applied to the pushrim as the SmartWheel does; the WMS measures force at the wheel–ground interface. The tangential force (F_t) from the WMS was calculated from the MCS controlling the torque of the rollers (Klaesner et al., 2014). The torque applied to the rollers by the wheels was sensed by the motor, and a control signal that controls the torque of the rollers was calculated, allowing them to turn at the appropriate speed. The tangential force was calculated by subtracting a speed-dependent voltage offset from this control signal and multiplying by a conversion coefficient. The MCS of the WMS was converted to F_t through custom Microsoft Excel spreadsheets.

2.2.5 Data Analysis

IBM SPSS Statistics software (version 21) was used for statistical analyses (SPSS Inc., 2012).

Actual surface comparisons to the WMS settings. Propulsion variables (cadence, average speed, peak force, average force, and push angle) measured by the SmartWheel were compared from the three different testing conditions (overground, low-grade ramp, and high-grade ramp) to those measured by the WMS. A paired-samples t-test was conducted to determine whether there was a significant difference between propulsion variables when pushing overground on a smooth, flat surface compared to propulsion variables when pushing on the WMS setting that was identified as most representative of pushing overground, the null hypothesis being that there is no difference between propulsion overground and on the WMS. A Pearson's product-moment correlation coefficient was run to assess the relationship between propulsion variables collected overground compared to those collected on the WMS. A Shapiro-Wilk test was used to assess normality of the variables. Scatterplots of each variable were created to evaluate the similarity of variables. We fitted multiple regression models for the five propulsion variables separately as the dependent variable to examine the relationship of each variable to other factors (independent variables). Our independent variables were the settings on the WMS (PC and DC), person factors (gender, injury, and weight), and chair factors (wheelbase length and axle position). Individual participant force profiles were compared between overground and the WMS, and effect sizes were calculated to examine variability within and between participants. This process was repeated for both the low-grade ramp and the high-grade ramp variables.

Assessing accuracy of quantification of wheelchair propulsion variables: WMS compared to SmartWheel. The WMS has the ability to measure variables such as cadence, average peak torque, and average force. These variables were compared to similar data collected from the SmartWheel. Paired t-tests were used to analyze the differences between SmartWheel and WMS data. Pearson's product-moment correlation coefficients were used to assess the relationship of the variables assessed by the WMS as compared to those assessed by the SmartWheel. Scatterplots of each variable were created to evaluate the similarity of variables.

2.3 Results

2.3.1 Actual Surface Comparisons to the WMS Settings: Overground (Group Comparison)

One outlier that was more than three times the interquartile range was removed from the cadence calculations. The values for all variables except push angle were statistically different between the overground surface and the WMS setting identified as the best match (Table 2.4). All five variables had higher values overground than on the WMS. Cadence and push angle values on the WMS most closely represented overground. Analyses showed the relationship to be linear, with each of the variables normally distributed ($p > 0.05$) as determined by the Shapiro-Wilk test. Comparing overground to the WMS, there were significant ($p < 0.05$) moderate-to-strong positive correlations for cadence ($r = 0.76$), average speed ($r = 0.65$), average force ($r = 0.55$), and push angle ($r = 0.87$). There was not a significant correlation for peak force.

Table 2.4 Comparison of propulsion variables: Three surfaces vs. WMS

Variable	**Overground vs. WMS**		**Low Ramp vs. WMS**		**High Ramp vs. WMS**	
	Surface	WMS	Surface	WMS	Surface	WMS
Cadence	1.0(0.1)*	1.0(0.1)*	1.1(0.2)*	0.9(0.1)*	1.1(0.3)*	0.9(0.1)*
Speed	1.56(0.26)*	1.16(.34)*	0.99(0.21)*	0.64(0.12)*	0.90(0.30)*	0.64(0.14)*
Peak Force	46.0(13.8)*	34.5(8.6)*	95.9(22.5)*	68.2(14.1)*	101.6(23.6)*	70.0(11.9)*
Average Force	25.7(7.9)*	19.7(4.5)*	60.3(14.7)*	42.5(2.6)*	67.5(17.7)*	43.9 (8.4)*
Push Angle	82.5(14.1)	79.0(19.0)	84.7(18.2)	89.0(15.5)	84.4(18.6)	88.0(16.0)

Note. *$p < 0.05$; data listed as mean (SD).

The propulsion variables (cadence, peak force, average force, and push angle) were used as the dependent variables. Gender, injury level, and wheelchair dimensions were not significant for any of the variables and, therefore, were excluded from the model. The assumptions of linearity, independence of errors, homoscedasticity, unusual points, and normality of residuals were met. PC, DC, and weight variables significantly (p < .0005) predicted speed (adj. R^2 = 0.80), peak force (adj. R^2 = 0.51), and average force (adj. R^2 = 0.52; Table 2.5). No significant findings were found for cadence or push angle.

Table 2.5 Summary of multiple regression analysis

Speed	b	SE	B	95% CI for b
Push coefficient*	3.663	0.648	0.78	2.198, 5.128
Decay coefficient	0.008	0.1	0.119	-.014, .030
Weight*	-0.005	0.001	-0.685	-.007, -.002
Peak Force				
Push coefficient	-35.864	25.444	-0.303	-93.423, 21.696
Decay coefficient*	1.21	0.382	0.731	.345, 2.074
Weight*	0.086	0.038	0.515	.000, .171
Average Force				
Push coefficient*	-35.533	13.186	-0.571	-65.363, -5.703
Decay coefficient	0.402	0.198	0.461	-.046, .850
Weight*	0.049	0.02	0.566	.005, .094

Note. *p < 0.05; b = unstandardized regression coefficient; SE = standard error of the coefficient; B = standardized coefficient; CI = confidence interval.

2.3.2 Actual Surface Comparisons to the WMS Settings: Overground (Individual Examples)

The group means described in the previous section indicates differences between pushing overground and pushing on the WMS (with the appropriate setting). These differences may be related to the inter-variability across participants and the intra-variability for certain participants. Inter-variability of the data indicates that participants pushed differently overground than on the WMS. These differences can be categorized across participants in three ways: participant force values and cadence were almost the same overground as compared to the WMS (Figure 2.3, Participant A, effect size for average force 0.12); participant force values and cadence overground had similar shapes compared to those on the WMS (see Figure 2.3, Participant B, effect size for average force 0.38); and participant force values and cadences were stronger and faster overground as compared to on the WMS (see Figure 2.3, Participant C, effect size for average force 0.67). In addition, intra-participant variability was evident in many participants who had similar rhythmic pushes on the WMS, but overground, the forces were not consistent across pushes. Participant C's average peak force across the five pushes overground ranged from 37 N to 75 N as compared to 25 N to 27 N on the WMS.

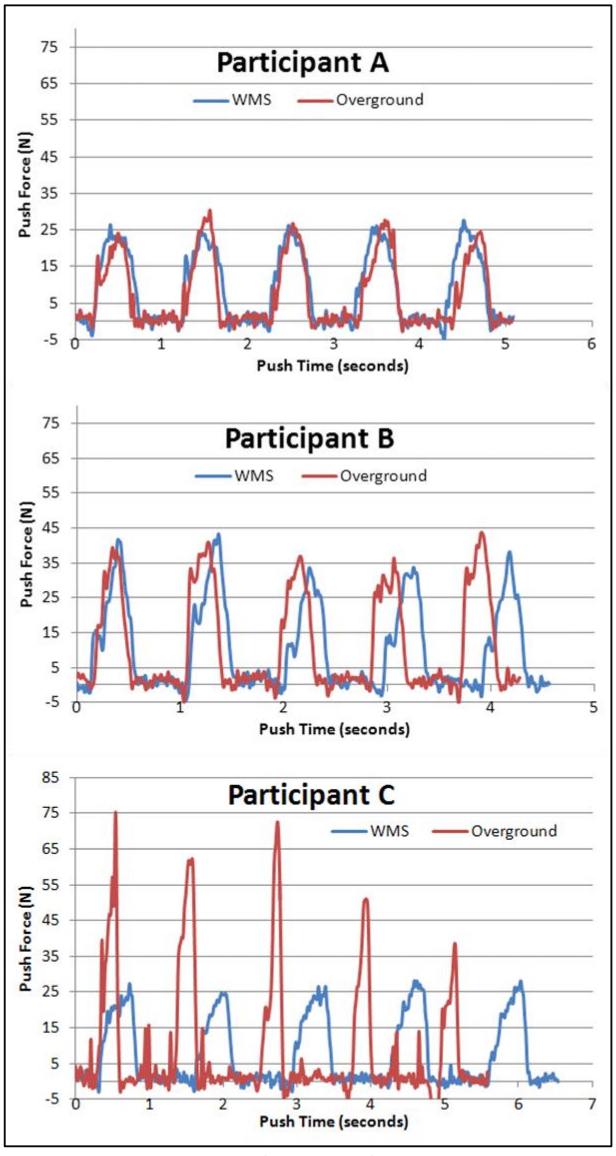


Figure 2.3 Individual force profile comparisons: Overground and WMS

2.3.3 Actual Surface Comparisons to the WMS Settings: Ramps (Group Comparison)

The propulsion variables were significantly different when pushing on the ramp surfaces compared to pushing on the WMS set to simulate ramps (see Table 2.4). For both sets of ramps, cadence, average speed, average peak force, and average force were significantly higher on the actual surface of the ramp than on the WMS. Push angle was shorter on the ramps than on the WMS but was not statistically different. Analyses showed the relationship to be linear, with each of the variables normally distributed, as assessed by the Shapiro-Wilk test ($p > 0.05$). Comparing the low-grade ramp to the WMS, there was a significant ($p < 0.05$) moderate-to-strong positive correlation for cadence ($r = 0.70$), peak force ($r = 0.78$), average force ($r = 0.78$), and push angle ($r = 0.83$). Average speed was not significant. Comparing the high-grade ramp to the WMS, there was a significant ($p < 0.05$) moderate-to-strong positive correlation for cadence ($r = 0.74$), peak force ($r = 0.84$), average force ($r = 0.96$), and push angle ($r = 0.79$). There was not a significant correlation for average speed.

2.3.4 Actual Surface Comparisons to the WMS Settings: Ramps (Individual Examples)

The peak and average forces were greater and the cadence faster on the ramps than on the WMS (Figure 2.4). The peak of the force profiles was held for a longer period of time on the WMS, while the peak force on the actual ramp was achieved more rapidly and not held for as long. This trend was common across participants.

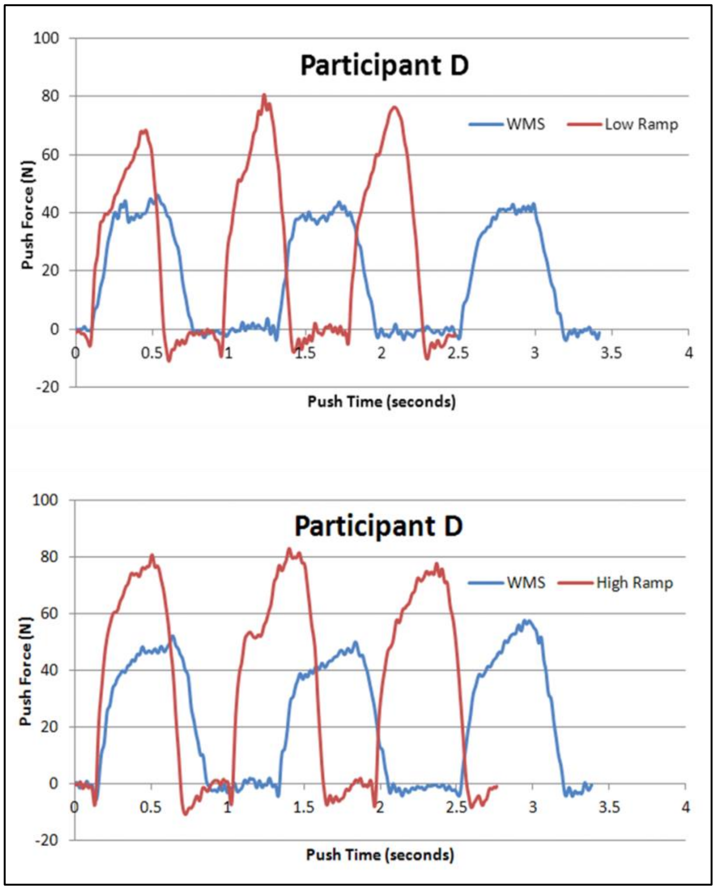


Figure 2.4 Individual force profile: Low ramp and high ramp

2.3.5 Assessing Wheelchair Propulsion Variables: WMS Compared to SmartWheel

Cadence and peak force values collected by the SmartWheel were similar to the values collected by the WMS (Table 2.6). Average force was higher as calculated by the SmartWheel compared to the WMS. The force data collected during the recovery phase were closer to zero for the SmartWheel (0.17 N) than for the WMS (6.82 N). This difference is apparent when comparing SmartWheel and WMS force profiles for one participant (Figure 2.5). Analyses showed the relationship to be linear, with each of the variables normally distributed, as assessed by the Shapiro-Wilk test ($p > 0.05$), and no outliers were removed. Comparing the SmartWheel propulsion variables to those collected by the WMS, there were significant ($p < 0.05$) moderate-to-strong positive correlations for cadence (r = 0.99), peak force (r = 0.96), and average force (r = 0.71).

Table 2.6 Comparison of propulsion variables: SmartWheel vs. WMS

Propulsion Variable	SmartWheel Mean (SD)	WMS Mean (SD)
Cadence	0.96 (0.14)	0.97 (0.14)
Peak force	38.92 (9.49)	37.99 (8.48)
Average force	22.36 (5.47)*	18.94 (3.95)*
Recovery force	0.17 (0.58)	-6.81 (3.97)*

Note. *p < 0.05.

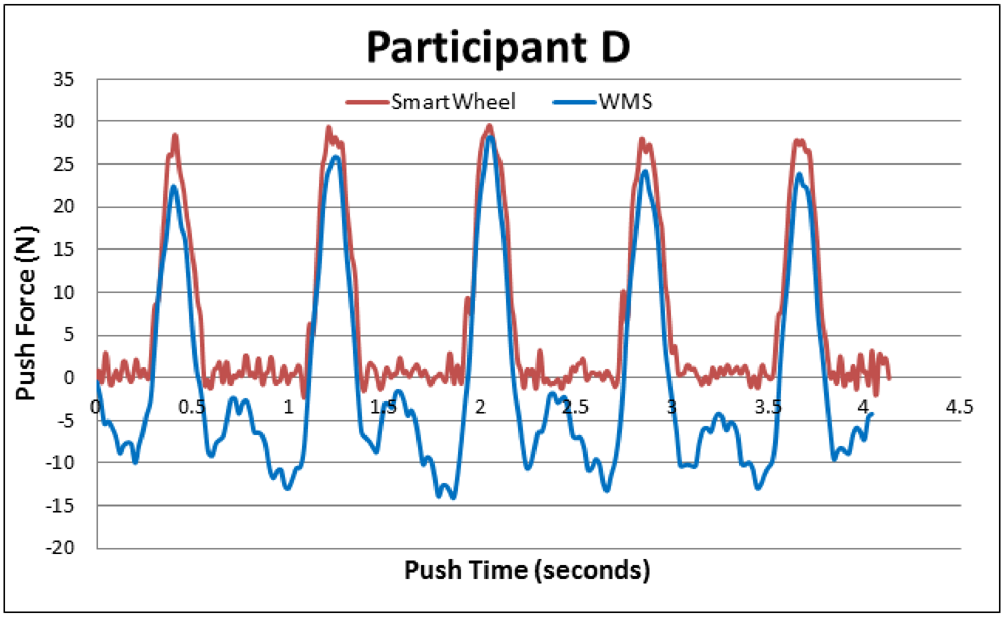


Figure 2.5 Individual force profile: SmartWheel and WMS

2.4 Discussion

The purpose of this research was to evaluate the accuracy of the WMS for simulating propulsion over actual surfaces (overground and ramps) and to assess the accuracy of the quantification of propulsion variables. This research study had many limitations, including a small sample size for the number of variables examined. The high variability within and between participants also resulted in lower correlations and significant differences between the WMS and real-life surfaces. In addition, identifying the best-fit WMS settings to compare across the three testing surfaces was challenging due to the difficulty in matching up two separate force profiles across different propulsion variables. The best setting for one variable was not always the best setting for all other variables. We have identified the need to modify the software model to take into account different factors, such as weight, in order to get one setting of DC and PC for each person to simulate different surfaces. The accuracy of the WMS was poor for the ramps and, with the current models, we cannot claim that we can simulate ramps with the system. However, the WMS demonstrated that it could accurately simulate overground movement for most important variables for users including cadence, push angle, and average force.

During the procedures, we did not control for speed or cadence; we had each participant propel at a self-selected speed, because trying to hold a certain speed may impact propulsion biomechanics. The lack of visual feedback provided from the WMS to the participant may also have had an influence on propulsion on the WMS. This may have resulted in lower correlations, because it is difficult (even over the same surface) to propel exactly the same way.

2.4.1 Actual Surface Comparisons to the WMS Setting: Overground and Ramps

Previous research has reached differing conclusions about the accuracy of devices simulating surfaces encountered in the environment by manual wheelchair users. Stephens and Engsberg (2010) found kinematic differences overground when comparing rollers and belted treadmills. Koontz and colleagues (2012) found kinetic differences in propulsion between overground and rollers. However, Kwarciak and colleagues (2011) reported a motor-driven belted treadmill to have similar kinetic propulsion variables as overground. We found the WMS (motor-driven roller system) to be comparable to overground in some wheelchair propulsion variables but not all. When pushing overground, participants overall pushed at a faster rate, with greater force, and with a slightly shorter push angle as compared to the WMS. Pushing on an actual ground or ramp surface has a goal, so users may push faster to reach their goal destination.

Much of the research studying ramps used actual ramps in the community or ramps built out of plywood in lab settings (Koontz, et al., 2005; Sabick, Kotajarvi, & An, 2004). However, kinematic and kinetic comparisons between actual ramps and simulation on devices are limited. In this study, users had a higher cadence, faster speed, and much higher force on the ramps as compared to the WMS. The software model on the WMS could be adjusted to require higher forces, but there are no consequences on the WMS as there are on an actual ramp. If a person does not have a rapid cadence with enough force on an actual ramp, he or she will roll backward down the ramp. On the WMS, participants are not forced to push harder at a quicker pace to keep from rolling backward, so it is difficult to get a best match for all variables from one WMS setting. It is difficult to simulate environments such as ramps on a machine-based simulator because of lack of consequences; however, additional software modeling that would include backward rolling of wheels may assist the WMS with matching push variables with variables measured on ramps.

The data described in this paper will assist in identifying the appropriate PC and DC so that, when a user applies force on the pushrims, the rollers will rotate at an appropriate rate to simulate rolling across a typical surface, slowing down as one would expect due to friction. This data comparison between the actual surface and the WMS provides us with an idea of what each of the coefficients equates to for simulating common resistances experienced by manual wheelchair users in everyday life. The higher DC matched more closely with participants' overground propulsion variables. The lower DC matched more closely with the ramps (see Table 2.2). Some of the middle WMS settings might be more appropriate for environmental surfaces with different rolling resistances, such as carpet. We could go even lower on the PC (we underestimated) and add into the software interface cueing to keep a faster cadence or the rollers will begin to roll backwards. The data collected in this paper may assist in updating the software model so that it may automatically calculate the proper parameters for each person on different surfaces.

2.4.2 Assessing Wheelchair Propulsion Variables

Technology has changed over the past decade, and the instrumented wheels such as the SmartWheel (Asato et al., 1993) and Optipush (Guo et al., 2011) were not accessible to researchers in the past; consequently, there was a stronger need to use testing wheelchairs for all participants (Boninger, Cooper, Robertson, & Shimada, 1997; Boninger et al., 2002; Guo et al., 2011; Kotajarvi, Basford, An, Morrow, & Kaufman, 2006). The development of force-sensing wheels has allowed participants to use their own wheelchairs rather than a standardized laboratory wheelchair. This allows for a more realistic assessment of wheelchair propulsion. However, the use of an instrumented wheel also has some limitations, including cost, wheel size, participants using a wheel with a pushrim that may be different from their own, and the measurement of force only applied directly to the pushrim.

The WMS measures tangential forces during the push phase (while the hand is in contact with the pushrim) similar to those measured by the SmartWheel. However, the WMS measures the forces applied to the motors by the wheels of the wheelchair via the rollers, whereas the SmartWheel measures the forces applied to the pushrims. The benefits of using the WMS to measure forces occurring on the pushrim include the ability to measure the push forces on wheelchairs with any size wheel and regardless of where the wheelchair user applies force to the wheel. The rollers on the WMS use separate motors for the right and left wheels; therefore, force can be measured at the same time on both sides without the need for two instrumented wheels. When using the WMS to measure force during propulsion, the participant can use his or her own wheelchair and wheels and does not have to acclimate to pushing on a different wheel or think about only pushing on the pushrim. The WMS does not have the ability to measure the resultant force, whereas an instrumented wheel has the ability to measure different forces acting upon the pushrim (Boninger et al., 2002). The WMS and the SmartWheel measured tangential force similarly during the push phase. However, during the recovery phase (when the hand is not in contact with the pushrim), the force on the WMS and the SmartWheel differed. As would be expected, the SmartWheel force was around zero during the recovery phase, but this was not the case for the WMS, since the WMS collects the data from the interaction between the wheel and the roller. This force during recovery may include forces placed on the roller by the wheel and may be related to the participant repositioning or shifting his or her center of gravity in preparation for the next push. The data may be useful in identifying participants who use their core or trunk during a propulsion cycle.

2.4.3 Future Directions

The WMS has clinical applications in that it has the ability to simulate different resistive surfaces while placing the wheelchair in a realistic position, providing opportunities for training wheelchair users in propulsion and body position. The WMS is also able to assess propulsion variables, making it useful for research purposes. Further development and research of the WMS may increase its application. Future directions include the following areas: (1) fine tune the computer models for simulating overground with an interface for determining the appropriate coefficients for each user; (2) adjust the WMS software model to require higher force and quicker cadence for simulating ramps; (3) develop and test procedures for measuring speed, distance, and push angle on the WMS; (4) integrate a user friendly system for providing visual feedback to the person on the WMS and explore the use of virtual reality to provide a more realistic experience; and (5) collect kinetic and kinematic variables at the same time to compare different surfaces to the WMS.

2.5 Conclusions

The WMS has the ability to simulate different environments and assess propulsion variables, and it adds to the equipment available to clinicians and researchers. Information to improve the software modeling of the WMS to simulate propulsion on different surfaces was gathered. Pushing on an overground surface moderately correlates with pushing on the WMS. The ramp models need to be modified to allow for higher forces and to implement a cue to increase cadence. With further software development, the WMS has possible clinical applications to simulate different surfaces and research applications in assessing propulsion variables.

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Chapter 3: Wheelchair Skills for New Manual Wheelchair Users: Health Care Professional and Wheelchair User Perspectives

This chapter has been submitted:

Morgan, K. A., Engsberg, J. R., & Gray, D. B. (Submitted). Important wheelchair skills for new manual wheelchair users: health care professional and wheelchair user perspectives. *Disability and Rehabilitation.*

Abstract

Purpose: The purpose of this project was to identify wheelchair skills currently being taught to new manual wheelchair users, identify areas of importance for manual wheelchair skills training during initial rehabilitation, identify similarities and differences between the perspectives of health care professionals and manual wheelchair users and use the ICF to organize themes related to rehabilitation and learning how to use a manual wheelchair.

Methods: Focus groups were conducted with health care professionals and experienced manual wheelchair users. ICF codes were used to identify focus group themes.

Results: The Activities and Participation codes were more frequently used than Structure, Function and Environment codes. Wheelchair skills identified as important for new manual wheelchair users included propulsion techniques, transfers in an out of the wheelchair, providing maintenance to the wheelchair and navigating barriers such as curbs, ramps and rough terrain. Health care professionals and manual wheelchair users identified the need to incorporate the environment (home and community) into the wheelchair training program.

Conclusions: Identifying essential components for training proper propulsion mechanics and wheelchair skills in new manual wheelchair users is an important step in preventing future health and participation restrictions.

3.1 Introduction

Approximately 276,000 people in the United States live with a spinal cord injury (SCI), and the most common type of wheelchair these individuals, particularly those who are newly injured, use for everyday mobility is a manual wheelchair (National Spinal Cord Injury Statistical Center, 2013). Manual wheelchairs may enhance the mobility of people with lower limb impairments and allow them to engage in major life activities by increasing independence, providing more choice in activities, and improving satisfaction with participation in many activities. Although wheelchairs may have a positive impact on the participation of individuals with mobility limitations, many manual wheelchair users still experience participation limitations (Kaye, Kang, & LaPlante, 2002; LaPlante & Kaye, 2010). To maneuver through their home and community environments independently, manual wheelchair users must be able to perform certain wheelchair skills, using a wheelchair in different ways and circumstances to overcome barriers (Kilkens, Dallmeijer, de Witte, van der Woude, & Post, 2004). Teaching manual wheelchair users skills to overcome barriers may increase mobility and enhance participation (Best et al., 2014).

During initial rehabilitation, the implementation of training and interventions to achieve an optimal level of wheelchair skill performance is important. Evidence suggests that training offered during rehabilitation is beneficial and influences the ability of wheelchair users to use their wheelchairs throughout their daily activities (Öztürk & Ucsular, 2011). Manual wheelchair skill performance of people with SCI is positively associated with participation in major life activities (e.g., domestic life, interpersonal interactions, and community and social life; Kilkens, Post, Dallmeijer, van Asbeck, & van der Woude, 2005). However, varying levels of manual wheelchair training (including the amount and content of training) are offered to new manual wheelchair users during rehabilitation (Boninger et al., 2002; MacPhee et al., 2004; Taylor et al., 2014). The time allowed for initial rehabilitation for persons with SCI under current health care insurance policies is brief (approximately 36 days), and insufficient attention is often given to manual wheelchair training (Kendall, Ungerer, & Dorsett, 2003; National Spinal Cord Injury Statistical Center, 2013). The wheelchair training that does occur in rehabilitation tends to be brief and based on the clinician's intuition and personal clinical experience (McNevin, Wulf, & Carlson, 2000). Therefore, manual wheelchair users in rehabilitation do not always develop independent wheelchair skills (Fliess-Douer, Vanlandewijck, Manor, & van der Woude, 2010).

Several training protocols, clinical guidelines, and resources relevant to independent manual wheelchair mobility have been developed (Axelson, Chesney, Minkel, & Perr, 1996; Kirby et al., 2004; Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005). When studies report on wheelchair training during rehabilitation, training has been found to be offered, but minimal evidence is presented regarding what wheelchair skills are taught and which training methods are used during inpatient SCI rehabilitation (Taylor et al., 2014). When sufficient time during initial rehabilitation is provided, a frequently used protocol is the Wheelchair Skills Training Program (WSTP). The WSTP provides information, techniques, and strategies for training manual wheelchair skills not included during conventional training programs (e.g., maneuvering obstacles such as curbs and performing wheelies; MacPhee et al., 2004). However, clinicians do not often use these approaches, usually because of time constraints, limited resources, or lack of knowledge (Best et al., 2014). Given that the cost containment approach to health care is unlikely to change, the use of validated wheelchair skills training programs is needed to provide evidence for determining the priority of skills required for manual wheelchair use. The information provided by these studies may be able to point to when the most efficient time is to train specific wheelchair skills over the continuum of care (e.g., inpatient, day program, outpatient, or community-based services).

A comprehensive and systemic approach to manual wheelchair training that is multidisciplinary and encompasses many environmental settings and various funding sources requires a framework or model that uses a globally agreed-upon language. The World Health Organization (WHO) International Classification of Functioning, Disability and Health (ICF) is a conceptual framework developed to provide a common language for communication among health care professionals and persons receiving rehabilitation services. The ICF emphasizes the description of information as it relates to health and disability rather than disease and dysfunction (WHO, 2001). The ICF has been used for research and clinical purposes to identify themes related to rehabilitation interventions both from the individual perspective and from the perspective of health care professionals (Coenen et al., 2006; Üstün, Chatterji, Bickenbach, Kostanjsek, & Schneider, 2003). The ICF has also been used to analyze qualitative data collected during focus groups (Gray, Hollingsworth, Stark, & Morgan, 2006; Gray, Hollingsworth, Stark, & Morgan, 2008; Jelsma, 2009; Kirchberger et al., 2010; Rauch, Fekete, Cieza, Geyh, & Meyer, 2013; Whiteneck et al., 2004). ICF Core Sets for different health conditions (including SCI) and for different health care settings have been developed for use clinically to provide health care professionals with a better understanding of the needs of the populations they serve (Cieza et al., 2010; Vidmar, 2013). Using the ICF to identify specific impairments, activity limitations, participation restrictions, and environmental factors that are barriers to full participation may provide health care professionals with a broader understanding of which manual wheelchair skills to teach and how and when to conduct training. Given the variability in experiences of manual wheelchair users receiving wheelchair skills training, the ICF can be a useful tool for identifying key elements of wheelchair skills to be addressed by health care professionals during initial rehabilitation and those that can be addressed when the consumer has returned to community life.

The purpose of this project was to (1) review wheelchair skills being taught during rehabilitation to people using a manual wheelchair for the first time, (2) identify important components for individuals to know when they are first learning to use a manual wheelchair, (3) compare the perspectives of health care professionals and manual wheelchair users for similarities and differences regarding what is being taught in rehabilitation and what should be taught, and (4) discuss the application of the ICF in understanding manual wheelchair use across Body Structure and Function, Activity and Participation, and Environment domains.

3.2 Methods

3.2.1 Participants

A convenience sample of health care professionals and manual wheelchair users was recruited through local rehabilitation facilities and an Independent Living Center. Health care professionals with at least one year of experience with clients who have had an SCI and use wheelchairs for mobility were included. Thirteen health care professionals providing rehabilitation to people with SCI in the Midwestern region of the United States took part in the focus groups. The health care professionals averaged 7.8 years of experience in seating and mobility, with equal representation from occupational and physical therapists (Table 3.1). Manual wheelchair users with SCI who were at least one year post-injury were included. Fourteen participants with SCI using manual wheelchairs as their primary means of mobility took part in the focus groups. On average, participants had been injured for 14.3 years, 79% had cervical level injuries, and 50% of the participants reported receiving a moderate level of wheelchair skills training during rehabilitation (Table 3.2).

Table 3.1 Health care professionals (N = 13)

Years of experience	Average in years	7.8
	Range, years	1–23
Occupation, n (%)	Occupational therapist	6 (46.2)
	Physical therapist	6 (46.2)
	Physical therapist assistant	1 (7.7)
ATP certification	Assistive technology professional	3 (23.1)
Employment site, n (%)	Community-based program	1 (7.7)
	University-based program	2 (15.4)
	Rehabilitation hospital[a]	8 (61.5)
	VA	2 (15.4)
Inpatient vs. outpatient, n (%)	Inpatient	7 (53.8)
	Outpatient	3 (23.1)
	Both	3 (23.1)

Note. [a]Three rehabilitation hospitals were represented.

Table 3.2 Experienced manual wheelchair users (N = 14)

Age	Average in years	39.5
	Range, years	22–57
Gender, n (%)	Male	13 (93)
	Female	1 (7)
Race, n (%)	White	12 (86)
	African American	2 (14)
Time using wheelchair	Average in years	14.3
	Range, years	1.5–42
Level of injury, n (%)	Cervical	11 (79)
	Thoracic	3 (21)
Received wheelchair skills training in rehab, n (%)	Little to none	3 (21)
	Moderate	7 (50)
	Extensive	4 (29)

3.2.2 Setting

The focus groups took place in a conference room housed in a community-based research facility.

3.2.3 Procedures

The study design was descriptive in nature, using focus groups to collect qualitative data. Focus groups were conducted by applying general rules for the implementation of focus groups

(Hammel et al., 2008; Kroll, Barbour, & Harris, 2007; Krueger & Casey, 2009). Focus groups for manual wheelchair users and health care professionals were conducted separately. Due to scheduling constraints, one group was conducted for health care professionals, and two groups for manual wheelchair users. Each participant was encouraged to provide an answer to each question. One moderator and two note-takers were present during the 90-minute, audio-recorded focus groups. Notes were taken during the focus groups to assist in identifying main themes and in identifying respondents on the audio recording transcription.

Guidelines were developed that included key questions to identify wheelchair skills taught during rehabilitation to new wheelchair users and skills that should be taught (Table 3.3). For the purposes of this study, we considered skills currently being taught as “actual” practices during rehabilitation and skills that should be taught as “ideal” practices for rehabilitation. The health care professionals were asked to discuss manual wheelchair skills they currently teach to new manual wheelchair users (actual) and what they think should be taught (ideal). In the focus groups for manual wheelchair users, participants were asked to discuss manual wheelchair skills that they were taught as new wheelchair users (actual) during the rehabilitation process. Manual wheelchair users were then asked to discuss manual wheelchair skills they thought should be taught (ideal) to new manual wheelchair users. During discussion in each of the focus groups, one of the note-takers wrote the actual and ideal wheelchair skills discussed on a whiteboard in the room. At the completion of the group discussion of each focus group, a member check was conducted to verify that the themes captured by the note-takers on the whiteboard reflected the perspectives of the participants. Before participants left, they were asked to individually rank-order the skills that were written on the whiteboard in order of importance for new manual wheelchair users to learn during the rehabilitation process. The participants ranked the top ten skills they thought were most important.

Table 3.3 Focus group structure: Health care professionals vs. manual wheelchair users

Health Care Professionals	Manual Wheelchair Users
Introductions: Occupation, work setting, years working in SCI rehab	Introductions: Time in wheelchair, level of injury, rehab experience
Actual	
Wheelchair training: When is it completed, who does it, for how long, & what skills are taught?	Wheelchair training: Did you receive any? If so, how, when, where, & what skills were learned?
Ideal	
Wheelchair training: What should be taught? when, where, and by whom?	Wheelchair training: What should be taught? when & where?
Ranking	
Ranking by importance: List ten most important things new wheelchair users need to know.	Ranking by importance: List ten most important things new wheelchair users need to know.

Note. SCI = spinal cord injury.

3.2.4 Data Processing and Analysis

Audio recordings and written notes were used to transcribe the statements and themes made by participants, to identify respondents, and to code participants' identities. A deductive content analysis, also known as directed content analysis, is a type of qualitative data analysis in which data are coded using predetermined categories (Elo & Kyngas, 2007; White & Marsh, 2006). A deductive content analysis was used to review transcripts to identify important skills for new manual wheelchair users to learn. The ICF was used to classify areas of wheelchair training for new wheelchair users related to the body, the individual, and the environment (Figure 3.1). The ICF comprises four components, and each is coded with a letter: Body Functions, b; Body Structures, s; Activities and Participation, d; and Environmental Factors, e. The ICF codes begin with one of these letters and continue with a chapter number (first level), second level, and the third and fourth levels. For example, the Environmental Factors category includes a "products and technology" domain, which is the first level of classification; "products and technology for personal use in daily living" is the second level of classification (WHO, 2001). The focus group content was coded to the second level.

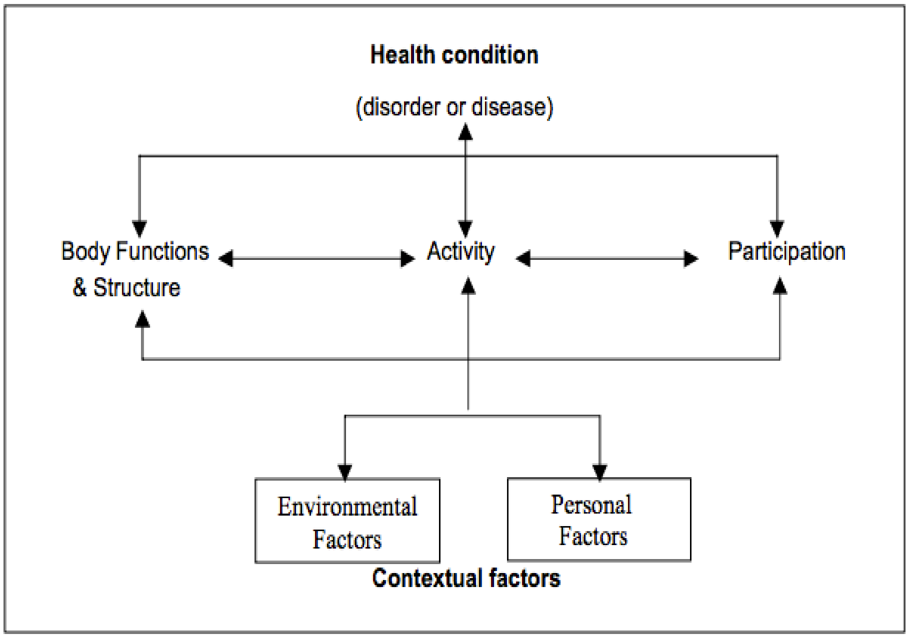


Figure 3.1 International Classification of Functioning, Disability and Health (ICF)

The transcripts were separately analyzed for health care professionals and manual wheelchair users. First, the transcripts were read thoroughly by each coder to get an understanding of the content. Next, for each transcript, the text was divided into sections for analysis. Within each section, words or sentences in the text that represented a specific concept were identified. Each identified concept was then linked to one or more ICF categories based on established rules (Cieza et al., 2002; Stucki, 2005; WHO, 2001). Each category was analyzed to determine whether it was currently being taught during initial rehabilitation or should be taught in rehabilitation. Three members of the research staff coded the transcripts; two members of the research staff coded all of the transcripts, and the third researcher (more experienced with coding) reviewed concepts that the first two coders coded differently and made the final decision regarding the classification. The concordance rate between the two primary coders was 81%. The codes were compared across focus groups (health care professionals and wheelchair users) to identify differences. The codes were then divided into skills that health care professionals reported teaching and skills that wheelchair users reported learning (actual), as well as what health care professionals and wheelchair users thought should be taught (ideal) to new manual wheelchair users. After each concept was coded, the number of participants associated with that code was counted.

The Activities and Participation component was further coded by the separation of activity and participation by reviewing all concepts in the transcripts coded with d codes. These concepts were reviewed and were associated with either a capacity qualifier (the ability of an individual to execute an action in a standardized environment without support) or a performance qualifier (what an individual does in his or her own environment). All capacity qualifiers were classified as an activity, and all performance qualifiers were classified as participation (WHO, 2001). Percentages of activity and participation codes were calculated for health care professionals and manual wheelchair users. In addition, the number of participants reporting the skill in his or her list of top ten skills was identified. A paired-samples t-test was conducted to determine significant differences ($p < 0.05$) between health care professional rankings and manual wheelchair user rankings. A customized Microsoft excel database and SPSS version 21 were used for data organization and analysis (Microsoft, 2011; SPSS Inc., 2012).

3.3 Results

Eighteen ICF chapters (out of a total of 30) and 44 second-level ICF categories (out of a total of 363) were identified (see Tables 3.4–3.7). Six codes (s720, d220, d475, d530, d650, d720) were applied to concepts identified solely as current wheelchair rehabilitation skills taught, and six codes (b130, d230, d520, d710, d750, d910) were used when coding content solely related to an ideal setting. Eight codes (b280, s720, d210, d220, d350, d710, d720, e130) were used for responses from health care professionals that were not used for responses from manual wheelchair users, and six codes (b730, b740, d475, d530, d750, e355) were applied to manual wheelchair user responses that were not applied to those of health care professionals. Themes and differences between the groups (health care professionals and manual wheelchair users) and situations (actual and ideal) are described below across the four ICF components and exemplified by original statements.

3.3.1 ICF Coding

Body Functions (b). Four chapters (out of eight) and six second-level categories (out of 79) were used in identifying content in the area of Body Functions (Table 3.4). Wheelchair users focused on strength and conditioning related to being able to push their wheelchairs as they perform their daily activities. They reported receiving this training in rehabilitation and stressed the importance of continuing to focus on strength (b730) and conditioning (b740) as they relate to learning to use the wheelchair during rehabilitation: “I did get trained to push a chair; mainly strength training is what they did with me” (manual wheelchair user). The health care professionals focused on decreasing pain (b280) and issues related to the skin and prevention of pressure sores (b810) on different areas of the body. Many references were made to pressure mapping, selecting a cushion, and educating about pressure relief: “I start with safety of the chair and pressure reliefs number one; … you’re going to be sitting in this all the time. If you can’t pressure relieve, then we need to look at something else” (health care professional).

During discussion of actual wheelchair training, there was no mention of psychological factors (b130) related to using a wheelchair. However, both health care professionals and manual wheelchair users discussed the importance of addressing and incorporating psychological factors, such as motivation for wanting interventions, for new manual wheelchair users. One health care professional noted, “I wonder if there isn’t somebody that should be part of the team that’s kind of helping with the psychological adjustment a little bit more, whether that be a peer or a professional person or … I’m not sure who that ideal person is, but I think that maybe it’s beyond some of our areas of expertise—it is mine—and it is just as important in their overall participation and getting back to life.” Wheelchair users also discussed the influence of psychological factors on training: “I guess the important thing—you’re so traumatized that if you do this [wheelchair training] too soon—you’re on so much *[sic]* drugs that half the stuff they told me, you *[sic]* don’t remember. You might want to start [wheelchair training] three months after [injury]” (manual wheelchair user).

Table 3.4 Body functions related to wheelchair skills training

ICF Code	ICF Category	Actual		Ideal	
Chapter 1: Mental functions		**HCP**	**MWU**	**HCP**	**MWU**
b130	Energy and drive functions	0	0	4	5
Chapter 2: Sensory functions and pain					
b280	Sensation of pain	5	0	3	0
Chapter 7: Neuromusculoskeletal and movement-related functions					
b710	Mobility of joint functions	4	3	1	1
b730	Muscle power functions	0	9	0	3
b740	Muscle endurance functions	0	3	0	3
Chapter 8: Functions of the skin and related structures					
b810	Protective functions of the skin	2	1	4	2

Note. Numbers in the right-hand columns represent the number of participants who mentioned content related to the corresponding code one or more times. *Actual* represents what was reported as practiced and experienced with manual wheelchair training; *ideal* represents what should be taught or learned related to manual wheelchair training. HCP = health care professionals, MWU = manual wheelchair users.

Body Structures (s). The fewest number of codes, two chapters (out of eight) and three second-level categories (out of 39), were used from the body structures component of the ICF (Table 3.5). One common theme related to body structures and wheelchair use mentioned by several health care professionals was protecting the upper extremities, particularly the shoulder joint (s720), from overuse injuries: “One thing I think is important is pushing technique for shoulder preservation” (health care professional). Wheelchair users had concerns about their hands and protecting them while pushing outside and through doorways: “I wish I learned more about hand protection and not burning your hands on the pushrims and tires” (manual wheelchair user). A recurring coded theme during discussion of an ideal setting for health care professionals was focus on positioning in the wheelchair, preventing pressure sores, and educating wheelchair users about pressure sores: “We’ve had several instances where somebody has come in for outpatient six weeks after leaving inpatient, and they’ve got this gaping wound on the inside of the ankle because they thought it was just a blister and it’s not a big deal, and they did not know who to call for help” (health care professional).

Table 3.5 Body structures related to wheelchair skills training

ICF Code	ICF Category	Actual		Ideal	
Chapter 7: Neuromusculoskeletal and movement-related functions		**HCP**	**MWU**	**HCP**	**MWU**
s720	Structure of shoulder region	2	0	0	0
s770	Additional musculoskeletal structures related to movement	2	4	0	3
Chapter 8: Skin and related structures					
s810	Structure of areas of skin	2	0	5	1

Note. Numbers in the right-hand columns represent the number of participants who mentioned content related to the corresponding code one or more times. *Actual* represents what was reported as practiced and experienced with manual wheelchair training; *ideal* represents what should be taught or learned related to manual wheelchair training. HCP = health care professionals, MWU = manual wheelchair users.

Activities and Participation (d). Codes from the Activities and Participation component of the ICF were the most frequently used in identifying the themes reported by the participants in the focus groups (Table 3.6). Eight out of the nine chapters were referenced, and 27 second-level categories (out of 85) were used. Many of the codes were from two chapters: Chapter 1: Learning and applying knowledge and Chapter 4: Mobility. Manual wheelchair users discussed the different ways they learned and acquired manual wheelchair skills during rehabilitation: “I guess I had my wheelchair skills experience; mostly [it] was just transferring with [a] transfer board. Primarily, it was just rolling down the hall, but I didn’t get my chair until I was home. So I pretty much had to learn those skills when I got home” (manual wheelchair user). Another manual wheelchair user shared that “the therapists would demonstrate [wheelchair skills], and then you would have people spotting you until you felt comfortable to try it on your own, so there’s still someone there to catch you or let you fall or whatever.”

Health care professionals mentioned the importance of manual wheelchair users being able to communicate to others how to help with using and maintaining the wheelchair: “Making sure that [wheelchair users] know all the adjustments on the chair, you know, either they can do it or instruct somebody to change the armrest height and leg rests and all of the adjustments that are on there, that they at least know how they work and can tell somebody if they are not able to do it themselves" (health care professional). Many wheelchair users reported learning transfers, including transfers in the home, in the car, and on airplanes: "We worked on shower transfers, toilet transfers, all that home stuff" (manual wheelchair user). This included the importance of transfers and the emphasis placed on transfers in rehabilitation: "An important thing to work on is every kind of transfer you can think of, multiple times" (manual wheelchair user).

Table 3.6 Activity and participation related to wheelchair skills training

ICF Code	ICF Category	Actual		Ideal	
Chapter 1: Learning and applying knowledge		**HCP**	**MWU**	**HCP**	**MWU**
d155	Acquiring skills	5	13	10	12
d175	Solving problems	3	3	9	5
d177	Making a decision	2	1	5	3
Chapter 2: General tasks and demands					
d210	Undertaking a single task	1	0	2	0
d220	Undertaking multiple tasks	1	0	0	0
d230	Carrying out daily routine	0	0	1	1
d240	Handling stress and other psychological demands	0	3	7	2
Chapter 3: Communication					
d350	Conversation	2	0	6	0
Chapter 4: Mobility					
d410	Changing basic body position	4	7	3	6
d415	Maintaining a body position	3	3	3	4
d420	Transferring oneself	4	11	4	8
d445	Hand and arm use	4	6	4	7
d455	Moving around	4	3	4	2
d460	Moving around in different locations	5	8	4	9
d465	Moving around using equipment	7	6	3	7
d470	Using transportation	2	4	3	0
d475	Driving	0	2	0	0
Chapter 5: Self-care					
d520	Caring for body parts	0	0	2	1
d530	Toileting	0	1	0	0
d570	Looking after one’s health	2	0	5	3
Chapter 6: Domestic life					
d620	Acquisition of goods and services	0	1	5	3
d650	Caring for household objects	1	3	0	0
Chapter 7: Interpersonal interactions and relationships					
d710	Basic interpersonal interactions	0	0	3	0
d720	Complex interpersonal interactions	1	0	0	0
d750	Informal social relationships	0	0	0	2
Chapter 9: Community, social and civic life					
d910	Community life	0	0	2	4
d920	Recreation and leisure	0	5	1	3

Note. Numbers in the right-hand columns represent the number of participants who mentioned content related to the corresponding code one or more times. *Actual* represents what was reported as practiced and experienced with manual wheelchair training; *ideal* represents what should be taught or learned related to manual wheelchair training. HCP = health care professionals, MWU = manual wheelchair users.

Content coded as Activities and Participation (d) was further subdivided to reflect the percentage of codes corresponding to activity-based themes (the execution of a task or action) versus the percentage of codes associated with participation-based themes (involvement in a life situation; WHO, 2001). The focus group content related to Activities and Participation was 79% activity based and 21% participation based. Regarding the actual rehabilitation process, participation-based themes were discussed by health care professionals 14% of the time and by manual wheelchair users 15% of the time. During discussions of what ideally should take place, themes related to participation increased to 21% by health care professionals and 33% by manual wheelchair users.

Environmental Factors (e). Four (out of five) environment chapters and eight second-level (out of 64) categories were identified with themes discussed during the focus groups (Table 3.7). Many of the codes for content related to the environment came from Chapter 1: Products and technology. Health care professionals referred to environmental factors more often when asked about an ideal situation than when they discussed actual situations; one health care professional emphasized the importance of “taking the time to simulate—to simulate not just [manual wheelchair users’] environment, but do their environment multiple times.” Manual wheelchair users talked at length about their experiences with their health care professionals (e355) during rehabilitation. One participant remarked that:

> If you’re with a therapist, they’re going to be like, “oh, don't do that,” so when you’re out with other people in the same situation, you’re like, “oh, they can jump off that curb,” so you just go and do it. I think just getting tossed into the mix of things was the best learning for me because the therapists—I just feel like they don’t know.

Overall, environment codes were identified more often with content discussed for an ideal situation than for actual situations. The health care professionals and manual wheelchair users reported wanting more opportunities related to using the wheelchair and practicing skills outside of the hospital environment. One health care professional commented that:

> I think, from my perspective, it's kind of ideal and I get to do it periodically … I get to go to the place where they [wheelchair users] work. We access every environment that they are going to be in, and it really works out great because, a lot of times, there's something that comes up—and it might be the littlest thing. If you don't go and have those experiences, then they just get in that situation and they have to figure out how to make the non-ideal situation work. Sometimes, I think that leads to some injuries and falls. It would be really nice for all of us to be able to go with these guys where they go and train them there.

Manual wheelchair users also emphasized the importance of training in the lived environment, as one participant emphasized, "There's got to be more training at the home."

Table 3.7 Environmental factors related to wheelchair skills training

ICF Code	ICF Category	Actual		Ideal	
Chapter 1: Products and technology		**HCP**	**MWU**	**HCP**	**MWU**
e115	Products and technology for personal use in daily living	4	1	7	6
e120	Products and technology for personal indoor and outdoor mobility and transportation	6	7	9	11
e130	Products and technology for education	0	0	2	0
e150	Design, construction and building products and technology of buildings for public use	0	4	3	8
e155	Design, construction and building products and technology of buildings for private use	0	1	2	2
Chapter 2: Natural environment and human-made changes to environment					
e210	Physical geography	3	2	4	4
Chapter 3: Support and relationships					
e355	Health professionals	0	5	0	4
Chapter 5: Services, systems and policies					
e580	Health services, systems and policies	3	4	3	2

Note. Numbers in the right-hand columns represent the number of participants who mentioned content related to the corresponding code one or more times. *Actual* represents what was reported as practiced and experienced with manual wheelchair training; *ideal* represents what should be taught or learned related to manual wheelchair training. HCP = health care professionals, MWU = manual wheelchair users.

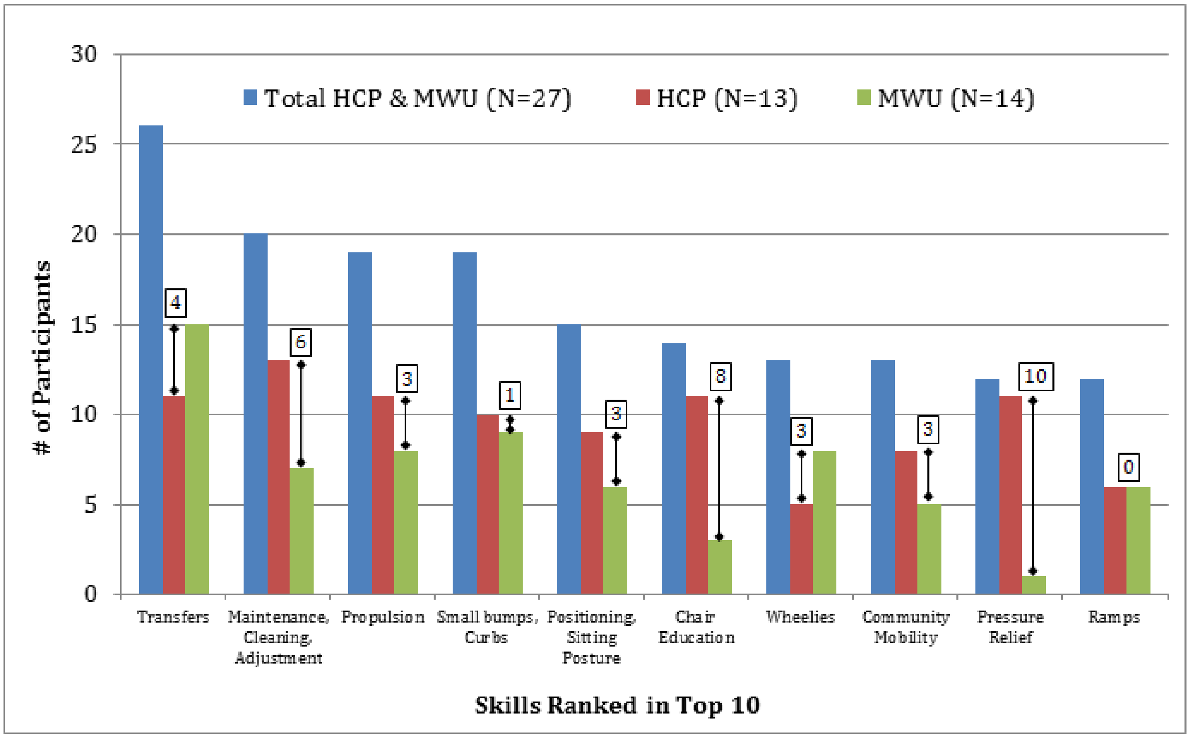
3.3.2 Identifying Important Skills for New Manual Wheelchair Users

Participants (manual wheelchair users and health care professionals) identified 21 manual wheelchair skills (Figure 3.2) and ranked their top 10 in order of importance. The four skills that were ranked in the top ten by all participants ($n = 27$) were transfers ($n = 26$), taking care of the wheelchair (this includes maintenance, cleaning, and adjustment; $n = 20$), propulsion techniques ($n = 19$), and maneuvering small bumps or curbs ($n = 19$; Figure 3.3). Performing activities of daily living in the wheelchair ($n = 2$) and going up and down stairs ($n = 2$) were among skills that were least identified in the top 10 important skills. More manual wheelchair users ($n = 15$) identified transfers in their top 10 list than did health care professionals ($n = 11$). Health care professionals ($n = 11$) reported the ability to perform a pressure relief in the wheelchair more commonly than did manual wheelchair users ($n = 1$). Health care professionals and manual wheelchair users identified similar themes; however, the order of importance of the skills for manual wheelchair users and health care professionals were statistically different ($p < 0.05$).

Manual Wheelchair Skills
General transfers (bed, shower/bathtub, car)
Maintenance/cleaning/adjustments
Propulsion techniques
Small bumps/curbs
Positioning/sitting, posture
Chair education (parts, vendor, etc.)
Wheelies
Community mobility
Pressure relief
Ramps (up and down)
Hills (up and down)
Strength and conditioning
Rough surfaces (gravel, grass, etc.)
Doors (opening and closing)
Floor-to-chair transfer
Turning and maneuvering/managing tight spaces
Assembling and disassembling wheelchair
Sitting balance
Psychological adjustment
ADLs in wheelchair
Stairs

Note. ADLs = Activities of daily living.

Figure 3.2 Manual wheelchair skills identified as important by health care professionals and manual wheelchair users.



Note. This figure shows only the skills that at least 10 participants reported in their top ten list of skills. Black arrows indicate difference between manual wheelchair users and health care professionals. HCP = health care professionals, MWU = manual wheelchair users.

Figure 3.3 Manual wheelchair skills identified during focus groups: ranked by importance by both groups, each group, and reported group differences.

3.4 Discussion

The purpose of this project was to identify wheelchair skills currently being taught to new manual wheelchair users, identify areas of importance for acquisition of manual wheelchair skill training during initial rehabilitation, identify similarities and differences between health care professional and manual wheelchair user perspectives, and use the ICF in organizing themes related to rehabilitation and learning how to use a manual wheelchair. The use of focus groups provided an opportunity for health care professionals and manual wheelchair users to share their thoughts about the current state of wheelchair training and potential priorities for the future (Hammell, 2001). This study had many limitations, including a small sample size and limited geographic representation of participants. The health care professionals and manual wheelchair users were located in the Midwestern geographical region; however, many participants received rehabilitation or worked in facilities outside of this geographical area. A few of the participants were injured for more than 10 years, and their experiences during rehabilitation may not reflect the current state of rehabilitation. Across participants in the manual wheelchair user group, the spectrum ranged from individuals who were newly injured to individuals who had been injured for over 40 years. This diverse participant population provided a picture of rehabilitation for manual wheelchair users across a wide range of time.

3.4.1 Actual Experience Reported by Health Care Professionals and Manual Wheelchair Users

Previous research provides varying descriptions of the amount of wheelchair training offered during rehabilitation, ranging from little to no training offered to more thorough and deliberate training offered over numerous therapy sessions (Boninger et al., 2002; Taylor et al., 2014). The experiences of wheelchair training during rehabilitation described by manual wheelchair users in this study are similar to those described in the literature. Manual wheelchair users in the focus groups reported differing experiences related to training, with half of the sample reporting one extreme or the other (no training or a great deal training) and the other half of the sample reporting that they received a moderate amount of training. The health care professionals all reported providing wheelchair training to new wheelchair users; however, the amount of training was dependent upon the circumstances. From the information provided in the focus groups, some level of wheelchair skills training is, for the most part, introduced during rehabilitation. The material covered during training varies, and the application of the information to the person's own environment does not necessarily translate to changes in participation in the person's lived environment.

The most common skills taught in rehabilitation as reported in the literature are transfers, wheelies, propulsion techniques, navigating different surfaces, and going up slopes (Kilkens, Post, Dallmeijer, Seelen, & van der Woude, 2003; Taylor et al., 2014). Transfers in and out of the wheelchair (e.g., to the bed, shower, or car) were repeatedly mentioned as a skill taught during rehabilitation. Wheelies were not mentioned often by health care professionals or manual wheelchair users as being taught during rehabilitation. Techniques for propelling a wheelchair were introduced but not explained or practiced, as reported by manual wheelchair users in the focus groups. Focus group participants did report some practice with maneuvering obstacles and going up and down ramps.

At the beginning of each focus group, manual wheelchair skills were vaguely defined. When asked about wheelchair skills training currently being provided during the rehabilitation process, many health care professionals responded by explaining the wheelchair seating evaluation process. Even after being redirected to the purpose of the discussion (wheelchair skills training), health care professionals made statements about the wheelchair seating process (e.g., meeting with the equipment provider, taking measurements, setting the axle position) rather than wheelchair skills training. This focus on the wheelchair fitting rather than wheelchair skills training may be due to the short duration of rehabilitation stays, which may leave insufficient time for actual wheelchair skills training (Kendall et al., 2003). The emphasis on the wheelchair fitting may also be related to how comfortable health care professionals are with teaching wheelchair skills. During the focus groups, we asked what should be taught but did not ask whether health care professionals felt equipped to teach these skills. Many comments from both health care professionals and manual wheelchair users indicated that therapists may not necessarily know some of the wheelchair skills or be comfortable teaching them. Wheelchair skills training may not be an area in which health care professionals are trained, feel comfortable with, or have support or time to offer during rehabilitation (Coolen et al., 2004).Therapists mentioned learning on the job and from other, more experienced therapists. Literature suggests that training in this area for therapists may not be extensive or hands-on, and this may lead to inadequate wheelchair training during rehabilitation, as well as safety concerns (Best et al., 2014; Giesbrecht et al., 2004; Kirby et al., 2004). Several manual wheelchair users in this study reported learning many of their wheelchair skills (especially advanced skills) outside of rehabilitation from experienced wheelchair users.

3.4.2 Ideal Experience Reported by Health Care Professionals and Manual Wheelchair Users

A disconnect between what wheelchair training is occurring in rehabilitation and what health care professionals and manual wheelchair users thought should occur was identified. Three of the areas that were evident in coding gaps between actual and ideal were use of the environment for training, addressing and accommodating for a psychological adjustment period, and teaching not just wheelchair use, but also how to care for and maintain the wheelchair. In the ideal setting, more participation-based training in the context of the environment was emphasized. Even though SCI rehabilitation focus is shifting away from a pure medical model, many barriers still exist to offering rehabilitation interventions with a participation focus (Gómara-Toldrà, Sliwinski, & Dijkers, 2014). These barriers identified by the health care professionals in the focus groups and supported by the literature include funding, time, policies, and limited access to support and resources (Isaacson, 2011; Mitchell, Jin, Kim, Giesbrecht, & Miller, 2014).

Another area identified by the health care professionals and the manual wheelchair users as needing more emphasis is the psychological factors that impact motivation to learn wheelchair skills. Adjusting to a disability (such as an SCI) and using a wheelchair for fulltime mobility is a process and often leads to depression, anxiety, and lack of motivation (Post, de Witte, van Asbeck, van Dijk, & Schrijvers, 1998).

Themes in the focus groups were similar to those in literature published on adjustment and impact on rehabilitation (Sand, Karlberg, & Kreuter, 2006). Manual wheelchair users discussed that they would have liked to be more included and consulted about rehabilitation plans for wheelchair training. Health care professionals and manual wheelchair users suggested extending the time wheelchair training is offered across settings (inpatient, outpatient, and community services) to allow for an adjustment period (Ditunno, 1994). The third reoccurring theme discussed by both participant groups was the need for more training related not just how to use the wheelchair, but also *about* the wheelchair—how to care for, adjust, and clean the wheelchair. Literature supports the finding that wheelchair users often are not informed about their wheelchairs, do not know how to care for them, and are unable to determine on their own when adjustments and maintenance are needed (Hansen, Tresse, & Gunnarsson, 2004).

3.4.3 Health Care Professional and Manual Wheelchair User Perspectives

Limited information exists in the literature on perspectives of health care professionals in comparison to those of manual wheelchair users on wheelchair training during rehabilitation for people with SCI. The results of this project provide a unique perspective of the two key players in wheelchair training during rehabilitation: the health care professional and the manual wheelchair user. While there were many commonalities in the themes identified by both groups, there were also some discrepancies or instances in which one group emphasized an area more than the other group. Health care professionals frequently discussed themes related to body functions and structures, such as pressure and skin, whereas manual wheelchair users emphasized transfers in and out of the wheelchair. Discrepancies between responses from manual wheelchair users and health care professionals were also identified when discussing what was taught during rehabilitation. For example, health care professionals explained that one of the routine skills that they teach to new manual wheelchair users is propulsion technique; however, manual wheelchair users repeatedly said that they received little to no direct instruction on how to push the wheelchair and, when they did, it was basic instruction over hospital floors. Health care professionals and manual wheelchair users both identified the importance of teaching the skills within the context of the person's environment, such as the home and community. Health care professionals and manual wheelchair users agreed on skills that should be taught but had differences in the order of importance of these skills.

3.4.4 Application of the ICF to Wheelchair Skill Training in Rehabilitation

Wheelchair training may be implemented across different settings by multiple professions, most commonly occupational and physical therapists. The ICF provides language to cut across health care professions and different settings and to connect to wheelchair users (Biering-Sørensen et al., 2006; Steiner et al., 2002). The structure that the ICF provides addresses the language gap between the medical model of a disease, deficit, and limitation with a focus on individual interventions and a social model that views the physical and social aspects of the environment for creating disability (WHO, 2001). Proper and effective wheelchair skill training is an example of a rehabilitation intervention that requires attention to both models. The ICF provides a structure to view wheelchair training rehabilitation with a biological-socio-environmental view (WHO, 2001).

The ICF has not previously been employed to analyze the specific components of wheelchair skills training during rehabilitation; however, the ICF has been used for wheelchair seating and training outcomes analyses. Many of these measures have been found to focus on body function and structure and standardized environments rather than participation and the natural environment (Gray et al., 2008; Jette, Haley, & Kooyoomjian, 2003; Perenboom & Chorus, 2003). Although many measures may be related to body functions and structures, those codes were used the least when identifying themes of what is actually offered in rehabilitation to address wheelchair skills. The health care providers and manual wheelchair users describe (as indicated by the ICF-coded themes discussed during the focus groups) the current state of wheelchair skills training intervention in rehabilitation as an activity-dependent intervention performed primarily in a controlled environment (Glass, 1998). Activity-dependent interventions are subject to performance measures in standard environments designed to reduce the number and types of variables present, they are dependent upon observation, and progress is measured by time taken and magnitude of response. On the contrary, participation-dependent interventions are assessed by the participant, done in the lived environment, are dependent upon support available (e.g., personal assistance and assistive technology) but often are difficult to implement and support in the rehabilitation setting. The current activity-dependent approach in wheelchair training rehabilitation may explain why skills vary greatly across manual wheelchair users and why many manual wheelchair users are unable to perform more advanced wheelchair skills in their own environments (Kirby, Swuste, Dupuis, MacLeod, & Monroe, 2002; MacPhee et al., 2004).

ICF Core Sets have been developed for more than thirty health care conditions (e.g., stroke, rheumatoid arthritis, low back pain, and SCI; Cieza et al., 2010; Vidmar, 2013). The ICF Core Set for SCI has similar codes identified in this study but provides a greater picture of SCI overall, with many codes specifically related to body structure and function (Cieza et al., 2010). The information gathered in this study could form the basis for establishing an ICF Core Set for manual wheelchair users to include Body Structures and Function, Activities and Participation, and Environment codes that were mentioned in the focus groups. An ICF Core Set with a limited number of codes for health care professionals and consumers may promote an understanding of the important variables to consider when training people to use manual wheelchairs.

3.4.5 Implications for Rehabilitation

People with SCI leaving rehabilitation have not felt prepared for everyday community living in part due to poor independent mobility skills (Cott, 2004). This project provides a view of wheelchair training interventions from the perspective of health care professionals and manual wheelchair users. Reviewing what is being covered in rehabilitation related to wheelchair skills training and what should be emphasized may provide information to help health care professionals identify ideas about other possible approaches in wheelchair skills training. The project specifically highlights manual wheelchair skills identified as important for new wheelchair users to learn. With limited time during rehabilitation, select skills identified as important for new manual wheelchair users could be the focus. Formalized wheelchair training protocols such as the WSTP could be utilized as a guide for health care professionals on how to teach the skills they have chosen to address during rehabilitation (MacPhee et al., 2004). Nineteen of the 21 skills discussed in the focus groups (see Table 3.8) are found in the WSTP. The results of this study help to identify important manual wheelchair skills that need further examination for ranking of importance and how best to teach them. This information may guide alternative approaches to providing further education and training about manual wheelchair use outside of initial rehabilitation.

3.4.6 Future Directions

In order to represent a wider experience of rehabilitation, future work could include recruiting a larger sample size with representation across the country and across different settings. In addition, the continuum of care in wheelchair skills being taught across settings needs to be examined to determine what is being taught in inpatient and outpatient rehabilitation and the potential need for community programs. ICF coding for related content could also be expanded to include third and fourth level codes. In addition, qualifier codes for the Activities and Participation and Environment components could be used to provide more information regarding wheelchair skills deemed most difficult to learn and environmental barriers and facilitators influencing participation using these skills. A larger sample across settings and with more levels coded could assist in the process of solidifying an ICF Core Set for manual wheelchair users.

3.5 Conclusions

The focus of rehabilitation for wheelchair skill training falls primarily in the Activity and Participation domains of the ICF. Health care professionals and manual wheelchair users identified the need to incorporate the environment (home and community) into the wheelchair training program. The focus groups identified key wheelchair skills that may be important to introduce to new manual wheelchair users during the continuum of rehabilitation. Many skills that were identified as important by participants (both health care professionals and manual wheelchair users) related to proper propulsion mechanics, transfers in an out of the wheelchair, providing maintenance to the wheelchair, and pushing over environmental barriers such as curbs, ramps, and rough terrain. The results of this study have important implications for health care professionals working with people who use manual wheelchairs. Identifying essential components for training proper propulsion mechanics and wheelchair skills in new manual wheelchair users is an important step in preventing future health and participation restrictions.

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Chapter 4: A Motor Learning Approach to Wheelchair Training for Brand New Manual Wheelchair Users: A Pilot Study

This chapter is in preparation:

Morgan, K. A., Tucker, S., Klaesner, J., & Engsberg, J. R. A motor learning approach to wheelchair training for new manual wheelchair users: A pilot study.

Abstract

Purpose: Developing evidence-based approaches to teaching wheelchair skills and proper propulsion for people with SCI is important to successful rehabilitation for everyday wheelchair use. The purpose of this project was to pilot test a manual wheelchair training program based on motor learning and repetition-based training for new manual wheelchair users with a spinal cord injury (SCI).

Methods: Six persons with a spinal cord injury requiring the use of a manual wheelchair participated in a wheelchair training intervention. The intervention included nine 90-minute training sessions. The primary focus was on wheelchair propulsion biomechanics and the secondary focus was on wheelchair skills. At each testing session (Pretest 1, Pretest 2 and Posttest), kinematics related to propulsion and wheelchair performance overground were measured. Kinetic propulsion variables and wheelchair skills were measured immediately before the intervention (Pretest 2) and immediately after (Posttest).

Results: Significant changes in area of the push loop, hand to axle relationship, and slope of the push forces were found. Changes in propulsion patterns were identified pre and post wheelchair training. No significant differences were found in peak and average push forces and wheelchair skills pre and post wheelchair training.

Conclusions: This project identified trends in change related to a repetition-based motor learning approach for propelling a manual wheelchair. The changes found were related to the propulsion pattern of the participants. Studying manual wheelchair use with new manual wheelchair users has potential for change and preventing or reducing pain and chronic overuse injuries. However, there are many challenges associated with implementing interventions for new manual wheelchair users.

4.1 Introduction

The most common type of wheelchair used for everyday mobility by persons with spinal cord injuries (SCI) is a manual wheelchair (National Spinal Cord Injury Statistical Center, 2013). While wheelchair propulsion is an essential skill for maneuvering a manual wheelchair, research suggests that the repetitive loading on the upper extremities may contribute to pain and chronic overuse injuries (Boninger et al., 2005; Gellman et al., 1988; Tun & Upton, 1988). Specifically, biomechanically poor wheelchair propulsion techniques have been associated with rotator cuff injuries, tendonitis, carpal tunnel syndrome, and median nerve injuries (Akbar et al., 2010; Davidoff, Werner, & Waring, 1991; Koontz et al., 2005). Pain and injury to the upper extremities is a major concern for manual wheelchair users because they depend upon their upper extremities to perform typical activities of daily living (e.g., transferring, getting dressed, and driving a vehicle; Robertson, Boninger, Cooper, & Shimada, 1996; Rodgers, Keyser, Rasch, Gorman, & Russell, 2001). Manual wheelchair users may benefit from training in proper wheelchair propulsion to help decrease the possibility of injuries that may affect their mobility and activities of daily living.

The literature contains substantial information regarding wheelchair propulsion mechanics, techniques, and skills and suggests that propulsion mechanics may be changeable through training (Fay et al., 2004; Mercer et al., 2006). Specifically, research suggests that important components of wheelchair propulsion training are decreasing push frequency, increasing push angle, and using a semicircular propulsion pattern or a pattern in which the hand drops below the pushrim toward the axle of the wheel during the recovery phase of the push (Boninger et al., 2005). The Clinical Practice Guidelines for the Preservation of Upper Limb Function Following Spinal Cord Injury (CPG) recommendations are based upon this research and emphasize minimizing the force and frequency of pushes and using long pushes during propulsion (Boninger et al., 2005; Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005; Sawatzky, DiGiovine, Berner, Roesler, & Katte, 2015). The goal of the guidelines is to promote a more efficient propulsion pattern, or a motion that requires fewer pushes on the pushrim but uses more of the pushrim to retain the same speed (Boninger et al., 2002). Increased propulsion efficiency minimizes unnecessary upper extremity use during propulsion and may lead to a reduction in chronic injuries of the upper extremities.

Different approaches to improving propulsion mechanics, including exercise programs, educational programs, and instructional programs based on visual and verbal feedback have been researched (de Groot, Veeger, Hollander, & van der Woude, 2005; Degroot, Hollingsworth, Morgan, Morris, & Gray, 2009; I. Rice, Pohlig, Gallagher, & Boninger, 2013; L. Rice, Smith, Kelleher, Greenwald, & Boninger, 2014; Zwinkels, Verschuren, Janssen, Ketelaar, & Takken, 2014). A limited number of studies have explored training methods implementing motor learning concepts important to skill acquisition, performance, and retention for new manual wheelchair propulsion (I. Rice, Gagnon, Gallagher, & Boninger, 2010; I. Rice et al., 2013; MacPhee et al., 2004). Motor learning consists of many components, but one of the most effective approaches to skill acquisition is increasing the number of times a skill is practiced (Kitago & Krakauer, 2013; Korman, Raz, Flash, & Karni, 2003). Motor learning of wheelchair propulsion is a complex skill and involves many repetitions and training sessions for the task to be performed without much thought and with little error (Baddeley & Longman, 1978; Karni, 1996; Kitago & Krakauer, 2013; Lang et al., 2009).

Research interventions involving training wheelchair propulsion biomechanics commonly do not use new manual wheelchair users but instead use either experienced manual wheelchair users or able-bodied participants. Using able-bodied participants does not address many factors involved with training new manual wheelchair users, such as medical-related issues, lack of support and resources, adjustment psychologically, and dependence on proper wheelchair seating and positioning (Boninger, Baldwin, Cooper, Koontz, & Chan, 2000; Kotajarvi, Basford, An, Morrow, & Kaufman, 2006). Training introduced closer to the time a person receives his or her wheelchair has the potential to decrease or delay the incidence of overuse injuries and pain and improve overall wheelchair skills and propulsion efficiency, resulting in an increase in participation (Kilkens, Post, Dallmeijer, Seelen, & van der Woude, 2003).

Although a relationship between wheelchair propulsion and chronic overuse injuries is documented, clinical guidelines have been developed, and research has been conducted on different approaches, new manual wheelchair users are often given little information or training on how to propel their wheelchairs (Boninger et al., 2002). Few rehabilitation programs focus on manual wheelchair propulsion training, despite evidence that suggests the benefits of training (MacPhee et al., 2004). Clinicians often report no implementation of formalized protocols or evidence-based practice into wheelchair training rehabilitation because of time, cost, and lack of knowledge (Best, Routhier, & Miller, 2014). When training does occur, it tends to be basic wheelchair training (e.g., addressing wheelchair use, propulsion, and navigating obstacles) for an average of one to four hours during the entire rehabilitation stay (Best et al., 2014). This limited time would not allow for specific propulsion instruction or practice time. Manual wheelchair propulsion is a complex, novel task that requires training to promote an efficient and effective propulsion pattern (Vegter, de Groot, Lamoth, Veeger, & van der Woude, 2013).

There is a paucity of research investigating manual wheelchair propulsion training methods that implement motor learning concepts, specifically repetition-based training. Literature on existing training interventions and their effectiveness is limited and difficult to translate to clinical settings and to new manual wheelchair users. Developing evidence-based approaches to teaching wheelchair skills and proper propulsion for people with SCI is important to successful rehabilitation for everyday wheelchair use. The purpose of this pilot study was to test a manual wheelchair training program based on motor learning principles for manual wheelchair users with SCI. We hypothesized that, after participants received the wheelchair training intervention, they would increase push length (also referred to as push angle), use a semicircular push pattern, decrease push force, increase push efficiency, and improve wheelchair skills proficiency.

4.2 Methods

4.2.1 Participants

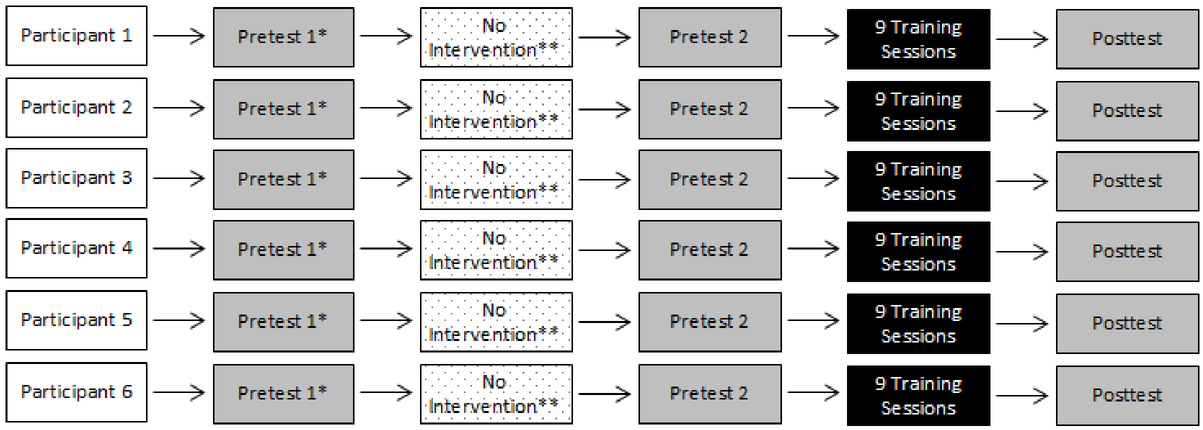
Six persons (four men, two women; average age, 38 ± 17.5) with an SCI or related neurologic condition requiring the use of a manual wheelchair were recruited through local rehabilitation facilities in a Midwestern area of the United States (Table 4.1). Fifty percent of participants reported still receiving outpatient rehabilitation services and that these services did not specifically address wheelchair propulsion or wheelchair skills. Participants were screened to ensure that they met the following inclusion criteria: were 18 years of age or older, had an SCI or related neurological condition requiring the use of a manual wheelchair, were considered not previously trained in wheelchair propulsion biomechanics, self-reported as being novice wheelchair users, and were able to self-propel a manual wheelchair. Participants also were required to provide informed consent. People were excluded from the study if they maneuvered their wheelchairs with their lower extremities or with only one arm. Participants were compensated for their time and effort. The project was approved by an institutional review board.

Table 4.1 Demographics of manual wheelchair users (N = 6)

Age	Average in years	38
	Range, years	20–69
Gender, n (%)	Male	4 (67)
	Female	2 (33)
Race, n (%)	White	3 (50)
	African American	2 (33)
Time using wheelchair	Average in months	12.3
	Range, months	6–18
Level of injury, n (%)	Cervical	2 (33)
	Thoracic	4 (67)
Receiving outpatient therapy, n (%)	Yes	3 (50)
	No	3 (50)

4.2.2 Procedure

A repeated measures within-subject design was used with participants acting as their own controls. Each participant completed a demographic survey during the first assessment. Two baseline measurements (Pretest 1 and Pretest 2) were taken three weeks apart and were followed by a nine-session intervention (wheelchair training program), then a Posttest (Figure 4.1). All assessment and training sessions took place in a community-based research facility. At each testing session (Pretest 1, Pretest 2, and Posttest), kinematics related to propulsion and wheelchair performance overground were measured. Kinetic propulsion variables and wheelchair skills were measured immediately before the intervention (Pretest 2) and immediately after (Posttest). Participants completed the nine-session training program over a timeframe of three to five weeks, completing two or three sessions per week.



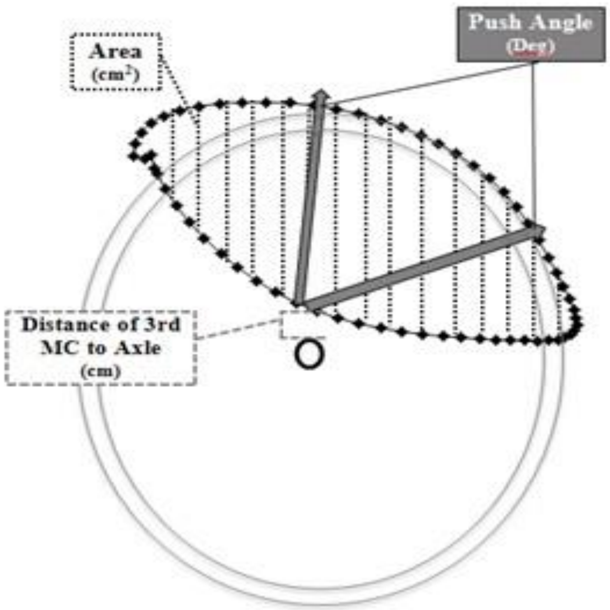
Note. *In Pretest 1, only kinematics that related to propulsion and wheelchair performance overground were tested. **Between Pretest 1 and Pretest 2, no intervention occurred for three weeks.

Figure 4.1 Research design: Within subject (repeated measures)

4.2.3 Outcome Measures

Propulsion Kinematics. A Video Motion Capture (VMC) system was used to collect kinematic data during propulsion. The VMC system (Motion Analysis Corporation) consisting of eight cameras was positioned to capture the movement of reflective markers placed on anatomical landmarks of each participants' third metacarpal and on the wheel axle of the participant's wheelchair as the participant propelled across the floor. The participant performed practice pushes across the 12-meter laboratory, and then three trials were recorded. The VMC recorded the motion as the participant propelled through the capture volume. By the time the participant entered the capture volume, he or she was propelling at a constant, self-selected normal speed (Stephens & Engsberg, 2010).

To quantify the motion of the participant's propulsion pattern, several variables were calculated (Figure 4.2). Each variable was calculated for the right arm and averaged across three pushes. Sagittal plane numerical data for the third metacarpal marker on the right hand were calculated relative to the marker placed on the axle of the right wheel. The propulsion phase was determined by measuring when the participant's third metacarpal was the same distance from the wheel axle as the wheel radius, indicating that the hand was in contact with the pushrim of the wheel (Julien, Morgan, Stephens, Standeven, & Engsberg, 2013). Recovery phase was considered when the hand was not in contact with the pushrim and was not moving forward.



Note. MC=Metacarpal.

Figure 4.2 Right hand push loop measurements designated by 3rd metacarpal

Three variables— area of the push loop, hand–axle relationship, and push angle—were compared across the three assessments. These three variables correspond to the recommendations outlined in the CPG (use of a semicircular propulsion pattern [area of push loop], bringing the hand down toward the axle during recovery [hand–axle relationship], and longer push strokes [push angle]; Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005). The area of the push loop (total area [cm^2]) represented the area made by the hand during the push and recovery phase. A positive area of the loop value indicates that the push loop is below the pushrim, and a negative value indicates that the area of the push loop during recovery is above the pushrim (Stephens & Engsberg, 2010). Hand–axle relationship was measured during the recovery phase and was defined as the distance of the third metacarpal from the axle at the closest point. Push angle was the angle in degrees between the points at which the hand contacted the pushrim and left the pushrim (Cowan, Nash, Collinger, Koontz, & Boninger, 2009). In addition, we classified the propulsion patterns found during all three assessments across all three trials of the VMC data according to four propulsion patterns described in the literature (Boninger et al., 2002; Stephens & Engsberg, 2010). The semicircular and double loop pattern most closely represents the CPG because, during the recovery phase of these two propulsion patterns, the hand moves down toward the direction of the wheel axle.

Propulsion Performance. The Wheelchair Propulsion Test (WPT) was used to measure push frequency and effectiveness while pushing overground over a smooth, flat surface (Askari, Kirby, Parker, Thompson, & O'Neill, 2013). The WPT also allows for observation and quantification of a participant's propulsion pattern. Participants were asked to propel 10 meters across a smooth, flat surface at a self-selected comfortable pace during Pretest 1, Pretest 2, and Posttest. A member of the research staff used a stopwatch to time how long it took each participant to propel across 10 meters and observed the propulsion pattern of the participant's right arm. The number of seconds (time) and the number of pushes (cadence) were recorded. The research staff member also answered two yes-or-no questions about the participant's hand placement during the push and recovery phases: (1) during the contact phases, did the participant generally begin the contact between the hands and the pushrims behind the top dead-center of the wheel? and (2) during the recovery phases, did the participant generally use a path of the hands that was predominantly beneath the pushrims? (Askari, et al., 2013). Variables calculated were contact (yes or no), recovery (yes or no), time to complete the 10 meters (seconds), the number of pushes needed to complete the 10 meters (cadence), speed (meters per second), push frequency (pushes per second), and push effectiveness (meters per push). The data collected from the WPT helped identify changes of propulsion performance pre- and post-intervention and how those changes related to the CPG of minimizing the frequency of pushes while retaining the same speed (Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005).

Propulsion Kinetics. The WheelMill System (WMS) is a computer-controlled wheelchair dynamometer roller system that has the ability to measure kinetic propulsion variables (Klaesner, Morgan, & Gray, 2014). The WMS measures the forces at the wheel–roller interface. A force from the WMS that is representative of the tangential force (F_t) was calculated from the motor control signal controlling the torque of the rollers (Klaesner et al., 2014). During Pretest 2 and Posttest, participants pushed for 30 seconds at a self-selected speed on the WMS. Peak force (the greatest amount of force [measured in Newtons]) and average force (measured in Newtons) were calculated across five pushes at a steady state. In addition, the slope of the smoothed calculated tangential force (Newtons per second) was calculated by taking a three point differentiation of the signal. A five-point moving average was used to smooth the signal. The local maximum slope for each of the five pushes was found, and these values were averaged across five pushes for each assessment (Pretest 2 and Posttest). The slope of the force was calculated to determine whether the load of force the participant applied to the pushrim changed post-training. The force variables (average force, peak force, and slope of the force) were used to identify whether the CPG of minimizing forces was met post-training (Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005).

Wheelchair Skills. The Wheelchair Skills Test (WST) version 4.2 was used to examine the participant's ability to safely complete wheelchair skills (e.g., propelling up and down ramps of varying slopes, turning in tight areas, maneuvering over curbs or obstacles of varying heights) in a controlled environment (Kirby, Swuste, Dupuis, MacLeod, & Monroe, 2002; Lindquist et al., 2010). The community research facility contained an indoor mobility skills course with obstacles that participants may encounter in the community (e.g., ramps, cross slope, and curbs of varying heights). Participants performed a series of tasks on the course and were scored on their completion of each task. Tasks were performed in order of difficulty. If a participant could not complete certain tasks, he or she was not asked to complete all tasks; for example, if a participant could not maneuver over a threshold-height obstacle, the participant was not tested on the different curb heights. A spotter strap was attached to the wheelchair in case the research team needed to intervene in an unsafe situation. A member of the research team scored each individual skill on a scale of 0 to 2, with 0 indicating that the skill was not completed, 1indicating that the skill was completed with difficulty, and 2 indicating that the skill was completed without difficulty (Kirby, Swuste, Dupuis, MacLeod, & Monroe, 2002; Lindquist et al., 2010). A wheelchair skill completion score (sum of scores ⁄ ([total number of skills – total number of skills not completed] x 2) x 100%) was calculated and compared across Pretest 2 and Posttest to identify changes in wheelchair skills.

Wheelchair Training Intervention. The training program was developed from current training methods and the best available evidence. The CPG recommend minimizing the force and frequency of pushes and using long strokes during propulsion (Boninger et al., 2005; Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005). The training program for manual wheelchair users was based on motor learning principles using a repetition-based approach to produce an efficient propulsion technique and to prevent chronic overuse injuries that limit independence for persons with SCI (Boudreau, Farina, & Falla, 2010; Dayan & Cohen, 2011; Lang et al., 2009; Nudo, 2006; Nyland et al., 2000).

The training program included nine 90-minute training sessions; training sessions were conducted two to three times per week. While increasing the number of practice repetitions is the emphasized component of motor learning in this study, other motor learning components that may affect skill performance and acquisition were also implemented (Kitago & Krakauer, 2013). Each training session included two propulsion practice sets and two opportunities to practice wheelchair skills (Table 4.2). Each session was organized to limit the number of variables presented to the participant at one time (Gevins et al., 1998; Schmidt & Wulf, 1997).

The primary focus of the training was propulsion biomechanics. Propulsion training was divided into two propulsion sets. Propulsion set A focused on using longer push strokes. Propulsion set B focused on dropping the hand down toward the axle. The two propulsion sets were randomized throughout training to maximize random practice. Participants were coached and cued throughout each session in order to correct propulsion form and provide extrinsic post-responsive information on propulsion movements. At the beginning of the training program, more cues were used; as the sessions progressed, the number of cues decreased (Goodwin, Eckerson, & Voll 2001). The trainer emphasized the participant's ability to self-identify when he or she needed to make a correction, having participants look in a mirror during their practice repetitions. All propulsion sets were completed on the WMS, and participants achieved 500–700 repetitions per session. After every three sessions, the number of repetitions per session increased (Sessions 1–3: 500 repetitions, Sessions 4–6: 600 repetitions, Sessions 7–9: 700 repetitions). Each participant completed 5400 repetitions by the end of the training program. Documentation in the research literature indicates that 300–800 repetitions per session turn a movement into a learned skill (Birkenmeier, Prager & Lang, 2010). After each propulsion set, the participant was taken off the WMS and the principles taught on the WMS were encouraged overground. However, the counted practice repetitions all occurred on the WMS.

Table 4.2 Training session outline

Time (min.)	Training
0:00–15:00	Check in, intro to training, review of last session
15:00–25:00	Propulsion A or B (250–350 reps)
25:00–45:00	Wheelchair skill practice
45:00–50:00	Break
50:00–60:00	Propulsion A or B (250–350 reps)
60:00–80:00	Wheelchair skill practice
80:00–90:00	Wrap up, schedule next session

The secondary goal of the training program was improvement of wheelchair skills. The wheelchair skills introduced during each session were used to vary the practice schedules of movement, provide external focus of attention, and further educate participants on valuable wheelchair skills. Wheelchair skills included in the sessions included basic wheelchair maintenance, backward propulsion, maneuvering tight spaces, opening and closing doors, going up and down ramps, pushing across a cross slope, going over curbs and bumps, and performing a wheelie. The portions of the training program that involved propulsion and maneuvering environmental obstacles were first taught on the WMS, which simulates the resistance and wheelchair position of surfaces such as ramps and cross slopes (Figure 4.3). The device provides an opportunity to safely train participants on propulsion techniques and obstacle manipulation while in a secure position, allowing participants to focus solely on the technique of each skill. Once these skills were introduced on the WMS, participants were transitioned onto the actual surfaces for additional training to introduce navigation of obstacles in the actual environment (Braun, Aertsen, Wolpert & Mehring, 2009). The additional training included pushing across ramps of varying slopes (up and down) and pushing over different surfaces (carpet, tile, gravel) using the techniques taught on the WMS. These ramps and surfaces were all located in and around the testing facility.

Note. Participant pushing on a cross slope simulated by the WMS (left picture). Participant pushing outside over a cross slope (right picture).

Figure 4.3 Cross slope practice

4.2.4 Data Analysis

Customized Microsoft Excel spreadsheets were used to process all project data (Microsoft, 2011). VMC data were tracked and edited using motion analysis software (Cortex 2.1, 2010). We used SPSS version 21 on a Windows-based computer for data analysis (SPSS Inc., 2012). A repeated measures analysis of variance (ANOVA) was used to determine whether there were significant differences in the wheelchair kinematic variables and the wheelchair performance variables across three testing times ($p < 0.05$). Mauchly's test of sphericity was used to test whether the assumption of sphericity was met. For the repeated measures ANOVA results, the assumption of sphericity was met ($p > 0.05$) for all variables. The Bonferroni *post hoc* tests were used to determine which assessments differed from one another. A paired t-test was used to determine significant differences in the wheelchair push force variables (WMS), and wheelchair skills (WST) variables between Pretest 2 and Posttest ($p < 0.05$). Effect sizes (partial η^2) were calculated to determine the magnitude of differences before and after wheelchair training. Individual results were also reported to identify inter-variability and intra-variability across participants and assessments.

4.3 Results

Six participants completed the three assessments and each of the nine training sessions. Below are group comparison results and overall trends of individual results.

4.3.1 Group Comparison

Propulsion Kinematics. Two of the three wheelchair push kinematics variables collected by the VMC system were found to be significant (Table 4.3). The wheelchair training intervention elicited significant changes in the area of the push loop, $F(2, 10) = 9.8$, $p < 0.01$, partial $\eta^2 = 0.66$, with the area remaining consistent between the two pretest measurements (34.8 cm^2 and 27.0 cm^2) and increasing post-intervention (336.67 cm^2; see Table 4.3). The area was a positive value, indicating that the hand motion during recovery was below the pushrim (or toward the wheelchair axle). *Post hoc* analysis revealed that the area of the push loop significantly increased ($p = 0.05$) from Pretest 2 to Posttest, with a mean difference of 309.7 cm^2 (95% CI, 5.7 to 613.6). The wheelchair training intervention also elicited significant changes in the hand–axle relationship pre- and post-intervention, $F(2, 10) = 5.2$, $p = 0.03$, partial $\eta^2 = 0.51$, with the distance between the third metacarpal and the wheel axle decreasing during recovery between the Pretest and Posttest assessments. *Post hoc* analysis showed no significant changes between each of the assessment points. The wheelchair training intervention did not elicit significant changes in push angle pre- and post-intervention, $F(2, 10) = 3.6$, $p = .07$, with the push angle increasing during the push phase between the Pretest and Posttest assessments. However, push angle did not increase for all participants.

Table 4.3 Repeated measures ANOVA: Wheelchair kinematics and wheelchair performance

Wheelchair kinematics (VMC)	Pretest 1	Pretest 2	Posttest
Area of the loop (cm^2)$^{*+}$	34.8(191.8)	27.0(227.1)	336.6(247.5)
Hand–axle relationship (cm)*	26.1(5.1)	27.1(4.5)	19.3(7.3)
Push angle (degrees)	76.8(11.3)	76.1(8.0)	85.6(11.2)
Wheelchair performance (WPT)			
Contact (yes or no)	0.8(0.4)	0.8(0.4)	1.00(0.00)
Recovery (yes or no)*	0.2(0.4)	0.2(0.4)	0.8(0.4)
Time to complete 10m(s)$^{*+}$	10.8(3.1)	11.5(2.6)	9.7(2.0)
Cadence (pushes)$^{*+}$	10.8(2.5)	11.0(2.5)	9.3(2.3)
Speed (m/s)$^{*+}$	0.98(0.24)	0.90(0.18)	1.07(0.19)
Push effectiveness (m/push)*	0.96(0.21)	0.95(0.21)	1.12(0.24)
Push frequency (push/s)	1.02(0.20)	0.96(0.1)	0.96(0.06)

Note. Mean score(standard deviation); *p < 0.05; $^{+}$Bonferroni significant between Pretest 2 and Posttest.

Propulsion Performance. Five of the seven WPT variables were found to be significant (see Table 4.3). The recovery item on the WPT (defined as bringing the hand below the pushrim toward the axle during the recovery phase of the push cycle) was found to be significant ($p < 0.01$, partial $\eta^2 = 0.67$). Prior to the wheelchair training program, only one participant brought his or her hand below the pushrim toward the axle during the recovery phase of the push cycle. After training, all but one participant brought their hands below their pushrims during the recovery phase. The wheelchair training intervention elicited significant changes in the time it took to complete 10 meters, $F(2, 10) = 10.3$, $p < 0.01$, partial $\eta^2 = 0.67$. *Post hoc* analysis revealed that the time to complete the 10 meter test significantly decreased ($p = 0.01$) from Pretest 2 to Posttest, with a mean difference of 1.8 seconds (95% CI, 0.75 to 2.9). The wheelchair training intervention elicited significant changes in the number of pushes (cadence) needed to push 10 meters, $F(2, 10) = 5.9$, $p = 0.02$, partial $\eta^2 = 0.54$. *Post hoc* analysis revealed that the number of pushes to complete the 10 meter test significantly decreased (p=0.03) from Pretest 2 to Posttest with a mean difference of 1.7 pushes (95% CI, 0.18 to 3.2).The wheelchair training intervention elicited significant changes in the speed (meters per second) to push the 10 meters, $F(2, 10) =$

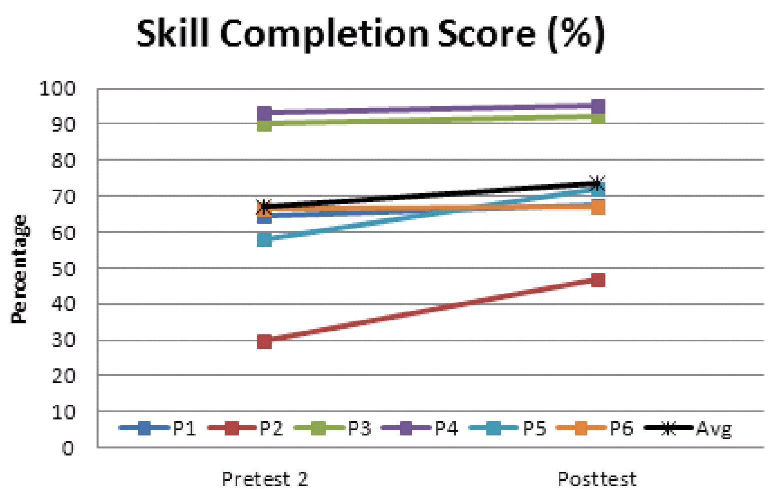
11.39, p <0.01, partial $\eta^2 = 0.70$. *Post hoc* analysis revealed that the speed across the 10 meter test significantly increased (p< 0.01) from Pretest 2 to Posttest, with a mean difference of 0.16 meters per second (95% CI, 0.24 to 0.10). The wheelchair training intervention elicited significant changes in the push effectiveness (meters per push) across the 10 meters, $F(2, 10)$ = 4.33, p <0.04, partial $\eta^2 = 0.46$. *Post hoc* analysis showed no significant changes between each of the assessment points. The wheelchair training intervention did not elicit significant changes in push frequency (pushes per second) before and after intervention, $F(2, 10) = 0.45$, $p = 0.65$. The push contact item of the WPT (defined as a long push stroke achieved by reaching back before the top dead-center of the wheel to initiate a push) was not significant (p = 0.40). All but one participant in the Pretest assessments initiated his or her push before the top dead-center of the wheel. After the wheelchair training intervention, all participants initiated pushes before the top dead-center of the wheel.

Propulsion Kinetics and Wheelchair Skills. The slope of the force elicited a significant decrease (p = 0.03) of 34.3 N/s (95% CI, 5.2 to 63.4) post-intervention (Table 4.4). Participants' forces (average and peak) decreased after the wheelchair training intervention (Table 4.4). However, no significant difference was found for average force (p = 0.10) or peak force (p = 0.13) in the paired t-test results. Wheelchair skills as measured by the WST also showed no significant difference (p = 0.08; see Table 4.4). All participants' wheelchair skills scores increased from Pretest 2 (67%) to Posttest (73%); two participants had increases of approximately 14–17%, and two participants already had high scores (i.e., 90% and 94%) before starting the training (Figure 4.4).

Table 4.4 Paired t-test: Wheelchair push forces and wheelchair skills

Wheelchair push forces (WMS)	Pretest 1	Pretest 2	Posttest
Average force (N)	—	10.9(4.5)	8.0(4.3)
Peak force (N)	—	20.6(8.6)	16.4(8.4)
Slope of the force (N/s)*	—	149.1(72.1)	114.8(56.6)
Wheelchair skills (WST)			
Skill completion score (%)	—	67.1(23.2)	73.45(18.0)

Note. Mean score(standard deviation); *p < 0.05.

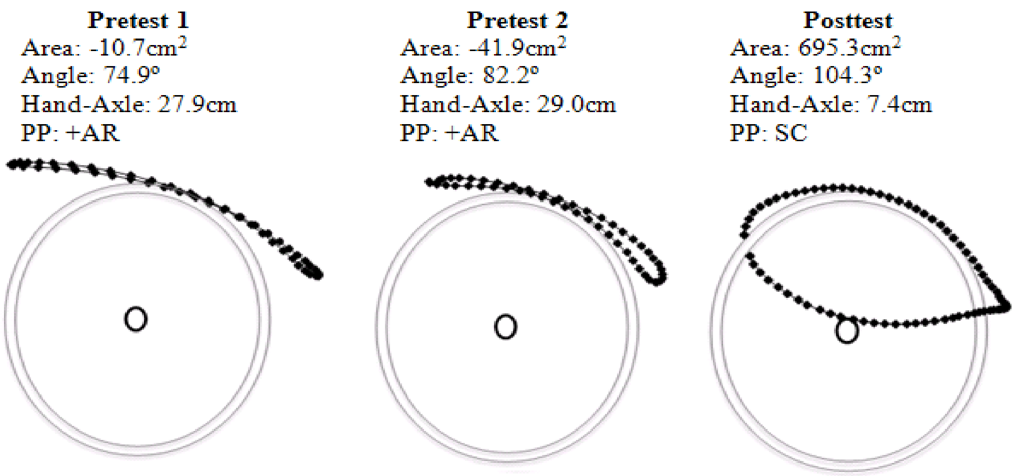


Note. P=Participant.
Figure 4.4 Wheelchair skills test scores

4.3.2 Individual Results

Three distinct groupings of kinematic results emerged among the participants: (1) changes in all three of the kinematic variables (i.e., area of the push loop, hand–axle relationship, and push angle) pre-and post-intervention; (2) changes in at least one kinematic variable; and (3) consistent variables across each assessment. Each of these groupings is described below in detail.

Two participants, Participants 1 and 3 (female, thoracic level of injury; male, thoracic level of injury) made kinematic changes in all three propulsion variables, which included increases in area of the push loop and push angle and decreases in distance from the hand marker to the wheel axle during the push recovery phase (example Participant 1; Figure 4.5). These two participants (Participants 1 and 3) changed their propulsion pattern to a semicircular or double loop pattern post-intervention (Table 4.5). Participants 1 and 3 also decreased the number of pushes and the amount of time it took to complete the 10-meter test and decreased their average force, max peak force, and slope of force pre-and post-intervention. However, their wheelchair skills scores remained consistent before and after the wheelchair training intervention.



Note. Area=area of the push loop; Angle=Push angle; Hand-Axle=Hand to axle relationship; PP=Propulsion pattern; +, hand did not drop below pushrim during recovery.

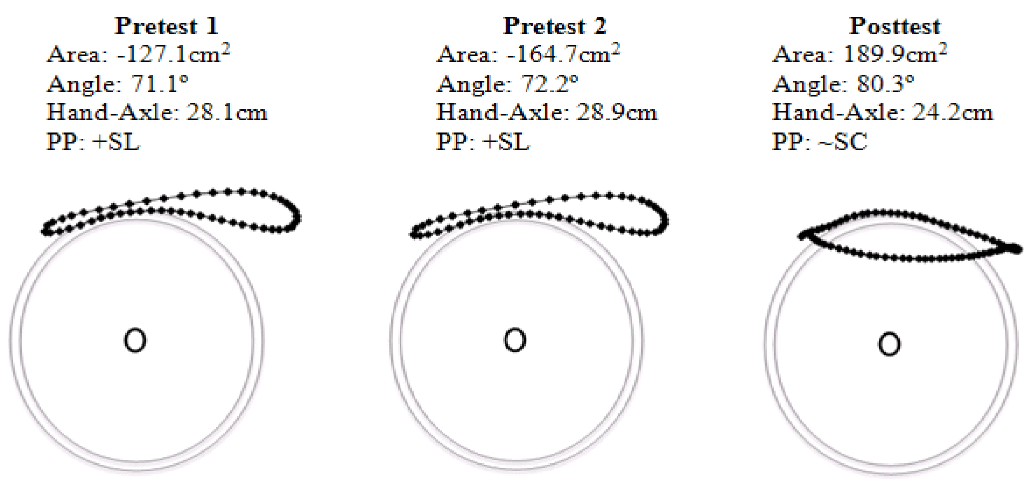
Figure 4.5 Participant 1: Wheelchair push kinematic measurements

Table 4.5 Propulsion patterns pre and post wheelchair training

Participant	Pre1T1	Pre1T2	Pre1T3	Pre2T1	Pre2T2	Pre2T3	PostT1	PostT2	PostT3
1	+AR	+AR	+AR	+AR	+AR	+AR	SC	SC	SC
2	~+AR	+AR	+AR	~+AR	~+AR	~+SL	~DL	~DL	~DL
3	~+SL	~+SL	~+SL	~+AR	~+AR	~+AR	DL	DL	DL
4	DL	DL	DL	DL	DL	DL	SC	SC	SC
5	+SL	DL	DL	+SL	+SL	+SL	~DL	~SC	SC
6	~+SL	~+SL	~+SL	+SL	~+AR	~+SL	~+AR	~SC	~SC

Note. Pre1=Pretest 1, Pre2=Pretest2, Pre3=Pretest3; T=trial; DL, double loop over pattern; SC, semicircular pattern; AR, arc pattern; SL, single loop over pattern; +, hand did not drop below pushrim during recovery; ~, inexact pattern match.

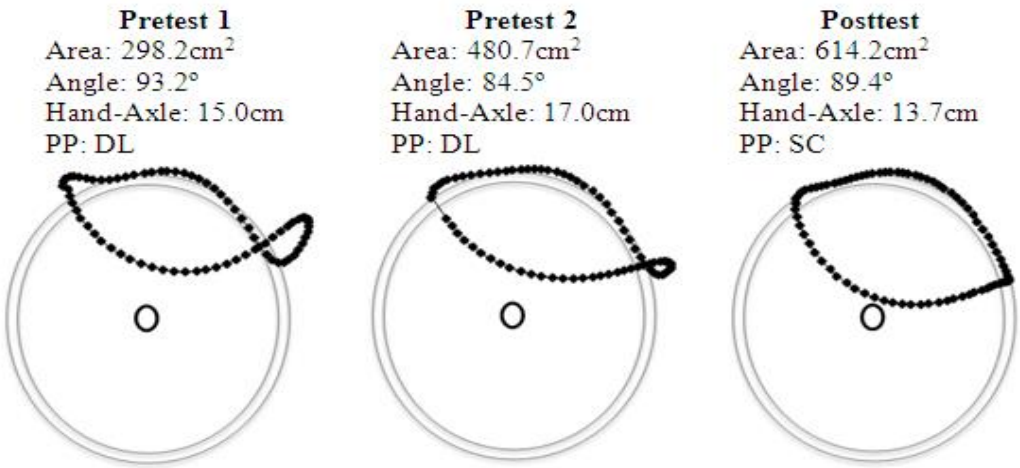
Three participants (female, cervical level of injury; male, cervical level injury; and male, thoracic level of injury) made changes in at least one of the kinematic variables (example Participant 5; Figure 4.6). All three of these participants (Participants 2, 5 and 6) changed their propulsion pattern post-intervention to either a double loop or semicircular pattern. Participant 2 decreased the number of pushes and the amount of time to complete the 10-meter test and increased her speed; the other two participants had consistent push performance across assessment times. Participants 5 and 6 decreased forces and slope of the forces pre-and post-intervention, and Participant 5 had consistent force values pre-and post-intervention. Participants 2 and 6 increased wheelchair skills, and Participant 5 made no improvements in wheelchair skill proficiency.



Note. Area=area of the push loop; Angle=Push angle; Hand-Axle=Hand to axle relationship; PP=Propulsion pattern; +, hand did not drop below pushrim during recovery; ~, inexact pattern match.

Figure 4.6 Participant 5: Wheelchair push kinematic measurements

One participant (male, thoracic level of injury) displayed biomechanics as described by the CPG both pre- and post-intervention. He increased the area of the push loop post-intervention (Participant 4; Figure 4.7). This participant (4) changed from a double loop pattern to a semicircular pattern post-intervention. His wheelchair push performance (WPT) remained consistent before and after intervention. His force values decreased after intervention. He had a high wheelchair skill completion score on the WST pre-intervention and, therefore, experienced no change in the score post-intervention.



Note. Area=area of the push loop; Angle=Push angle; Hand-Axle=Hand to axle relationship; PP=Propulsion pattern.

Figure 4.7 Participant 4: Wheelchair push kinematic measurements

4.4 Discussion

The primary purpose of this investigation was to pilot-test a manual wheelchair training program for new manual wheelchair users with SCI. We found indications of changes in propulsion that follow the recommended CPG (Paralyzed Veterans of America Consortium for Spinal Cord Medicine, 2005). However, this study had many limitations, including a small sample size and heterogeneity (length of injury and level of injury) of the participants recruited. The small sample size and range in length of injury were the result of difficulty recruiting new manual wheelchair users; in part, this was because of difficulty recruiting participants who were medically stable and emotionally ready to work on wheelchair skills and because of lack of resources to support potential participants in getting to and from the training sessions (Best et al., 2014; Mitchell, Jin, Kim, Giesbrecht, & Miller, 2014). Duration of injury did not always equate to duration of wheelchair use. For example, the participant who had been injured for 36 months reported not independently using her manual wheelchair since she received it. She relied on her daughter to push her wheelchair for her. Even though she was 36 months post-injury, she was a new independent manual wheelchair user when she entered the training program. This study had a small sample design, with participants serving as their own controls, which can be useful for evaluating changes following an intervention, especially when participants have significant individual variability (Korn, McShane, & Freidlin, 2013; Ottenbacher, 1990). However, an experimental design with a larger sample size, random selection, and a control group would permit the use of a more powerful statistical approach. A methodological limitation of the study was that the kinematic data and kinetic (force data) were collected on different surfaces. The force data were collected on a wheelchair roller system, so the force data may not be representative of overground propulsion.

All six participants made changes related to the CPG. Some participants made changes across all variables and others just a few of the variables. The significant results from the area of the push loop and the hand to axle relationship (from the VMC data) and the recovery item (on the WPT) indicate changes in the propulsion patterns, with participants bringing their hands down towards the axles of their wheelchairs. This was further indicated by classification of propulsion patterns exhibited by each participant across all assessments and trials (see Table 4.5). The changed propulsion pattern toward a semicircular and/or double loop pattern meets part of the CPG recommendations. Significant changes in push effectiveness and speed as measured by the WPT may be related to the changes in propulsion pattern. The significant decrease in the slope of the force post-intervention may indicate a decrease in the rate of loading the force onto the pushrim. A few of the reasons push angle and average and peak forces were not significant include wheelchair positioning issues, variability in injury level, one participant having good biomechanics to start, and some participant inconsistencies across assessments and training. Even though these variables were not significant, changes were made across participants, with two participants making dramatic changes in each of these variables. The secondary purpose of the study was to identify whether the person's ability to complete wheelchair skills independently and safely improved after receiving the training. No significant difference was found in wheelchair skill proficiency before and after wheelchair training intervention. Several reasons for this could be attributed to a ceiling effect (two participants started the intervention with high scores), the fact that only 20 out of the 32 items on the WST were addressed during training, and that some of the advanced skills (e.g., wheelies) may require more training time than was allotted.

Manual wheelchair training studies often use able-bodied participants to study the impact of training on new manual wheelchair users (van der Woude, van Croonenborg, Wolff, Dallmeijer, & Hollander, 1999; Vegter et al., 2013) or use experienced wheelchair users (Degroot et al., 2009; I. Rice et al., 2013). The results from such studies may be difficult to translate to new wheelchair users, because wheelchair positioning may not have as much of an impact on propulsion biomechanics for an able-bodied person, and more experienced users may be positioned more optimally for propulsion. Wheelchair positioning is not always optimal for proper biomechanics for new wheelchair users receiving their first wheelchair, with common issues being maneuverability and use of the wheelchair across environments (Kittel, Marco, & Stewart, 2002). Some participants in this study experienced wheelchair positioning that prevented them from fully implementing the training recommendations. For example, one participant was seated high in the wheelchair to make transfers in and out of the wheelchair easier, but this made it difficult for her to drop her hands toward the axle during the recovery phase of her push. However, she did increase her push angle and overall wheelchair performance overground. Previous studies have addressed some of the pain and chronic overuse injuries of manual wheelchair users by modifying the wheelchair and the person's position relative to the wheelchair (Boninger et al., 2000; Kotajarvi et al., 2006). Results suggest that wheelchair seating and positioning have an impact on biomechanics and wheelchair skills.

The results of this project are similar to those found in previous wheelchair training research. Studies using components of motor learning, such as visual feedback, found subtle changes in propulsion biomechanics, including longer slow push patterns similar to the changes found in this study (de Groot et al., 2005; Kotajarvi et al., 2006; I. Rice et al., 2013; Vegter, Lamoth, de Groot, Veeger, & van der Woude, 2014). Across studies, variables associated with push forces have varied in response to wheelchair propulsion interventions, including decrease in push force, increase in push force, and no change in push force (Degroot, et al., 2009; Kotajarvi et al., 2006; I. Rice et al., 2013). We did not find significant change related to average or peak force, but did find change in the slope of the force. The WPT results found in this study were similar to those of new wheelchair users' median results reported in a previous study (Askarai, et al., 2013). The main focus of this study was wheelchair propulsion biomechanics, with a secondary emphasis on wheelchair skills. Although there was some indication of change in wheelchair skills (7% increase), the results were not significant. Studies solely focused on wheelchair skills have had significant changes, with increases up to 25% in wheelchair skills scores on the WST post-intervention (MacPhee et al., 2004).

The wheelchair training intervention described in this paper included wheelchair propulsion training and wheelchair skills training. Other interventions tended to focus on either teaching propulsion techniques or wheelchair skills. The duration of the wheelchair training intervention included nine 90-minute sessions. Other wheelchair training interventions ranged from one visit total to seven weeks consisting of two to three visits per week (de Groot, De

Bruin, Noomen, & van der Woude, 2008; Vegter et al., 2014). Studies using exercise and motor learning approaches were longer in duration (I. Rice et al., 2013; Vegter et al., 2014). The number of sessions and the amount of time per session for this study were necessary for the repetition-based approach and focused on turning proper biomechanics into a learned motion (Baddeley & Longman, 1978). Each session consisted of 500 to 700 total practice repetitions for a total of 5,400 repetitions by each participant at the completion of the wheelchair training intervention. The number of practice propulsion repetitions during rehabilitation for manual wheelchair users with SCI is unclear. Recommendations of 300 to 800 practice repetitions per session for skill acquisition has been documented in the neurorehabilitation literature (Birkenmeirer, et al., 2010). The number of practice repetitions offered in this study falls within that range. All participants tolerated and completed the number of repetitions per session

This is one of few manual wheelchair training studies to use components of motor learning and provide instruction-based interventions with relatively new manual wheelchair users with SCI. This study confirms the importance of wheelchair seating and positioning in conjunction with wheelchair training. The CPG provide recommendations based on research for clinicians to follow when teaching wheelchair propulsion biomechanics but no information on how to teach these recommendations. A validated wheelchair training protocol, the Wheelchair Skills Training Program (WSTP), provides an approach to teaching wheelchair biomechanics and background on motor learning, stating the importance of practice but indicates that the specific amount of practice varies (Coolen et al., 2004; Best, Kirby, Smith, & MacLeod, 2005; MacPhee et al., 2004). Furthermore, clinicians report that they rarely use validated protocols when teaching wheelchair skills during rehabilitation (Best et al., 2014). The results of this study indicate that new manual wheelchair users can tolerate up to 700 practice propulsion repetitions per session and that approximately 5000 repetitions contribute to changes in propulsion patterns. This instruction was provided by a clinician and did not require a computer system with feedback. More research is needed to understand “dosing,” or the number of repetitions needed to promote the propulsion techniques described in the CPG. As rehabilitation advances, it is important that clinicians use evidence-based practices, such as training programs based on motor learning principles (Wulf, Shea, & Lewthwaite, 2010).

Future research is needed to further test repetition-based wheelchair training with a more rigorous research design, to measure kinematics and kinetics at the same time overground, and to examine the retention of propulsion biomechanics and skills after the training sessions. Additionally, other factors involved in motor learning, the rate at which new wheelchair users learn, and the involvement of depression, motivation, and cognitive processing in the motor learning process should be evaluated in relation to the training program. Future studies should include a review of wheelchair positioning and allow for adjustments prior to the training. In conjunction with wheelchair seating setup, practicing the proper push biomechanics through repetition-based training may promote the use of the recommended and researched biomechanics.

4.5 Conclusions

This project identified trends in change related to a repetition-based motor learning approach for propelling a manual wheelchair. The changes found were related to the propulsion pattern of the participants. Studying manual wheelchair use with new manual wheelchair users has potential for change and preventing or reducing pain and chronic overuse injuries. However, there are many challenges associated with the implementation of interventions with new manual wheelchair users. The results of this study have clinical implications, as the motor learning principles used in the training program developed during this research could be applied to wheelchair skills training during rehabilitation.

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Chapter 5: Conclusion

5.1 Summary of Major Findings

The goal of this dissertation was to better understand methodologies related to training new manual wheelchair users how to efficiently and effectively use their wheelchairs. To this end, we investigated (1) the accuracy of a wheelchair device to assess and simulate overground propulsion, (2) the current state of wheelchair training for new wheelchair users and recommendations for future areas of focus, and (3) the impact of repetition-based training on new manual wheelchair user's propulsion biomechanics. A mixed methods approach was implemented, with quantitative data collected in Chapters 2 and 4 and qualitative data in Chapter 3. This approach assisted in collecting data that provided both a rich, detailed picture of wheelchair training and methods for testing devices and procedures for training. Major findings of each section, within the context of current literature, are as follows.

5.1.1 Chapter 2

Belted treadmills, rollers, and ergometers that are commonly used for research and clinical purposes vary in the propulsion experiences for the wheelchair user. Some devices offer a comparable experience to an individual's actual propulsion pattern in the environment, and some may not (Koontz, Worobey, Rice, Collinger, & Boninger, 2012; Kwarciak, Turner, Guo, & Richter, 2011; Mason, Lenton, Leicht, & Goosey-Tolfrey, 2014; Stephens & Engsberg, 2010). Few of these devices simulate real-life conditions (e.g., changes in surface and speed) encountered by manual wheelchair users during their participation in everyday activities (Kwarciak et al., 2011; Mason et al., 2014). In addition, many of these devices are not able to assess variables related to manual wheelchair propulsion, such as force. Often, additional instruments such as force-sensing wheels are needed (Cooper, 2009; Guo, Kwarciak, Rodriguez, Sarkar, & Richter, 2011).

In Chapter 2, we tested the WheelMill System (WMS), a motor-driven dynamometer roller system, for its accuracy in simulating surfaces and quantifying propulsion variables. Three studies have compared overground propulsion to a device; two of the studies found differences between overground and devices such as rollers and belted treadmills (Koontz et al., 2012; Stephens and Engsberg, 2010). However, Kwarciak and colleagues (2011) reported a motor-driven belted treadmill to have similar kinetic propulsion variables as overground. We found the WMS to be comparable to overground in some wheelchair propulsion variables but not all. When pushing overground, participants generally pushed at a faster rate, with greater force, and with a slightly shorter push length than they did on the WMS. Kinematic and kinetic comparisons between actual ramps and simulation on devices are limited (Koontz et al., 2005; Sabick, Kotajarvi, & An, 2004). When we looked at the WMS in comparison to ramps, users had a higher cadence, faster speed, and much higher force on the ramps than on the WMS. Pushing on an actual ground or ramp surface has a goal, so users may push faster to reach their goal destinations. The software model on the WMS could be adjusted to require higher forces, but there are no consequences (i.e., rolling backward if the force of propulsion is not great enough) on the WMS as there are when pushing on an actual ramp.

Currently, in research and in the clinic, force-sensing wheels are used to measure propulsion forces (Boninger, Cooper, Robertson, & Shimada, 1997; Boninger et al., 2002; Guo et al., 2011; Kotajarvi, Basford, An, Morrow, & Kaufman, 2006). The use of an instrumented wheel has some limitations, including cost, wheel size, participants using a wheel with a pushrim that may be different from their own, and the measurement of force only as applied directly to the pushrim. The WMS measures tangential force during the push phase similarly to that measured by an instrumented wheel. However, the WMS measures the force applied to the motors by the wheels of the wheelchair via the rollers, whereas instrumented wheels such as the SmartWheel and the Optipush measures the force applied to the pushrim (Asato, Cooper, Robertson, & Steer, 1993; Guo et al., 2011). The benefits of using the WMS to measure force include the ability to measure the push force on wheelchairs with wheels of any size and the ability to measure force regardless of where the wheelchair user applies force to the wheel. The WMS does not have the ability to measure the resultant force, whereas an instrumented wheel has the ability to measure different forces acting upon the pushrim (Boninger et al., 2002). The WMS senses forces applied by the wheelchair to the rollers; tangential force applied by the user to the wheelchair pushrims is sensed by the motors during the push phase and can be measured. Other forces, such as changes in position or center of gravity, can also be sensed by the WMS motors. The tangential forces measured by the WMS were similar to the tangential forces measured by the SmartWheel. However, during the recovery phase, the force on the WMS and the SmartWheel differed. This force detected by the WMS during recovery may include forces placed on the roller by the wheel and may be related to the participant repositioning or shifting his or her center of gravity in preparation for the next push. This data may be useful in identifying participants who use their core or trunk during a propulsion cycle.

5.1.2 Chapter 3

During initial rehabilitation, the implementation of wheelchair training to achieve an optimal level of wheelchair skill performance is important (Best, Miller, & Routhier, 2014). Evidence suggests that training offered during rehabilitation is beneficial and influences the ability of wheelchair users to use their wheelchairs throughout their daily activities (Öztürk & Ucsular, 2011). Discrepancies in rehabilitation priorities often exist between health care professionals and consumers (Simpson, Eng, Hsieh, & Wolfe, 2012). Limited information exists in the literature on the perspectives of health care professionals and manual wheelchair users on the wheelchair training process during rehabilitation for people with SCI. The results of this project provide a unique perspective of the two key players in wheelchair training during rehabilitation: the health care professional and the manual wheelchair user. While there were many commonalities in the themes identified by both groups, there were also some discrepancies or instances in which one group emphasized the importance of a specific wheelchair skill more than the other group.

Previous research provides varying descriptions of the amount of wheelchair training offered during rehabilitation, ranging from little to no training to more thorough and deliberate training offered over numerous therapy sessions (Boninger et al., 2002; Taylor et al., 2014). The experiences of wheelchair training during rehabilitation described by manual wheelchair users in this study are similar to those described in the literature. Manual wheelchair users in the focus groups reported differing experiences related to the amount of training received, with half of the sample reporting that they received either no training or a great deal of training and the other half of the sample reporting that they received a moderate amount of training.

The most common skills taught in rehabilitation as reported in the literature are transfers, wheelies, propulsion techniques, navigating different surfaces, and going up slopes (Kilkens, Post, Dallmeijer, Seelen, & van der Woude, 2003; Taylor et al., 2014). During this study, transfers in and out of the wheelchair (e.g., to the bed, shower, or car) were repeatedly mentioned as a skill taught during rehabilitation. Wheelies were not mentioned often by health care professionals or manual wheelchair users as being taught during rehabilitation. Techniques for propelling a wheelchair were introduced but not explained or practiced, as reported by manual wheelchair users in the focus groups. Focus group participants did report some practice with maneuvering obstacles and going up and down ramps. A disconnect between what wheelchair training is occurring in rehabilitation and what health care professionals and manual wheelchair users think should occur was identified. Three of the areas that were identified in the focus groups that are not adequately addressed but should be are: training in the environment, addressing and accommodating a psychological adjustment period, and teaching not just wheelchair use, but also how to care for and maintain the wheelchair. The results of this study have important implications for health care professionals working with people who use manual wheelchairs. Identifying essential components for training proper propulsion mechanics and wheelchair skills in new manual wheelchair users is an important step in preventing future health and participation restrictions.

5.1.3 Chapter 4

Finally, we wished to examine the use of repetition-based training on the biomechanics of wheelchair users. The results of this project are similar to those found in previous wheelchair training research. Studies using aspects of motor learning such as visual feedback found subtle changes in propulsion biomechanics, including longer, slower push patterns similar to the changes found in this study (de Groot, Veeger, Hollander, & van der Woude, 2005; Kotajarvi, Basford, An, Morrow, & Kaufman, 2006; Rice, Pohlig, Gallagher & Boninger, 2013; Vegter, Lamoth, de Groot, Veeger, & van der Woude, 2014). We found significant changes in the area of the push loops and the hand to axle relationships. Across studies, variables associated with push forces have varied in response to wheelchair propulsion interventions, including decreases in push force, increases in push force, and no change in push force (Degroot, Hollingsworth, Morgan, Morris, & Gray, 2009; Kotajarvi et al., 2006; Rice et al., 2013). We did not find significant change related to average or peak forces, but did find significant changes in the slope of the force. The Wheelchair Propulsion Test (WPT) results found in this study were similar to those of new wheelchair users' median results reported in a previous study (Askarai, Kirby, Parker, Thompson, & O'Neill, 2013). The main focus of this study was wheelchair propulsion biomechanics, with a secondary emphasis on wheelchair skills. Although there was some indication of change in wheelchair skills, the results were not significant. Studies solely focused on wheelchair skills have shown significant increases in wheelchair skills scores post-intervention (MacPhee et al., 2004).

Manual wheelchair training studies often use able-bodied participants to study the impact of training on new manual wheelchair users (van der Woude, van Croonenborg, Wolff, Dallmeijer, & Hollander, 1999; Vegter, de Groot, Lamoth, Veeger, & van der Woude, 2013) or experienced wheelchair users (Degroot et al., 2009; Rice et al., 2013). The results from such studies may be difficult to translate to new wheelchair users because wheelchair positioning may not have as much of an impact on propulsion biomechanics for an able-bodied person, and more experienced users may be positioned more optimally for propulsion. Wheelchair positioning is not always optimal for proper biomechanics in new wheelchair users receiving their first wheelchairs, with common issues being maneuverability and use of the wheelchair across environments (Kittel, Marco, & Stewart, 2002). This was one of many challenges found in implementing a training intervention with new manual wheelchair users.

5.2 Significance and Clinical Implications

Manual wheelchair biomechanics research is extensive in identifying different propulsion patterns and in measuring push forces. Research is more limited in interventions for addressing poor biomechanics and application to clinical settings. Specifically, devices to provide training and collect data may not be optimal, and new manual wheelchair users receive a limited amount of training. The significance of the research in Chapters 2 through 4 is that it provides more information on devices, manual wheelchair and health care professional perspectives on training, and a motor learning approach that uses instruction and repetition-based training to facilitate more efficient and effective propulsion habits.

Chapter 2 discusses the WMS, which has many possible clinical applications in that it has the ability to simulate different resistive surfaces while placing the wheelchair in a realistic position. The WMS is also able to assess propulsion variables, making it useful for research purposes. The WMS is one of few devices that allow a person to use his or her own wheelchair without the need of an instrumented device, allows for the placement of the wheelchair in different positions, and can control different parameters for simulation. This device clinically could provide opportunities for training wheelchair users in propulsion and body position.

Chapter 3 provides a view of wheelchair training interventions from the perspectives of health care professionals and manual wheelchair users. Reviewing what is being covered in rehabilitation related to wheelchair skills training and what should be emphasized may provide information to assist health care professionals in identifying ideas about other possible approaches in wheelchair skills training. The project specifically highlights manual wheelchair skills identified as important for new wheelchair users to learn. With limited time during rehabilitation, select skills identified as important for new manual wheelchair users could be the focus. Formalized wheelchair training protocols could be utilized as a guide for health care professionals on how to teach the skills they have chosen to address during rehabilitation. The results of this study help to identify important manual wheelchair skills that need further examination for ranking of importance and how best to teach them. This information may guide alternative approaches to providing further education and training about manual wheelchair use outside of initial rehabilitation.

Wheelchair skills are being addressed frequently during rehabilitation at the activity-dependent level. A desire for more effort and emphasis on training in context was expressed by health care professionals and wheelchair users. The results of this project provide information about important skills for new manual wheelchair users to learn including propulsion techniques, transfers in an out of the wheelchair, providing maintenance to the wheelchair, and navigating barriers such as curbs, ramps and rough terrain. Environment factors (in the home and community) are important to incorporate into wheelchair training to maximize safe use of manual wheelchairs in a variety of environmental settings. The ICF was useful in identifying themes and may have applications for understanding manual wheelchair rehabilitation for wheelchair users and therapists.

Chapter 4 describes the pilot-testing of one of few manual wheelchair training studies to use motor learning principles and provide instruction-based interventions with relatively new manual wheelchair users who have SCI. This study confirms the importance of wheelchair seating and positioning in conjunction with wheelchair training and the difficulty of implementing interventions with new manual wheelchair users. The results of this study indicate that new manual wheelchair users can tolerate up to 700 practice propulsion repetitions per session and that approximately 5000 repetitions contribute to changes in propulsion patterns. This instruction was provided by a clinician and did not require a computer system with feedback.

5.3 Limitations

An overall limitation across all three chapters is small sample size. With a small sample size, we could not use the most robust statistical approaches. For example, in Chapter 4, an experimental design with a larger sample size, random selection, and a control group would permit the use of a more powerful statistical approach. The health care professional and manual wheelchair samples in Chapter 3 represented only one geographic region. In Chapters 2 and 4, we did not control many factors, such as the speed of the participant; we had each participant propel at a self-selected speed, because trying to hold a certain speed could impact propulsion biomechanics. This may have resulted in lower correlations, because it is difficult (even over the same surface) to propel exactly the same way. In Chapters 2 and 4, we did not test kinematics and kinetics at the same time on the same surface. A methodological limitation of Chapter 4 was that the kinematic and kinetic data were collected on different surfaces. The force data were collected on a wheelchair roller system, so the force data may not be representative of overground propulsion.

5.4 Suggestions for Future Research

In general, more studies are needed to understand interventions in the clinical setting and the translation of research interventions to the clinical setting. Below are suggestions for future research as it relates to each chapter.

5.4.1 Chapter 2

Further development and research of the WMS may increase its application. Fine-tuning of the software models for simulating overground propulsion with an interface for determining the appropriate coefficients for each user is needed. The software model for ramps needs to be adjusted and tested with higher forces and quicker cadences. Test procedures for measuring speed, distance, and push length on the WMS could be developed and compared to similar data collected by instrumented wheels. Kinetic and kinematic variables could be collected at the same time to compare different surfaces to the WMS. Visual feedback and virtual reality could be used in combination with the WMS to identify whether this feedback would improve the simulation of surfaces on the WMS.

5.4.2 Chapter 3

In order to represent a wider experience of rehabilitation, future work could include recruiting a larger sample size with representation across the country and across different settings. In addition, the continuum of care in wheelchair skills being taught across settings needs to be examined to determine what is being taught in inpatient and outpatient rehabilitation and the potential need for community programs. ICF coding could also be expanded to include third- and fourth-level codes. In addition, qualifier codes for the Activities and Participation and Environment components could be used to provide more information regarding which wheelchair skills are deemed most difficult to learn and environmental barriers and facilitators that influence participation using these skills. A larger sample across settings and with more levels coded could assist in the process of solidifying an ICF Core Set for manual wheelchair users.

5.4.3 Chapter 4

Future research is needed to further test repetition-based wheelchair training with a more rigorous research design, to test kinematics and kinetics at the same time overground, and to examine retention of propulsion biomechanics and skills after the training sessions. More research is needed to understand “dosing,” or the number of repetitions needed to promote the propulsion techniques described in the Clinical Practice Guidelines (CPG). Additionally, other factors involved in motor learning, the rate at which new wheelchair users learn, and the involvement of depression, motivation, and cognitive processing in the motor learning process should be evaluated in relation to the training program. Future studies should include a review of wheelchair positioning and allow for adjustments prior to the training. In conjunction with wheelchair seating setup, practicing the proper push biomechanics through repetition-based training may promote the use of the recommended and researched biomechanics.

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<u>Appendix</u>

Appendix 1: The Development of an Instrumented Wheelchair Propulsion Testing and Training Device

This paper has been published:

Klaesner, J., Morgan, K. A., & Gray, D. B. (2014). The development of an instrumented wheelchair propulsion testing and training device. *Assistive Technology, 26*(1), 24–32.

Abstract

Purpose: Several types of testing devices and training surfaces have been used to examine wheelchair propulsion. Testing and training wheelchair users on the actual surface of interest such as tile floors or ramps is ideal but difficult. Devices such as treadmills, dynamometers, and ergometers allow for a wheelchair user to be observed in a controlled space. However, these devices often do not have the ability to realistically simulate the environment. This article describes an instrumented wheelchair dynamometer system, the WheelMill System (WMS) that adjusts the resistance of the rollers and changes position of the wheelchair.

Methods: Three participants wheeled on the WMS, over a tile surface and up two different graded slopes with the SmartWheel to compare speed and forces.

Results: The participants' speed was faster on the tile than the WMS. The peak forces for each propulsion stroke varied more on tile than the WMS. For the slopes the speed oscillated over a greater range and was slower and the measured forces were higher.

Conclusions: The WMS has the potential to reasonably simulate propulsion over a tile floor but more research is needed for up slopes. The WMS may have several research and clinical applications.

Appendix 2: Repetition Based Training for Efficient Propulsion in New Manual Wheelchair Users

This paper has been submitted and is under revision:

Will, K., Engsberg, J. R., Foreman, M., Klaesner,, J., Birkenmeier, R., & Morgan, K. A. Repetition based training for efficient propulsion in new manual wheelchair users. *Journal of Spinal Cord Injury Medicine.*

Abstract

Purpose: The purpose of this project was to determine the number of propulsion repetitions necessary to produce changes in propulsion biomechanics of new manual wheelchair users with spinal cord injuries.

Methods: Five new manual wheelchair users with spinal cord injury participated in this a nine-session manual wheelchair training program that aimed to improve propulsion biomechanics through 5,400 propulsion repetitions. A single subject design was used. Assessments were performed on a wheelchair dynamometer at 7 levels of repetition dosing. Kinematic measurements (i.e., push loop height, push angles, cadence) were taken using video cameras and Microsoft Kinect systems. Kinetic measurements (i.e., peak force, average force, rate of rise of force) were taken using a wheelchair dynamometer system.

Results: All five participants had improvements in propulsion biomechanics, which occurred in the first levels of repetition dosing (between 1000-2700 repetitions); there were variances in type of change (kinematic or kinetic).

Conclusions: Results suggest that proper propulsion biomechanics can be learned with appropriate dosing. The variability among participants in the type of change that occurred at different dosing levels may be due to differences in wheelchair positioning and level of injury. The impact of manual wheelchair users learning efficient propulsion is great, as engagement in daily activities is dependent upon the health of the upper extremities.