University of Alberta

KINETIC ANALYSIS OF MANUAL WHEELCHIAR PROPULSION UNDER DIFFERENT ENVIRONMENTAL CONDITIONS BETWEEN EXPERIENCED AND NEW MANUAL WHEELCHAIR USERS WITH SPINAL CORD INJURY

by

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DEDICATION

I dedicate this thesis to my parents for their

continued support and to Mahender, who has been

a great source of motivation and inspiration

ABSTRACT

Objectives: To compare wheelchair propulsion kinetics between new (acute) and experienced (chronic) manual wheelchair users with spinal cord injury (SCI) under natural environmental conditions and secondly; to examine the association between shoulder pain and propulsion kinetic outcomes.

Methods: Thirteen participants per group participated**.** Propulsion kinetic parameters were measured using the Smartwheel. Shoulder pain was assessed using Wheelchair Users Shoulder Pain index. A factorial ANOVA was used to determine interaction and main effects of group (acute, chronic) and condition (tile, carpet and ramp).

Results: Participants in both groups were matched for level of injury. There was no significant difference between groups for propulsion kinetics including peak force, push frequency, push length and speed. Push mechanical effectiveness was significantly higher in the acute group. Shoulder pain was significantly associated with propulsion kinetic outcomes in the acute group.

Conclusion: Our findings suggest individual attention to propulsion kinetics during propulsion training under acute rehabilitation and follow-up programs designed to refine propulsion strategies for people with chronic SCI living in the community.

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CHAPTER ONE

INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

A spinal cord injury (SCI) is damage or trauma to the spinal cord that results in loss or impaired function causing reduced mobility or sensation. Common causes of SCI include trauma due to car accident, gunshot, falls, sports injuries and diseases such as transverse myelitis, polio, spina bifida and friedreich's ataxia (American Spinal Injury Association, 2009). The severity of loss of function from SCI is determined by level of the lesion and degree of damage to the spinal cord. The higher the level of lesion, the more profound the loss of function (Curtis et al., 1999). Injury to the spinal cord at the cervical level leads to tetraplegia (impairment or loss of motor and/or sensory function in all four extremities as well as trunk). Injury to the spinal cord below the cervical region (thoracic, lumber or sacral segments) leads to paraplegia (impairment or loss of motor and/or sensory function in lower extremities with or without trunk involvement) (American Spinal Injury Association, 2009) (Figure 1.1). SCI is classified as a complete lesion when there is no sensory or motor function below the level of injury or in the sacral segment S4-5. An injury is defined as incomplete when sensory and/or motor functions are preserved below the neurological level of injury (American Spinal Injury Association, 2009).

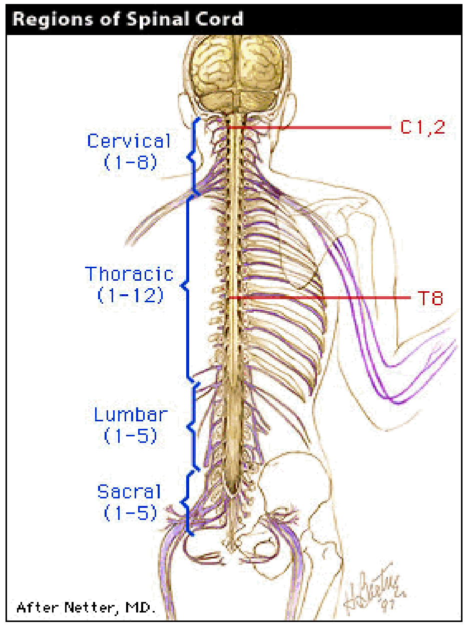

Figure 1.1: Dorsal view of spinal cord (Anatomy of the spinal cord, assessed 2009).

In an epidemiological study, the reported incidence of SCI in Alberta, Canada was 52.5/ million population (Dryden et al., 2003). According to this study, in Alberta, the median age of SCI is 35 years. SCI due to motor vehicle accidents primarily occur among individuals between 15-29 years of age and falls related SCI primarily occur to those older than 60 years. The incidence rates for males are consistently higher than for females for all age groups with a ratio of 3:1.

Usually individuals with SCI are left with considerable residual disability which leads to changes in their usual patterns of daily living (Wood-Dauphinee et al., 2002). Long term survival with SCI depends on individuals learning the necessary techniques during and after rehabilitation to manage their physically changed body as well as developing strategies to re-enter the world as persons with disability (Lucke, Coccia, Goode, & Lucke, 2004). Care and rehabilitation for someone with a SCI includes not only the prevention of death and disability, but also the facilitation of functional recovery and personal independence, the promotion of community reintegration, and ultimately optimal quality of life after SCI (Wood-Dauphinee et al., 2002).

Wheelchair propulsion is a form of mobility that facilitates community participation and functional independence for people with SCI (Cowan, Boninger, Sawatzky, Mazoyer, & Cooper, 2008). Selection of a wheelchair for individuals with SCI depends upon their level of injury and functional status (Copper, Boninger, & Robertson 1998). Generally, persons with SCI at cervical level - 6 or below are able to propel manual wheelchairs (Somers, 2001). However, the full time use of a manual wheelchair has its challenges. Wheelchair propulsion has been implicated as a causative factor for the development of shoulder and wrist pain in manual wheelchair users due to excessive wear and tear of the joints (Hurd, Morrow, Kaufman, & An, 2008a; Pentland & Twomey, 1994). It has been reported that ergonomics of the interface between the wheelchair and its user leads to upper extremity pain which may impair his/her mobility, and the ability to complete basic activities of daily living (ADLs) (Cowan et al., 2008; Hurd et al., 2008a). Community dwelling manual wheelchair users with SCI reported poor life satisfaction and lower community participation due to upper extremity pain (Tonack et al., 2007). Less specific muscle training of the upper extremity during acute rehabilitation and performing ADLs under different environmental conditions after going back to the community may be reltated to an increase in pain after the acute rehabilitation (Van Drongelen et al., 2006).

Past laboratory research has shown that new and experienced manual wheelchair users develop different strategies of propulsion (Robertson, Boninger, Cooper, & Shimada, 1996). However, there is a lack of information about the differences in propulsion kinetics between new and experienced manual wheelchair users in commonly encountered environmental conditions. The current research will provide information on the propulsion outcomes under natural environmental conditions and their relation with shoulder pain in new and experienced manual wheelchair users with SCI.

1.2 OBJECTIVES OF THE STUDY

There were two research questions in this study

1. Do propulsion kinetic outcomes such as peak force, push length, push frequency, speed and push mechanical effectiveness, generated in different environmental conditions, differ between males with SCI undergoing acute rehabilitation and males with chronic SCI who have been living in the community for at least one-year post injury?

2. Is there a relationship between propulsion kinetic outcomes and perceived shoulder pain while performing ADLs in each group?

1.3 RESEARCH HYPOTHESIS

Our hypotheses were as follows:

1. The propulsion kinetics generated under various environmental conditions such as tile, carpet and ramp will be different between males with SCI who are undergoing acute rehabilitation and males with chronic SCI living in the community.

2. History of perceived shoulder pain in the past week while performing different ADLs will have a negative relationship with the propulsion kinetic outcomes such as peak force, push length, push frequency, speed and push mechanical effectiveness in each group.

1.4 LIMITATIONS OF THE STUDY

1. The study will not provide any information on the wheelchair propulsion kinetics in females with SCI.

2. The subjects were tested in their own wheelchairs. According to past research, differences in the position of axle might influence wheeling. At the beginning of the current study, participants were asked to wheel in a standardized wheelchair. Balancing in the standardized wheelchair for people with higher levels of injury was challenging and we elected to test participants in their own wheelchairs.

3. In the current study, data was collected one time only. There were no repeated measures in the study.

1.5 RISKS AND BENEFITS

Possible Benefits: Participants learned more about their wheeling and how it might be associated with pain in their upper extremity.

Possible Risk: There were no risks involved beyond those that might happen with every day wheeling such as arm pain and falling. Participants were watched closely at all times when they were wheeling during the test.

1.6 ETHICAL CONSIDERATIONS

Prior to the beginning of the study, the project was reviewed by the Health Research Ethics Board- Panel B from the University of Alberta and received ethical approval. The ethics approval for the acute group was obtained on April 05th of 2006. The project was resubmitted to the ethics board with revisions and with the addition of group of people with chronic SCI. The revised application received ethical approval on July 11th of 2008 (see Appendix A).

The subjects enrolled in this research project were invited to take part and the researchers explained what was involved in the research. Subjects were asked to present themselves with their manual wheelchairs. Before the test, subjects read the information letter (see Appendix B) and signed the consent form (see Appendix C), in order to assure confidentiality and privacy of the participants. The data files assigned with the participants' code numbers were stored in a password protected computer. All written data files were locked in a file cabinet.

CHAPTER TWO

LITERATURE REVIEW

2.1 SHOULDER PAIN AND ITS PREVALENCE IN PEOPLE WITH SCI

Due to repetitive use of the upper extremities that results from manual wheelchair propulsion, the prevalence of upper extremity pain and injury in people with SCI is alarmingly high (Subbarao, Klopfstein, & Turpin, 1995). Published research and surveys of manual wheelchair users indicate that the prevalence of shoulder pain in people with SCI is between 31% and 73% (Gironda, Clark, Neugaard, & Nelson, 2004; Samuelsson, Tropp, & Gerdle, 2004). Curtis et al. (1999) surveyed 195 people with SCI and reported that among the respondents, more than two thirds of the sample reported shoulder pain since beginning wheelchair use. In a recent cross sectional survey, out of 88 subjects with SCI, 67% reported shoulder pain since they had become a manual wheelchair user (Alm, Saraste, & Norrbrink, 2008).

In a longitudinal study, data was collected to determine shoulder pain and range of motion (ROM) problems in people with SCI at 2 points in time, 3 years apart. This study found that 30 % of the subjects developed shoulder pain and 22% had restricted shoulder ROM within those 3 years (Ballinger, Rintala, & Hart, 2000). Moreover, Lal (1998) reported 72% of 53 patients with SCI had radiological evidence of degenerative changes in the shoulders. It has been reported that manual wheelchair users with SCI decline functionally over a long term, due to shoulder pain (Gerhart, Bergstrom, Charlifue, Menter, & Whiteneck, 1993; Jensen, Hoffman, & Cardenas, 2005).

Research indicates that shoulder pain in manual wheelchair users has detrimental effects on overall independence, mobility, and the ability to perform work tasks and leisure activities (Brose et al., 2008; Hurd et al., 2008a; Subbarao et al., 1995). The incidence of upper extremity pain increases linearly with time since injury for persons with paraplegia (Jensen, et al., 2005). It has been reported that early onset of shoulder pain i.e. pain at the acute phase of SCI may be the most important predictor of the shoulder pain at a later time (Van Drongelen et al., 2006). Upper extremity weight- bearing activities and chronic overuse leads to development of soft tissue disorders and degenerative changes in shoulder joint (Curtis et al., 1999).

2.2 BRIEF ANATOMY OF SHOULDER JOINT COMPLEX

The shoulder joint complex consists of four different joints including the sternoclavicular joint, acromioclavicular joint, scapulothoracic joint and glenohumeral joint (Figure 2.1). The sternoclavicular joint is a sellar joint between the medial end of clavicle and the manubrium of the sternum. The acromioclavicular joint is a planar articulation of the lateral end of clavicle to the acromion. In the scapulothoracic joint, the scapula is suspended on the rib cage by muscles (Goldstein, 2004). Finally, the glenohumeral (GH) is a true ball and socket joint formed between the head of the humerus and glenoid cavity of the scapula providing three degrees of motion, flexion- extension, abductionadduction and medial- lateral rotation to do various tasks in different planes (Goldstein, 2004).

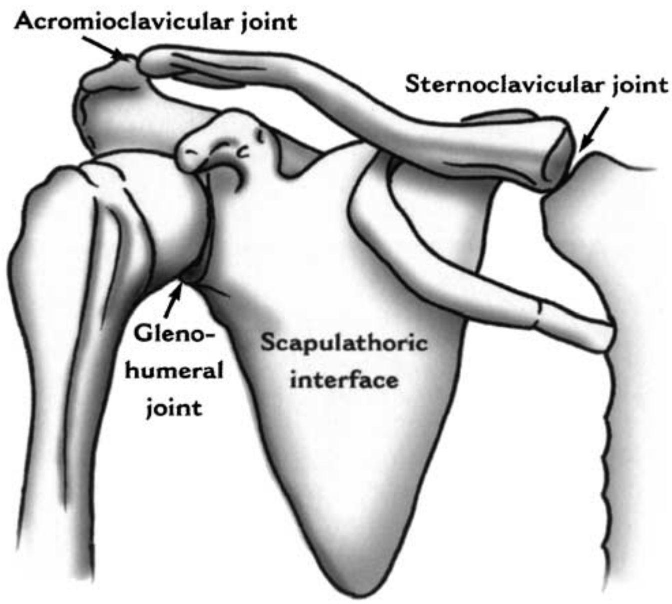

Figure 2.1: Shoulder joint complex (Samuelsson et al., 2004).

The glenohumeral joint is the largest joint in shoulder joint complex. It has a large amount of mobility but it is not designed to have weight-bearing and locomotive functions (Goldstein, 2004). The stability and balance of the GH joint are related to the alignment of the scapula to the humerus and net joint reaction force at the glenoid cavity (Goldstein, 2004).

The stabilizers of GH joint include soft tissues such as muscles, the labrum, glenohumeral ligaments and the joint capsule (Curl & Warren, 1996). The dynamic stability of the GH joint is primarily provided by the rotator cuff muscles including the subscapularis, supraspinatus, infraspinatus and teres minor (Dark, Ginn, & Halaki, 2007) (Figure 2.2). The rotator cuff muscles provide stability to the GH joint by compressing the head of humerus to the glenoid cavity during shoulder movements (Wuelker, Korell, & Thren, 1998). Compression forces created by contraction of the rotator cuff muscles enables the humerus to pivot on its head within the glenoid cavity during shoulder movements (Lippitt & Matsen, 1993). It limits the potential humeral head translation generated by muscles producing shoulder movement and thus prevents joint subluxation and provides more stability (Lippitt & Matsen, 1993). When the center of the humeral head articular surface is aligned symmetrically to the center of glenoid cavity, the joint remains stable and lower muscle work is required to provide stability to the joint (Goldstein, 2004; Lippitt & Matsen, 1993).

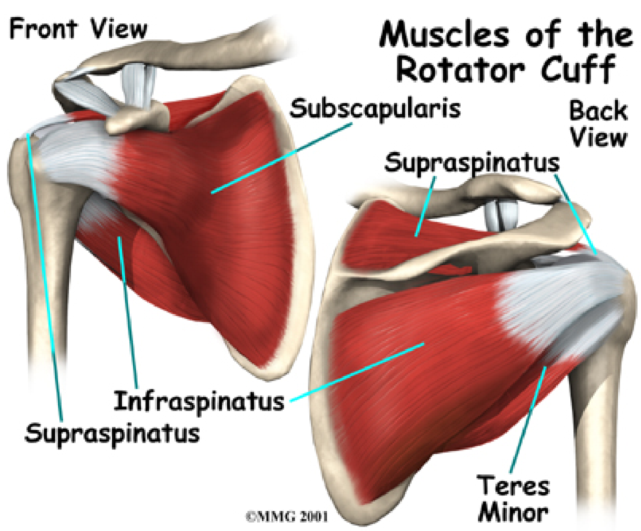

Figure 2.2: Muscles of the rotator cuff (Schultz, 2009)

During weight bearing activities including transfers and manual wheelchair propulsion in people with SCI, poor trunk control results in poor alignment of the humeral head with the glenoid cavity. Therefore, forceful muscle work must be generated to maintain the stability of the joint (Hastings & Goldstein, 2004). This forceful muscle work, done repetitively, can lead to injury to the rotator cuff, shoulder pain or both (Goldstein, 2004; Hastings & Goldstein, 2004).

2.3 FACTORS LEADING TO SHOULDER PAIN IN SCI

2.3.1 Imbalance in shoulder musculature

In people with SCI who use manual wheelchairs for mobility, the rotator cuff muscles are more susceptible to fatigue and injury due to their small volume when compared with the other propulsive muscles such as pectoralis major and deltoid (Mulroy, Gronley, Newsam, & Perry, 1996). In general, the critical zone for injury to the rotator cuff is the insertion of supraspinatus tendon into the humeral head. This critical zone has veins, capillaries and arteries and supplies the rotator cuff (Cooper et al., 1998). Any activity that forces the humeral head further into the glenohumeral joint can cause impingement of the rotator cuff tendons under the acromioclavicular arch (Hastings & Goldstein, 2004). Therefore, intrinsic (within the joint), and external forces such as overhead activities, transfers and wheelchair propulsion can put stress on the rotator cuff tendons (Cooper et al., 1998). Furthermore, any weakness or imbalance in shoulder muscles can lead to abnormal biomechanics and thus injury (Burnham, May, Nelson, Steadward, & Reid, 1993).

In people with SCI who use a manual wheelchair, shoulder force generated during wheelchair propulsion can drive the humeral head towards the acromion. Usually, the muscles around the glenohumeral joint counterbalance this external force generated by the propulsion (Burnham et al., 1993; Collinger et al., 2008). In people with SCI, uneven loading on surrounding muscles during propulsion, and weak rotator cuff may lead to impingement of the soft tissue structures within the acromiohumeral space (Goldstein, 2004; Lippitt & Matsen, 1993).

Additionally, in people with SCI who use a manual wheelchair for mobility, the repetitive nature of the stroke pattern involved in wheelchair propulsion encourages protraction and elevation of the scapula with relative internal rotation of the humerus (Burnham et al., 1993). Therefore, in manual wheelchair users with SCI, protracted shoulders with shortened anterior and lengthened posterior muscles and forward position of head put the shoulder joint at risk of pain and injury (Consortium for Spinal Cord Medicine, 2005; Nawoczenski, Ritter-Soronen, Wilson, Howe, & Ludewig, 2006).

2.3.2 Postural changes due to wheelchair propulsion

Sitting posture in a wheelchair has been investigated as a predictor or causative agent in upper extremity stress disorders (Hastings & Goldstein, 2004). Due to decreased trunk stability, individuals with complete SCI who use a manual wheelchair commonly sit in their wheelchairs in a 'C'-shaped kyphotic posture with a posterior pelvic tilt (approximately 15 degree more tilt than non impaired individuals), an extended cervical spine and a flattened lumbar spine (Alm, Gutierrez, Hultling, & Saraste, 2003; Hobson & Tooms, 1992). This sitting posture allows them to propel the wheelchair and perform most of their ADLs (Figure 2.3).

Normally, spinal alignment and scapular position on the thorax optimize GH stability. Functional mobility of the shoulder is dependent upon spinal alignment (Hastings & Goldstein, 2004). The kyphotic posture due to trunk instability of the individual sitting in his/her wheelchair changes the vertical alignment of the scapula over the thorax and rotates it downward and forward in sagittal plane. This position of the scapula alters the normal alignment of the acromion process and glenoid fossa potentially contributing to shoulder pain (Samuelsson et al., 2004). Moreover, the presence of a flexed kyphotic posture during wheelchair propulsion results in poor push mechanism and places the upper extremity under more stress (Hastings & Goldstein, 2004).

Figure 2.3: (A) Individual is seated properly in wheelchair. (B) Sitting sliding forward in the seat (C) Forward trunk lean, trunk muscles imbalance (Hastings & Goldstein, 2004).

2.3.3 Forces applied on shoulder joint during transfer

For persons with paraplegia, transfers are commonly performed several times a day for normal and independent function (Pentland & Twomey, 1991). During transfers in people with paraplegia, more force is applied beneath the trailing hand than with the leading hand, since the trailing hand is placed closest to the body (Forslund, Granstrom, Levi, Westgren, & Hirschfeld, 2007) (Figure 2.4). The arterial pressure on the shoulder during transfers from wheelchair to bed has been shown to be 2.5 times greater than that recorded when the shoulder is non weight bearing (Bayley, Cochran, & Sledge, 1987). The increased pressure stresses the vasculature of the rotator cuff and can contribute to tendon degeneration (Bayley et al., 1987).

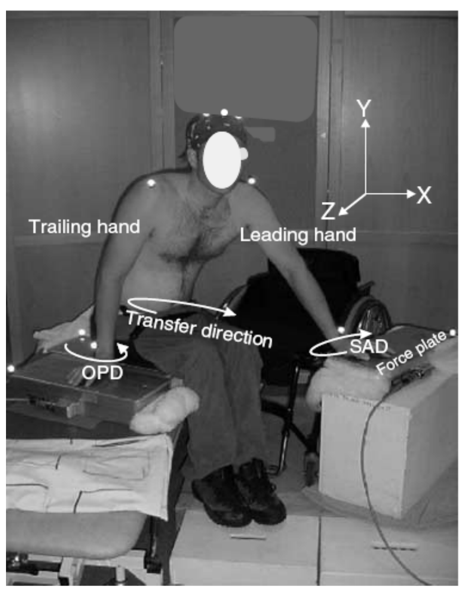

Figure 2.4: Forces on shoulder and hand during transfer (Forslund et al., 2007).

During transfers, the weight of the body is transferred from the trunk through the clavicle and scapula across the subacromial soft tissue to the humeral head (Bayley et al. 1987). The scapula and humerus move in directions that have the potential to reduce the magnitude of available subacromial space (Forslund et al., 2007). Zuckerman et al. (1992) showed that 5° changes in the slope of the acromion and an average 20% reduction in the available subacromial space were significantly related to the incidence of rotator cuff tears. Therefore, transfers inherently utilize movement patterns that place the shoulder at greater risk for impingement.

2.3.4 Forces applied on shoulder joint during propulsion

High rates of rise or rapidly applying force to the wheelchair pushrim, and subsequently having those forces transmitted up into the arm, have been found to be particularly detrimental to the shoulder joints (Fronczak, Boninger, Souza, & Cooper, 2003). During propulsion, the most efficient force applied to a handrim is a force that is tangential to the rim itself (Ft) (Boninger, Cooper, Robertson, & Rudy, 1997a) (Figure 2.5).

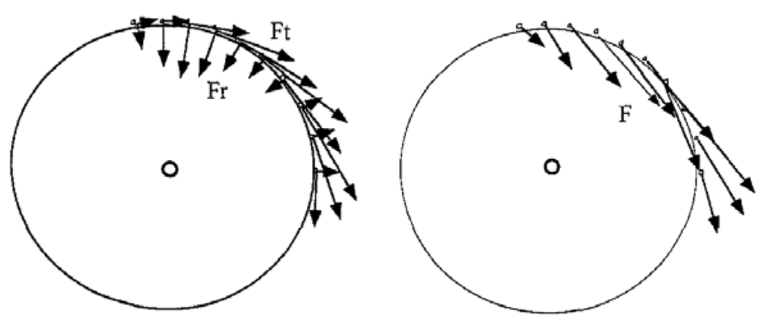

Figure 2.5: wheelchair users, plotted at the point of force application (PFA): Fr, radial force; Ft, tangential force; F, resultant pushrim force (Cooper et al., 1996).

The tangential forces produce the forward motion that results in wheelchair propulsion (Boninger et al., 1997a). During the push phase, the hands of the users have to follow the circular path of the pushrim. The forces exerted by the hands do not influence the trajectory of the hands, which makes possible the application of non-tangent forces at the pushrim (Rozendaal, Veeger, & van der Woude, 2003; van der Woude, Veeger, Dallmeijer, Janssen, & Rozendaal, 2001). A non-tangential force i.e. Radial force (Fr), (directed down into the axle of the wheelchair) (Figure 2.5), is required to create friction on the handrim during wheelchair propulsion (Boninger et al., 2003).

Boninger et al. (2003) implied that a reaction force at the pushrim with greater radial component would increase the upward force acting along the humerus, which may further lead to shoulder impingement. In another study it has been found that a force tangent to the wheel yields a higher flexion moment at the shoulder. As a result, the flexor muscles would have to be more active to maintain the tangent force direction (Desroches, Aissaoui, & Bourbonnais, 2008). Increased activity of the flexor muscles, more specifically of the anterior deltoid, may induce an upward gliding of the humeral head resulting in a higher proximal shoulder force component (Mulroy et al., 1996). Higher proximal shoulder force components are found to be detrimental to the shoulder joint (Mercer et al., 2006).

2.3.5 Push mechanical effectiveness

Push mechanical effectiveness (PME) indicates the approximate ratio of applied force which is directed in such way that wheelchair is accelerated

(Smartwheel User's Guide, 2008). PME is defined as Ft/F where Ft is the amount of force tangent to the handrim required to move wheelchair forward and F is the total resultant force (Boninger et al., 2002 ; Smartwheel User's Guide, 2008). Higher the tangential force more is the PME (Boninger, Cooper, Robertson, & Shimada, 1997b; Smartwheel User's Guide, 2008). The PME varies among the manual wheelchair user population. For younger populations with SCI and wheelchair athletes, the tangent component represents between 50% and 80% of the resultant force, whereas for an elderly population, it does not exceed 50% (van der Woude et al., 2001; Aissaoui, Arabi, Lacoste, Zalzal, & Dansereau, 2002).

In one study, it was implied that higher mechanically effective force is associated with less total force needed to push the wheelchair forward hence lower force borne on the shoulder joints (Boninger et al., 1997b). Whereas, in other studies it was mentioned that a higher component of the force tangent to the wheel was significantly associated with higher proximal and anterior shoulder joint forces (Desroches et al., 2008; Mercer et al., 2006; Rozendaal et al., 2003).

Therefore, preferred force direction, which may maximize mechanical effectiveness while minimizing the load on the shoulder, may be achieved by teaching the wheelchair propulsion according to the individual’s physical capacity, by visual feedback of the forces at the pushrim and by improving the wheelchair propulsion techniques (Desroches et al., 2008; de Groot, Veeger, Hollander, & van der Woude, 2002a; Rozendaal et al., 2003).

2.3.6 Wheelchair propulsion parameters and techniques

Wheelchair propulsion has been implicated as a significant contributing factor to the incidence of upper extremity pain and injury (Pentland & Twomey, 1994). During wheelchair propulsion, the shoulder is repetitively moved through an arc of motion against resistance, which may lead to excessive wear and tear of the joint (Boninger, Cooper, Baldwin, Shimada, & Koontz, 1999). Besides the forces applied on the handrim (discussed earlier, section 2.3.4), the shoulder joint pain that accompanies propulsion also depends on the pushing parameters used including push speed, push frequency, push length, duration of force, direction of force application and the techniques of wheelchair propulsion (Boninger et al., 1999; Van Drongelen et al., 2005) (Figure 2.6).

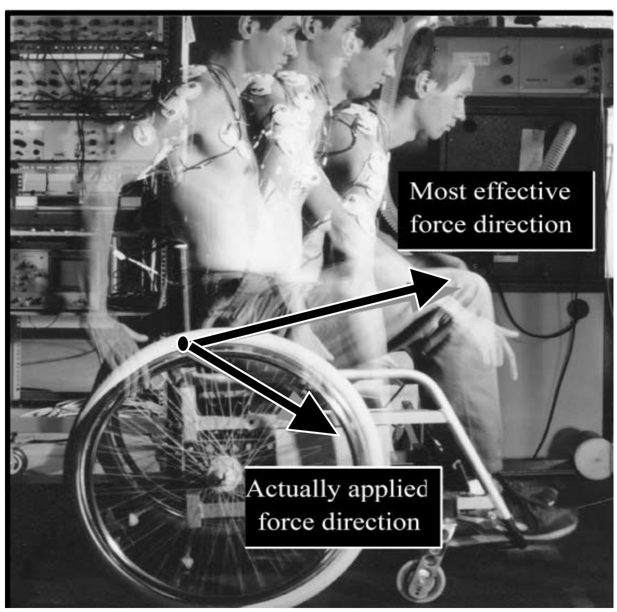

Figure 2.6: The direction of the propulsion force during 'normal' propulsion and its relation with the most effective force direction (Van der Woude et al., 2001).

2.3.6.1 Push speed

Push speed is how fast the person pushes the wheelchair after the initial start up stroke (Minkel, 2009). Boninger et al. (1999) found that manual wheelchair users who push with a faster cadence and load the pushrim more rapidly, have a greater risk of shoulder and wrist pain. On the other hand, pushing the wheelchair at less than functional (safe walking) speed and/or minimum safe speed (e.g. 1.3 m/s and/ or 1.06 m/s respectively) is detrimental to the shoulder joints (Minkel, 2009).

2.3.6.2 Push frequency

Push frequency identifies how often the person contacts the pushrim to generate the force to achieve the speed (Minkel, 2009). The more wheelchair users are able to apply long and smooth strokes with reduced stroke frequency, and minimize wasted forces (e.g., pushing directly down on the handrim), the more they will be able to prevent the onset of arm pain and injury (Boninger et al., 2002). Wheeling continuously for 40 pushes without relaxation, keeps the upper limbs in abduction continuously which may lead to excessive wear and tear of GH joint (Boninger, Impink, Cooper, & Koontz, 2004).

2.3.6.3 Push length

Push length (Figure 2.7) is the length of the arc from initial contact on the pushrim until contact release (Minkel, 2009). It has been found that people with a high level of SCI push the handrim with shorter push lengths as compared to people with low levels of SCI (Dallmeijer, van der Woude, Veeger, & Hollander, 1998). Previous studies have shown that an increase in the push length results in a reduction of stroke frequency for a constant speed due to the force being applied for a long period of time (Masse, Lamontagne, & O'Riain, 1992; Minkel, 2009). Longer push length is clinically important to prevent shoulder injuries (Minkel, 2009). In a recent propulsion study among people with SCI, it was found that the push length remained similar (i.e. 94-100º) when compared across the different surfaces such as tile, carpet and ramp (Cowan et al., 2008).

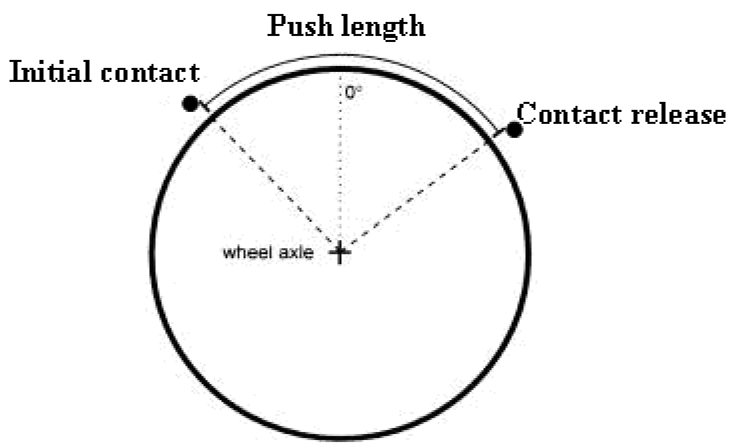

Figure 2.7: Push length, starting from initial contact on the pushrim to contact release (Majaess, Kirby, Ackroyd-Stolarz, & Charlebois, 1993).

2.3.6.4 Propulsion technique

A variety of different hand trajectory patterns have been classified during the recovery phase of propulsion cycle, including arc (user's hand travels back along the pushrim in between pushes), semicircular (hand drops below the pushrim during recovery phase), single loop (lifting the hand above the pushrim during recover phase) and double loop (begins with the hands rising above the pushrim, then crossing over and dropping under the pushrim during the recovery phase) (Boninger et al., 2002; Richter, Rodriguez, Woods, & Axelson, 2007).

In people with SCI who use manual wheelchair, improper propulsion techniques have been found to be related to upper extremity pain and injuries (Richter et al., 2007; Shimada, Robertson, Boninger, & Cooper, 1998). An arching pattern puts more stress on the upper extremity as it requires an abrupt change in the velocity of arms (Richter et al., 2007). Single loop is found to be themost common pattern used by people with SCI but it demands high shoulder joint acceleration which may contribute to shoulder injury (Shimada et al., 1998).

However, semicircular pattern is associated with lower stroke frequency and smaller shoulder joint acceleration; hence it has been found to be the most efficient pattern of recovery in a propulsion cycle (Richter et al., 2007). Chou et al. (1991) observed stroke patterns in experienced and non experienced manual wheelchair users and concluded that experienced wheelchair users used semicircular pattern while non experienced implemented the arching pattern.

2.3.7 Personal Factors

2.3.7.1 Age and duration of injury

Elderly people with SCI have high incidences of upper limb strain due to wheelchair propulsion (Alm el al., 2008). It has been also reported that wheelchair propulsion and transfers are the main cause of upper limb strain in the long term (Subbarao at el., 1995). Aging with and longer duration of SCI are related to functional decline (Kemp & Thompson, 2002; Thompson, 1999). With SCI, age – related decline in the musculoskeletal system become more devastating due to manual wheelchair propulsion in long term (Pentland & Twomey 1994).

2.3.7.2 Gender

Gender is considered to be one of the risk factors for shoulder injuries in people with SCI. Boninger et al. (2003) conducted a comparative study on pushrim forces applied on the handrim between men and women with SCI. In this study, women were found to propel with a significantly higher radial force (see section 2.3.4) which was further related to degenerative changes in the shoulder joint over the time. Pentland & Twomey (1991) concluded that out of 11 women with paraplegia, 73% reported shoulder pain primarily due to wheelchair propulsion. Similarly, Curtis & Black (1999) reported that among the females with SCI who use manual wheelchair for their mobility, 90% reported shoulder pain after the use of manual wheelchair. The higher rate of joint injuries in females as compared to the males may be due to difference in the anatomy and alignment of structures, higher degree of laxity of joints in females and differences in the physical strength in males and females (Boninger et al., 2003; Pentland & Twomey, 1991).

2.3.7.3 Body weight

Wheelchair skill performance is negatively correlated with high body mass index (BMI) because activities including moving and lifting the body are the essence of wheelchair mobility and are more difficult with a higher body weight (Janssen et al., 1996). High BMI generates more pain and dysfunction in shoulder joint as more body weight places more stress upon the upper extremity during wheelchair propulsion (Kilkens et al., 2005). It has been reported that reduced propulsion force and better propulsion techniques can be achieved by maintaining the ideal body weight (Consortium for Spinal Cord Medicine, 2005).

2.3.7.4 Level of Injury

The higher the level of injury, the more prevalent shoulder pain is (Sie, Waters, Adkins, & Gellman, 1992). People with tetraplegia are generally more limited in upper extremity strength and function than people with paraplegia (Curtis et al., 1999). Therefore, people with tetraplegia who use manual wheelchairs would experience more shoulder pain during functional activities than people with paraplegia (Gronley et al., 2000; Kilkens et al., 2005). In a recent study it was concluded that in people with tetraplegia, increased age, increased spasticity in elbow extensors (which limits shoulder flexion), delayed acute rehabilitation and shoulder pain were related to shoulder ROM problems (Eriks-Hoogland, de Groot, Post, & van der Woude, 2009).

There is a functional anatomical difference within individuals with different levels of paraplegia. Individuals with paraplegia have fully innervated shoulder musculature but they have variable levels of trunk innervations (Hastings & Goldstein, 2004). High prevalence of rotator cuff lesions have been found in people with higher level of paraplegia (T2-7) (Sinnott, Milburn, & McNaughton, 2000). A T2 complete injury results in the absence of trunk control because only the highest intercostals muscles are innervated. A T6 complete injury has upper intercostals muscles as well as little abdominal muscles innervated (Hastings & Goldstein, 2004). Therefore, an injury above T8 level of spinal cord results in theabsence or weakness of abdominal and spinal musculature which may change the spinal alignment (Sinnott et al., 2000). The postures of the trunk and spinal alignment have a direct influence on the shoulder joint stability and functional mobility (discussed earlier, section 2.3.2). In people with lower level of paraplegia, the additional hip musculature and pelvis stability improves trunk stability and hence shoulder mechanics (Hastings & Goldstein, 2004).

2.3.8 Factors related to wheelchair setup

The wheelchair is an integral part of the life of an individual with SCI. The configuration of the wheelchair has direct effects on the performance of its user. Poorly fit wheelchair has been found to be detrimental to the shoulder joints in people with SCI who use manual wheelchair (Boninger et al., 2005; Copper et al., 1998).

2.3.8.1 Weight of wheelchair

Prolonged use of heavy, poor performance wheelchairs contributes to a high incidence of repetitive strain injury (Copper et al., 1998). Encountering different environmental conditions in a heavy wheelchair may lead to excessive strain on the shoulder joint. The additional weight of the wheelchair decreases the functional velocity of propulsion and increases the amount of resultant forces on the pushrim (Cowan, Nash, Collinger, Koontz, & Boninger, 2009). Higher resultant forces on the pushrim are detrimental to the shoulder joints (Consortium for Spinal Cord Medicine, 2005; Cooper et al., 2006).

2.3.8.2 Axle Position

If the rear wheel axles are positioned behind the center of gravity, more weight will be borne on the front casters making the wheelchair harder to push (Hastings & Goldstein, 2004). On the other hand, a more forward axle position has been found to be associated with increases in the contact angle between hand and pushrim which is associated with lower peak forces, smooth joint excursions and fewer strokes to go the same speed (Boninger, Baldwin, Cooper, Koontz, & Chan, 2000; Consortium for Spinal Cord Medicine, 2005).

In recent studies, it has been shown that a wheel axle placed 4- 8 cm forward of the shoulder yielded a significant decrease in upward peak forces on the propulsive muscles (i.e., pectoralis major, anterior deltoid) which could reduce the risk of shoulder muscle fatigue and injury (Desroches, Aissaoui, & Bourbonnais, 2006; Gutierrez, Mulroy, Newsam, Gronley, & Perry, 2005; Mulroy et al., 2005).

However, keeping the axle position forward has been proven to decrease stability (Consortium for Spinal Cord Medicine, 2005). Decreased stability may make it easier to “pop a wheelie” for negotiating curbs and other obstacles; however, it is also easier to tip over (Majaess et al., 1993). It has been suggested that the most important parameter in wheelchair positioning is the location of the wheel axle with respect to the user's morphology (Boninger et al., 2000).

2.3.8.3 Seat height

Increased distance between the axle and the shoulder adversely affects mechanical efficiency, therefore the higher the seat the less effective the push, leading to shoulder pain (Boninger et al., 2000). Decreasing the vertical distance between the shoulder and the axle increases the push length (Boninger et al., 2000; Kotajarvie et al., 2004; Masse et al., 1992). Clinically, longer push lengths with a constant force will require a low frequency to maintain the functional speed (Cowan et al., 2008; Minkel, 2009). However, keeping the seat height too low, the wheelchair user will be forced to push with arms abducted which may lead to shoulder impingement.

In a recent study, is has been shown that for people with SCI, seat height is optimal when the angle between the upper arm and the forearm (elbow angle) is kept between 100- 130° when the hand is resting at top dead centre of the pushrim. This seat height showed the highest mechanical efficiency during wheelchair propulsion (van der Woude et al., 2009).

2.3.8.4 Cambered wheels

Camber can be achieved by angling the wheels such that the bottoms of the wheels are farther apart than the tops (Trudel, Kirby, & Bell, 1995). Cambered wheels have better lateral stability, lower rolling resistance, lower downward turning moment on lateral slopes, and, in turns at higher speeds, there is less stress on the bearings (Perdios, Sawatzky, & Sheel, 2007; Trudel et al., 1995; Veeger, van der Woude, & Rozendal, 1989). Besides the greater stability of cambered wheelchairs, cambered rear wheels provide an easier reach to the handrim and less hampered arm movements by reducing static efforts of shoulder abductors (Perdios, et al., 2007).

A study examined the effects of 0°, 3°, and 6° of camber during steady state, over- ground wheeling. A camber of 6° was most preferred in terms of stability on a side slope, hand comfort on the pushrims, maneuverability, and overall preference (Perdios et al., 2007). In another study, 15° increased rear-wheel camber from top to bottom has shown some minor disadvantages, such as increased wheelbase and decreased wheelchair height, that may present problems when the user is negotiating obstacles (Trudel et al., 1995).

2.3.8.5 Seat angle (Dump)

Increasing seat dump (smaller seat - to - back angle) (0 – 15°) provides users with more pelvic and trunk stability, which may facilitate wheelchair propulsion (Authier, Pearlman, Allegretti, Rice, & Cooper, 2007; Cooper et al., 1998). In a study, seat angle at 14° with low back rest (meeting the lowest ribs) was found to be associated with better postural alignment and hence improved wheeling efficiency (Hastings, Fanucchi, & Burns, 2003).

2.3.9 Built environment

In general, people with SCI who are living in the community and use manual wheelchairs for their mobility, come across different environmental conditions including inclined surfaces, carpeted floors, interlocking pavements and grass (Koontz et al., 2005). As ground conditions become more challenging, manual wheelchair users must push with an adequate amount of force to overcome the demands of the environment. To overcome the resistance provided by these surfaces, manual wheelchair users need to apply more force and wheel torque (Koontz et al., 2005). In a recent study it was concluded that high pushrim force is necessary to overcome the greater rolling resistance on the carpet than the tile surface (Hurd, Morrow, Kaufman, & An, 2008c).

Ramps and side slopes (cross slope) are routinely encountered during outdoor sidewalk wheeling. Wheelchair propulsion on side slopes leads to propulsion asymmetry (Hurd, Morrow, Kaufman, & An, 2008b). Hurd et al. (2008b) asked 12 manual wheelchair users with SCI to push on a 2º right cross slope (right side lower) and found side to side propulsion asymmetry. They concluded that in the cross slop conditions, the lower arm is exposed to greater propulsion demand in an effort to resist the downward turning tendency (Figure 2.8).

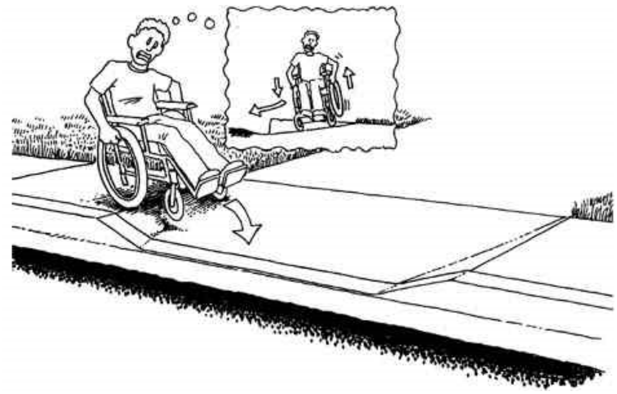

Figure 2.8: Propulsion asymmetry in manual wheelchair users on cross slope (U.S. Department of Transportation, 2009).

2.4 RECOMMENDATIONS TO PREVENT SHOULDER INJURIES IN MANUAL WHEELCHAIR USERS

The clinical practice guideline from Paralyzed Veterans of America titled "Preservation of Upper Limb Function Following Spinal Cord Injury: A Clinical Practice Guideline for Health – Care Professionals," published in 2005, outlined 35 recommendations for clinical practice to reduce or prevent upper extremity impairments in people with SCI. The propulsion ergonomics, wheelchair setup and patient education related recommendations from the guideline are summarized in the Table 2.1.

Table 2.1: Propulsion ergonomics, wheelchair set up and patient education related recommendations from the clinical practice guideline (Consortium for Spinal Cord Medicine, 2005).

Propulsion ergonomics	
Minimize task frequency	Decrease the frequency of the propulsive stroke, decrease the number of transfers needed each day, switch to a power wheelchair when appropriate
Minimize the force required to complete upper limb tasks	Maintain an ideal body weight, improve wheelchair propulsion techniques, ensure optimal biomechanics during weight bearing, switch to power mobility when appropriate
Wheelchair set up	
Wheelchair weight	Lighter wheelchair will reduce the forces needed to propel the wheelchair.
Adjust rear axle	Move the axle forward incrementally, provided the wheelchair user feels safe
Seat height	The point at which angle between upper arm and the forearm is between 100-120^{o} when hand is resting on top dead centre of the pushrim
Patient education	
Push length	Recommend longer and smooth propulsion strokes to decrease the push frequency and to minimize the push force
Push pattern	Recommend Semicircular pattern in which user's hand drops below the pushrim during recovery phase. Semicircular pattern is associated with a lower push frequency
Seated posture and stabilization	Recommend back rest below the scapula and appropriate seat dump for better propulsion, recommend to sit on a light weight cushion to stabilize the pelvis hence provide a postural support as well as even pressure distribution.

2.5 INSTRUMENTS USED FOR MEASURING PROPULSION KINETICS

Wheel-based measurement systems allow for the collection of propulsion kinetics and joint kinematics in a variety of settings. Kinematics is a 3 D motion analysis system used to collect information about real time movement patterns of upper extremities, head and torso during propulsion. Kinematics systems measure stroke patterns, joint acceleration, joint ROM and position (Koontz, Cooper, Boninger, Souza, & Fay, 2002). By contrast, propulsion kinetics estimate net shoulder-joint forces and moments (rotational effect of a force) during wheelchair propulsion at various speeds, over simulated inclines, and for varying external power outputs (Kulig et al., 1998; Rodgers et al., 1994).

In wheelchair propulsion kinetic studies, a wheelchair ergometer (Brown, Knowlton, Hamill, Schneider, & Hetzler, 1990), dynamometer (DiGiovine, Cooper & Boninger, 2001) roller system (Rodgers et al., 1994), treadmill (Sanderson & Sommer, 1985; Veeger, Van der Woude, & Rozendal, 1992), or instrumented wheels (Richter et al., 2007) have been used alone or in combination to simulate wheelchair motion.

2.5.1 Stationary wheelchair ergometer and dynamometer

A stationary computer controlled wheelchair ergometer was designed for the analysis of various simulated wheelchair pushing conditions, such as varying resistance, velocity, and slope (Niesing et al., 1990). This system allows for seat configuration changes, different pushrim sizes, and adjustments in camber. Pushrim forces are measured in three directions (tangential, radial, and axial) through transducers mounted on the axle attachment point (Niesing et al., 1990).

The terms ergometer and dynamometer are often considered as interchangeable (DiGiovine et al., 2001). An ergometer can measure work and power only, and has no method of adding power to the system, though it may be able to apply a load. A dynamometer, on the other hand, not only measures work and power but also measures torque and speed (or position) directly, and has the ability to apply a load or add power to the system (DiGiovine et al., 2001).

Both systems have been used in research to measure the kinetics of wheelchair propulsion with varying degree of success (de Groot, Veeger, Hollander, & Van der Woude, 2002b; Robrtson et al., 1996). These systems are limited to the stationary manual wheelchair propulsion within laboratory settings. Nevertheless, laboratory investigations may not accurately capture the wheeling demands manual wheelchair users encounter on a daily basis.

2.5.2 Research treadmill

A multigrade treadmill has been used in research to measure propulsion kinetics on various slopes and at different speeds (Richter et al., 2007; Niesing et al., 1990). From a mechanical perspective, treadmill propulsion has been found to be nearly identical to over-ground propulsion (Richter et al., 2007; Van der Woude et al., 2001). On the other hand, pushing on a treadmill within laboratory settings is considered different as the user must maintain a fixed propulsion speed and must maintain a straight heading in order to avoid hitting into the rails of the treadmill. These limitations of pushing on a treadmill may lead the subject to be more conservative than he would be if pushing over ground (Richter et al., 2007).

2.5.3 Roller system

During wheelchair propulsion studies, various types of roller systems including custom-made roller systems, commercially available roller systems and roller systems linked to commercially available bicycle ergometers have been used (DiGiovine et al., 2001).The roller system has been used in research to add friction during wheelchair propulsion to manipulate the rolling resistance (Rodgers et al., 1994).

2.5.4 Instrumented wheels

A few force sensing wheels have been used in research to obtain a complete three-dimensional biomechanical understanding of wheelchair propulsion. Rodgers et al. (1994) described a 38- cm instrumented pushrim which permited continuous sampling of tangential force applied to the pushrim. Strauss et al. (1991) reported on the development of a dynamic force and torque sensing wheelchair wheel. The calibration of their system revealed problems in terms of linearity and drift that only permitted reliable measurement of torque. Another instrumented wheel known as Propulsiometer was developed by Beneficial Designs (Nashville, TN) (Richter & Axelson, 2005). The Propulsiometer is capable of measuring the dynamic 3-dimensional forces and moments applied to the handrim during propulsion. Propulsiometer measures handrim loads using a commercially available 6 degree-of-freedom load cell located at the center of the wheel (Richter et al., 2007; Richter & Axelson, 2005).

The Smartwheel (Figure 2.9), a commercial force and torque sensing pushrim, has been used in research to examine three dimensional (3-D) propulsion forces, moments within laboratory settings and over different surfaces and inclines in more free living environments (Koontz et al., 2005; Robertson et al., 1996). A standard Smartwheel weighs 4.9Kg (1.1lb). The Smartwheel is available in various sizes and can be mounted to a variety of wheelchairs, which allows it to be used to assess an individual in his/her personal wheelchair (Smartwheel User's Guide, 2008).

Figure 2.9: The Smartwheel (Smartwheel User's Guide, 2008)

Dr. Rory A. Cooper and his colleagues built the original hard-wired Smartwheel and published the first paper validating its use as a propulsion biomechanics measurement tool (Asato, Cooper, Robertson, & Ster, 1993). The close agreement between kinetic results obtained using the Smartwheel (concerned with motion produced under action of forces) and the kinematics results (obtained through video analysis) provided validation of the ability of the Smartwheel to detect forces applied during wheelchair propulsion (Asato et al., 1993).

When the Smartwheel is manufactured, the calibration constants are loaded into it. The Smartwheel uses 12 calibration constants to convert between the raw voltages provided by 6 strain gauges into actual forces and moments applied to the pushrim (Asato et al., 1993; Smartwheel User's Guide 2008). These constants are transferred into the computer when the Smartwheel is connected the first time.

The Smartwheel works on sensors and a microprocessor to sense the propulsion kinetics and transmits them to a personal computer (Cooper et al., 1998). The Wi-Fi high-speed wireless link allows for the collection of data from almost anywhere. On the computer screen, data can be visualized in real time. The real-time visual feedback information includes graphs that display stroke length and amount of force exerted on the handrim at different speed with each push. (see Figure 2.10 for example)

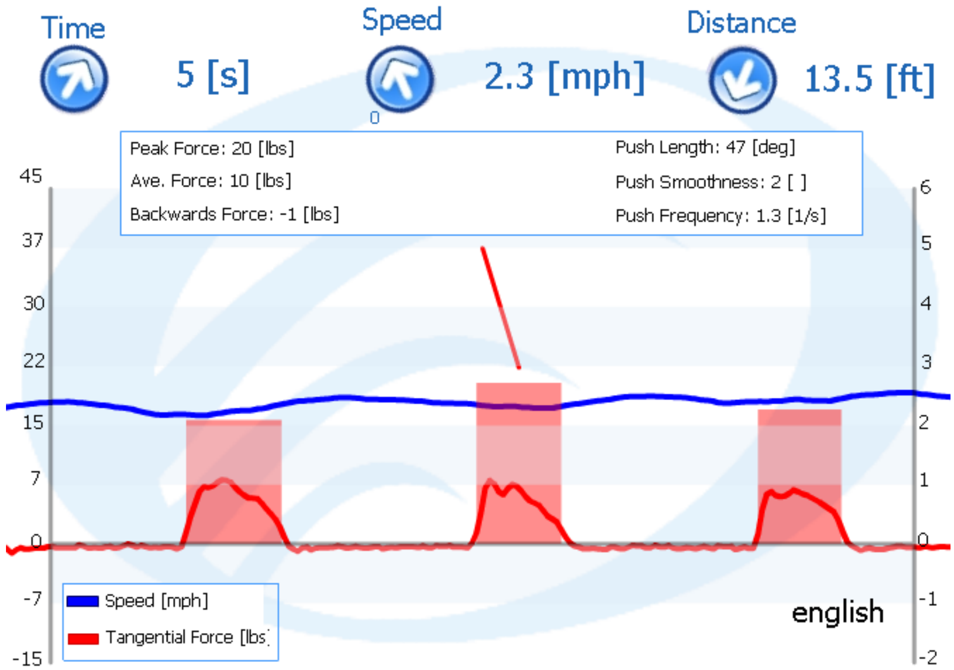

Figure 2.10: Computer screen display of the propulsion data (Smartwheel User's Guide 2008).

The Smartwheel precisely measures different wheelchair propulsion kinetics (Appendix D) and generates a report of the outcomes (Smartwheel User's Guide, 2008). This report provides the information on the propulsion kinetics applied by the user on different surfaces during the first three pushes (startup state) and on steady state (all pushes after first three) separately (see Figure 2.11 for example).

Session Results- Startup

These parameters are calculated from the first 3 pushes

	Tile Protocol	Carpet Protocol	Ramp Protocol	
Peak Force Push 1 [N]	69	34	68	
Peak Force Push 2 [N]	84	15	61	
Peak Force Push 3 [N]	94	41	71	
Distance after 2nd Push [m]	1.7	1.5	1.1	
Distance After 3rd Push [m]	2.8	2.5	2.4	
Speed After 2nd Push [m/s]	1.5	0.6	0.2	

Session Results - Steady State

These parameters are averages calculated from all pushes except for the first 3.

	Tile Protocol	Carpet Protocol	Ramp Protocol	
Peak Force [N]	93	21	39	
Avg. Push Force [N]	64	17	35	
Peak Backwards Force [N]	-4	-2	-4	
Speed [m/s]	1.1	1.2	1.3	
Avg. distance / push [m]	1.1	1.2	1.1	
Push Length [deg]	116	26	53	
Push Frequency [1/s]	1.00	0.99	1.19	
Peak/Avg. Force Ratio	1.5	1.2	1.1	
Push Mechanical Effectiveness	0.56	0.65	0.49	

Figure 2.11: Smartwheel data report, showing start up and steady state propulsion kinetics separately.

New Smartwheel software was released in 2008 (Smartwheel User's Guide 2008). In addition to the propulsion parameter displayed in the Smartwheel reports, the reports generated with the new software compares the key performance measures of push force, push frequency, push length and speed used on the steady state to a national database (Cowan et al., 2008). Figure 2.12 is an example of the report showing the propulsion kinetics applied by the individual in steady state on the tile protocol and their comparison with the national database.

Key Data from Client Session & Comparison to Database Averages

(These key parameters are calculated from all pushes except for the first 3. Database averages may not be available depending upon protocol chosen)

	Tile Protocol			**Database Average † ╪**	**Database Top 25% ‡**
Speed [m/s]	0.8			1.2	1.5
Push Frequency [1/s]	0.9			1.0	1.1
Push Length [degree]	59.0			100.6	107.1
Force (Weight Normalized) %	14.4			9.7	11.3

Figure 2.12: Smartwheel data report generated with 2008 software to compare the participant's pushing kinetics with the national database.

2.6 SUMMARY

In summary, people with SCI become dependent on the use of their upper extremities for the performance of activities like transfers and wheelchair propulsion from the beginning of their acute rehabilitation. Evidence suggests that manual wheelchair propulsion contributes to upper extremity pain due to the additional forces imposed at the joints (Fronczak et al., 2003; Van Drongelen et al., 2005). Excessive wear and tear of the upper extremity joints starts from the beginning of SCI due to personal, wheelchair related and built environmental factors.

Laboratory based research has shown that experienced and non experienced manual wheelchair users demonstrate differences in their pushrim kinetics applied on the handrim (Robertson et al., 1996). Very few studies have focused on the measurement of wheelchair propulsion kinetics in the different environmental conditions (Hurd et al., 2008c; Kilkens et al., 2005). No specific studies have been published in the scientific literature to distinguish differences between propulsion kinetics generated in new and experienced wheelchair users with SCI under commonly encountered natural environmental conditions.

CHAPTER THREE

METHODS AND PROCEDURES

3.1 PARTICIPANTS

There were two groups of participants included in this study. One group was individuals with SCI who were undergoing acute rehabilitation and the second group was individuals with chronic SCI who were living in the community at least since one year after their injury.

3.1.1 Recruitment

3.1.1.1 Participants in acute group

Participants in the acute group were recruited from individuals with SCI who were undergoing acute rehabilitation at the Glenrose Rehabilitation Hospital (GRH). The procedure of the study was explained by the researcher to the physical therapists working in the SCI unit at GRH. The physical therapists were asked to recruit the participants who met the following inclusion criteria:

1.) People with SCI between 18-65 years of age
2.) Undergoing their acute rehabilitation
3.) Full time manual wheelchair users

3.1.1.2 Participants in chronic group

The chronic group was tested after the acute group. Participants in the chronic group were matched with the acute group by the level of injury (see Table 3.1).

Table 3.1: Matching between the groups by level of injury

	C6-C8 (3 in each group)	**T1-T6 (4 in each group)**	**T7 and below (6 in each group)**
Acute	C6, C6-7, C8-T1	T3, T4, T4, T5-T6	T9, T9, T11, T11-T12, T12-L1, T12-L2
Chronic	C6-C7, C7-C8, C7-T1	T4, T4, T4-T5, T6	T8-9-10, T11-T12, T11-12, L1, L2, L2- L3

Recruitment for participants in chronic SCI group was done through GRH, Canadian Paraplegic Association (CPA) and through exercise and fitness centers in the community. Through the participants we recruited from CPA, we learned about recreation centers in the city and we went there to recruit people with SCI in the community. Posters including the study objectives, eligibility criteria and benefits of the research study were posted at all those places.

Based on the acute group, for chronic group we included only males with SCI with the following inclusion criteria:

1.) Males with SCI between 18-65 years of the age
2.) Living in the community at least one year after SCI
3.) Full time manual wheelchair users

3.2 SAMPLE SIZE

The sample size for this study was estimated using result of previous comparative study about analyzing the pushrim forces and joint kinetics during propulsion in new and experienced manual wheelchair users (Robertson et al., 1996). This study was conducted in a laboratory setting and participants were asked to push a wheelchair fitted with a Smartwheel for 20 seconds on a stationary wheelchair dynamometer at a fixed speed. Five consecutive strokes at the middle of the bout were collected for analysis. The study concluded that experienced manual wheelchair users applied lower peak forces on the handrim during propulsion. They demonstrated a large effect size (1.97). With a large effect size, of at least 1.00, a desired statistical power of 0.80, and a significance level of $p < .05$, 13 subjects were required in each group (Cohen, 1988) (Appendix E).

3.3 INSTRUMENTATION

In this study, data relevant to wheelchair propulsion kinetics was collected and examined using the Smartwheel. In addition, shoulder pain was assessed using the Wheelchair Users Shoulder Pain Index scale (WUSPI) (Curtis et al., 1995b).

3.3.1 The Smartwheel

A 24" Smartwheel (Three Rivers Holdings, Mesa Arizona) was used to calculate the propulsion kinetics applied by the participants in both groups under different environmental conditions. The Smartwheel has demonstrated excellent accuracy, linearity, and precision in measuring propulsion kinetics applied at the pushrim (Asato et al., 1993; Cooper, Robertson, VanSickle, Boninger, & Shimada, 1997). Details about the system components and the functioning of the Smartwheel have been discussed earlier in Chapter 2 under section 2.5.4. For the current study, data for the acute group was initially collected using Smartwheel 2005 software. After the release of the Smartwheel 2008 software, all data from the old version was transferred to the new software and new reports were generated.

3.3.2 Wheelchair Users Shoulder Pain Index (WUSPI)

We used the WUSPI to measure the intensity of shoulder pain experienced by the participants while performing different activities of daily living (see Appendix F). The WUSPI was designed to measure the severity of shoulder pain with functional activities in persons who use manual wheelchairs (Curtis et al., 1995a). The WUSPI has shown high levels of test-retest reliability (0.99) and internal consistency (Cronbach's alpha = 0.98), as well as concurrent validity (Curtis et al., 1995b). Concurrent validity was established, as total score on the WUSPI showed a significant negative correlation to shoulder range of motion

(ROM), indicating decreasing shoulder ROM with increased score on the WUSPI (Curtis et al., 1995b).

There were two parts to the WUSPI questionnaire. In the first part of the questionnaire, participants answered the questions about their history of shoulder pain during rest, currently, before or after manual wheelchair use. The second part of the WUSPI contained 15 items representing functional activities in four areas: transfers, wheelchair mobility, self-care, and general activities (see Appendix F). The scale collected information on shoulder pain experienced while performing functional activities in past seven days. In the current study, the second part of WUSPI was used for the analysis.

On the second part of WUSPI scale, the participants respond to each of the 15 items using a Visual Analogue Scale anchored by the phrases “no pain” at zero indicating that shoulder pain did not interfere with the activity and “worst pain ever experienced” at 10 cm indicating shoulder pain completely interfered with that activity. Participants also respond “not performed” if they did not perform any of the activities in past week. The total index score was calculated by taking the sum of individual item scores. Thus, total index score ranged from 0 to 150. The average WUSPI score was calculated by dividing the total score by the number of completed items.

PROCEDURES

3.4.1 Acute group

Data collection for participants in the acute group was done at the GRH. The information letter was provided to the participant by the physical therapists working in SCI unit at GRH and consent was obtained. During the test day, the Smartwheel general questionnaire that provided general information about the participant and his SCI (see Appendix G) was completed by the physical therapists in the SCI unit. Prior to the wheeling test, the investigator administered the WUSPI scale to the participant. For example, the investigator read the questions and the participant indicated his response to each individual question in the scale.

Subsequently, the participant was asked to transfer to a comfortable exercise bed (transfer board or manual assistance was provided if needed). The Smartwheel was then fitted on the dominant side of participant's own wheelchair. Application of the Smartwheel rim did not alter individual wheelchair settings. After the participant moved to his wheelchair fitted with the Smartwheel, the Smartwheel was switched on to communicate with a wirelessly connected computer. At that time, according to the instructions provided by the Smartwheel user's guide, the participant was asked to sit as stationary as possible by keeping his hands on his lap (Smartwheel User's Guide 2008).

The required information about the participant (see Figure 3.1) was inputted into the Smartwheel software in the computer.

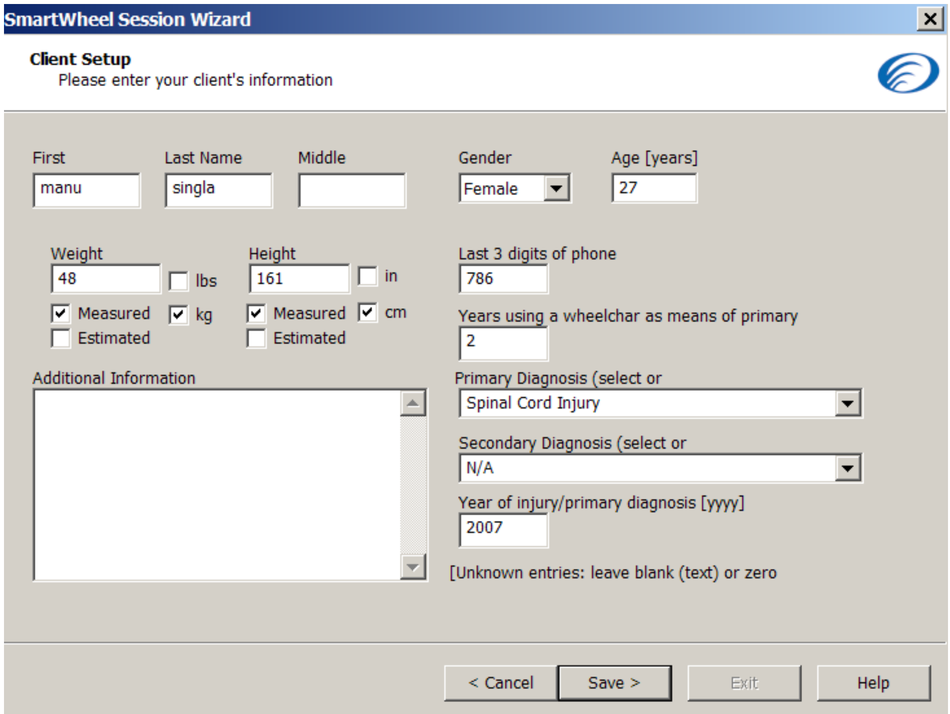

Figure 3.1: The set up screen

The participant was asked to wheel (for at least 5 minutes) to familiarize himself with the wheelchair fitted with the Smartwheel. Once he felt comfortable with wheeling, he was asked to complete the wheeling tasks as specified by the Smartwheel Standard Clinical Evaluation Protocol (SSCEP) (see Appendix H). The SSCEP included, 1) 10m of straight line wheeling over a smooth, level, tile floor; 2) 8m of straight line wheeling over a smooth, level, low pile carpet; 3) wheeling up a 5m ramp; 4) figure-8 wheeling on a smooth level tile floor. Figure-8 wheeling protocol was not included during data collection because it is a skill assessment of maneuverability and it can not be accurately assessed using one Smartwheel. The instructions provided to the participant during testing were taken from the each component of the SSCEP (see Appendix H). It took 90 minutes in total to complete the testing.

3.4.2 Chronic group

The procedures for the chronic group were exactly the same as the acute group except for the research site. Data collection for the chronic group was done at the Department of Physical Therapy, University of Alberta. From the beginning of the study, we used Smartwheel 2008 software for the data collection about propulsion kinetics applied by the participants under different environmental conditions.

The tiled surface and the 8m smooth and leveled low pile carpet used at the new research site for the tile and carpet protocol respectively, were the same as the tile and carpet surface we used at the GRH. The ramp used for the chronic group had a 5 degree slope which was the same as the ramp used to test the acute group.

Before the beginning of data collection for the chronic group, we proposed that we would use a standardized wheelchair to control different confounding factors which might be associated with the participant's own wheelchairs in the community. Considering that, we started testing participants in our standard wheelchair [Invacare make (16"X18"X14")]. However, we had challenges with some participants when using a wheelchair that was not their own. They did not feel comfortable to be tested in the standard wheelchair (i.e. for the most part there was challenge with balance in the persons with higher levels of injury).

Many reported that wheeling in the standard wheelchair did not feel like their usual wheeling. Therefore, we tested participants in their own wheelchairs. When possible, we tested participants in their own wheelchair, and in the standard wheelchair.

3.5 DATA ANALYSIS

Statistical analysis in the current study was performed using SPSS software (version 16.0; SPSS Inc, Chicago, IL).

3.5.1 Descriptive statistics

The participant's personal characteristics were described using mean and standard deviation or appropriate identifier depending on the level of measurement.

3.5.2 Factorial ANOVA

We used Factorial ANOVA to determine the interaction and main effects of group (acute and chronic) and condition (tile, carpet and ramp) for dependent variables such as peak force, push frequency, push length and speed and push mechanical effectiveness.

3.5.3 Correlation analysis

The association between perceived shoulder pain in the last week and propulsion kinetics applied under different environmental conditions in each group was explored using Pearson's Product Moment correlation. Statistical significance was set at $p < 0.05$.

CHAPTER FOUR

RESULTS

4.1 PARTICIPANT CHARACTERISTICS

Two groups of people with SCI were included in this study with 13 participants in each group. Participants in both groups were full time manual wheelchair users. The first group consisted of individuals undergoing acute rehabilitation after SCI and the second group was people with chronic SCI who were living in the community at least one year after their injury. The demographic and SCI- related descriptive information of participants in each group have been summarized in Table 4.1 & 4.2.

Groups were matched by the level of injury. In each group there were 3 of 13 participants with a level of injury between C6-C8, 4 with injuries between T1-T6 and 6 participants with a level of injury T7 and below. Among the participants in the acute group, 5 of 13 had complete SCI, 4 had incomplete SCI and for 4 participants their extent of SCI was unknown. In the chronic group, 10 of 13 participants had complete SCI and 3 had incomplete. Out of 13 participants in the chronic group, 7 participants were involved in a three times a week exercise program in the community. There was no significant difference found between the groups for shoulder pain reported on WUSPI scale ($p = 0.337$). Four of 13 participants in the acute group and 5 of 13 participants in the chronic group scored the lowest possible score (i.e. zero) on the WUSPI indicating they had no pain while performing different ADLs in the past week.

Table 4.1: Personal characteristics for 13 participants in acute group

Age (Yr)	Body weight (Kg)	Height (cm)	Level of Injury	Extent of injury (complete/ incomplete)	Time since injury (month)	Wheelchair use (Hours/day)	Average WUSPI Score	Wheelchair make
21	61	173	T9	Complete	2	10	0.1	TiLite
19	64	178	C8-T1	Unknown	2.5	9	0.8	Quickie
29	75	178	T3	Complete	2	9	0.7	TiLite
19	62	185	C6-C7	Complete	3	8	0	TiLite
49	73	175	T5-T6	Incomplete	2.5	8	0	Quickie
49	72	183	T12-L2	Complete	4	8	0	Quickie
56	79	175	T11	Incomplete	2	9	0	Action Pro
20	77	175	C6	Incomplete	4	12	0.5	TiLite
41	50	173	T12-L1	Unknown	4	8	0.4	Quickie
29	64	180	T4	Unknown	2.5	12	0.9	TiLite
41	91	191	T4	Incomplete	5	10	1	TiLite
37	75	173	T9	Complete	2	14	0.2	Quickie
24	50	175	T11-T12	Unknown	3.5	10	3.1	Quickie
Mean(Standard Deviation)								
33.4 (12.9)	68.7 (11.6)	178.0 (5.5)	-	-	3.0 (1.0)	9.8 (1.9)	0.6 (0.8)	-

WUSPI = Wheelchair User Shoulder Pain Index

Average score of WUSPI was calculated by dividing the total score for shoulder pain ranged from 0 – 150 on Visual analogue scale in WUSPI by the number of completed item out of 15 activities of daily living.

Table 4.2: Personal characteristics for 13 participants in chronic group

Age (Yr)	Body weight (Kg)	Height (cm)	Level of Injury	Extent of injury (complete/ incomplete)	Time since injury (Years)	Wheelchair use (Hours/day)	Average WUSPI Score	Wheelchair make
36	104	185	L2	Incomplete	8	16	1.4	Invacare
33	73	168	T6	Complete	15.5	16	0	Top End
55	103	175	L1	Incomplete	10.2	14	0	Quickie
44	100	178	C6-C7	Complete	26	15	0.5	Quickie
61	86	180	T11-T12	Complete	24	16	1.7	TiLite
52	64	185	C7-T1	Complete	6	15	0	TiLite
23	70	`75	T8-9-10	Complete	2.9	15	0.4	Colours
44	77	193	T4	Complete	19.7	15	0.9	Quickie
26	75	185	C7-C8	Complete	7.8	15	0	Quickie
42	72	173	L2-L3	Complete	32	14	3.8	Quickie
40	87	175	T4-T5	Complete	8	15	3.1	TiLite
31	73	180	T4	Complete	1.8	10	0	TiLite
25	74	175	T11-T12	Incomplete	1.3	10	1.4	Quickie
Mean(Standard Deviation)								
39.4 (11.9)	81.4 (13.4)	177.5 (7.5)	-	-	12.6 (123.9)	14.3 (2.0)	1.0 (1.2)	-

WUSPI= Wheelchair User Shoulder Pain Index

Average score of WUSPI was calculated by dividing the total score for shoulder pain ranged from 0 – 150 on Visual analogue scale in WUSPI by the number of completed item out of 15 activities of daily living.

4.2 FACTORIAL ANOVA

A 3X2 Factorial ANOVA was used to determine the interaction effect (group by condition) and the main effects of group (acute and chronic) and environmental condition (tile, carpet and ramp) on propulsion kinetics applied such as peak force normalized with participant's body weight, push frequency, push length, speed and push mechanical effectiveness (PME). Statistical significance was set at $p < 0.05$.

The mean and the standard deviation of each propulsion parameter applied by the groups under different environmental conditions and their comparison with the national database (Cowan et al., 2008) are shown in Table 4.3. In the acute group, we had missing data for the tile protocol for one participant.

There was no significant interaction effect (group by condition) found for any of the dependent variables. We found a significant main effect of the group for PME. We also found a significant main effect of condition for all the variables except for average push frequency (see Table 4.4).

There was a main effect of environmental condition for peak force, push length, speeds and PME. A Bonferroni post hoc test was performed to determine where the difference lay. We found a significant difference between the values for the outcomes of force and speed ($p < 0.01$) for all three environmental conditions (tile, carpet and ramp). PME ratio on ramp was significantly different from tile and carpet ($p < 0.003$). Push length on tile was significantly different from carpet and ramp ($p < 0.025$).

Table 4.3: Descriptive statistics for propulsion kinetics for both groups under different environmental conditions in current study and their comparison with the national database

Tile			
	Acute group	**Chronic group**	**Average from National database** (Cowan et al., 2008).
Force (weight normalized)%	9.1± 3.0	9.3± 4.2	9.7
Push frequency (1/sec)	1.1± 0.2	0.9± 0.2	1.0
Push length (degree)	62.8± 10.2	64.1± 22.4	100.6± 18.0
Push speed (m/s)	1.5± 0.3	1.4± 0.3	1.2± 0.3
PME (%)	0.7± 0.1	0.6± 0.2	Not available
Carpet			
	Acute group	**Chronic group**	**Average from National database**
Force (weight normalized)%	12.8± 3.3	11.3± 3.6	10.8
Push frequency (1/sec)	1.1± 0.2	1.1± 0.2	1.0
Push length (degree)	76.7± 12.9	73.4± 12.2	97.2± 19.6
Push speed (m/s)	1.1± 0.2	1.1± 0.3	1.0± 0.3
PME (%)	0.8± 0.1	0.7± 0.1	Not available
Ramp			
	Acute group	**Chronic group**	**Average from National database**
Force (weight normalized)%	16.5± 3.6	18.4± 7.6	16.2
Push frequency (1/sec)	1.2± 0.2	1.1± 0.3	1.0
Push length (degree)	73.5± 14.2	87.1± 16.2	94.1± 20.6
Push speed (m/s)	0.8± 0.3	1.0± 0.4	0.7± 0.3
PME (%)	0.9± 0.1	0.8± 0.1	Not available

Mean± standard deviation
PME = Push Mechanical Effectiveness
Note: Standard deviations for Force (weight normalized) % and Push frequencies on tile and carpet in national database were not available.

Table 4.4: Interaction and main effects of group and environmental condition on propulsion kinetics

	Main effect Groups		**Main effect Environmental conditions**		**Group * Environmental conditions**	
	F Value	**P Value**	**F Value**	**P Value**	**F Value**	**P Value**
Force (Weight Normalized) %	0.047	0.829	21.989	0.000	0.954	0.390
Average push frequency (1/sec)	2.295	0.134	2.565	0.084	0.345	0.710
Average push length (degree)	1.241	0.269	8.154	0.001	2.121	0.127
Average speed (m/s)	0.262	0.611	17.433	0.000	1.394	0.255
PME (%)	8.782	0.004	14.689	0.000	0.139	0.870

Group * Environmental conditions: Two- way group by environmental condition interaction
F Value: the variance of propulsion variables attributed to main effects of group and condition and group by condition interaction effect
P Value: level of significance
PME: Push Mechanical Effectiveness

4.3 CORRELATION ANALYSIS

Table 4.5 presents the results of the correlation analysis performed to determine if there was an association between perceived shoulder pain while performing different ADLs in the past week and propulsion kinetics applied under different environmental conditions. For the participants in the acute group, we found that higher perceived shoulder pain was significantly associated with higher forces applied on the tile surface ($p = 0.007$). In the acute group, we also found that higher perceived shoulder pain was significantly associated with higher push frequency on tile ($p = 0.006$) and carpet ($p = 0.035$). For the chronic group, there were no significant associations between the average scores obtained for shoulder pain from WUSPI scale and any of the propulsion kinetics applied on tile, carpet and ramp.

Because nine of the 26 participants had no reported shoulder pain, we re-ran the correlation analysis with those pain-free individuals excluded. For the acute group we found that higher PME on the ramp was significantly associated with lower shoulder pain ($p = 0.013$). In the acute group, we also found that higher perceived shoulder pain was significantly associated with higher push frequency on tile ($p = 0.034$). In the chronic group, there remained no significant associations.

Table 4.5: Correlation matrix of propulsion kinetics and WUSPI score in acute and chronic group

Variables	Acute Group *r* Value	Acute Group *p* Value	Chronic group *r* Value	Chronic group *p* Value
Tile Force (Weight Normalized) %	0.734	0.007**	0.263	0.386
Carpet Force (Weight Normalized) %	0.132	0.668	0.393	0.184
Ramp Force (Weight Normalized) %	- 0.134	0.663	0.215	0.480
Tile Frequency (1/s)	0.740	0.006**	0.127	0.679
Carpet Frequency (1/s)	0.587	0.035 *	- 0.109	0.723
Ramp Frequency (1/s)	- 0.379	0.201	0.311	0.301
Tile Push Length (degree)	- 0.215	0.502	0.294	0.330
Carpet Push Length (degree)	- 0.464	0.110	0.346	0.247
Ramp Push Length (degree)	- 0.156	0.611	0.088	0.776
Tile Speed (m/s)	0.401	0.197	0.191	0.533
Carpet Speed (m/s)	0.020	0.948	0.369	0.215
Ramp Speed (m/s)	- 0.468	0.107	0.212	0.487
Tile PME (%)	- 0.085	0.792	0.098	0.750
Carpet PME (%)	-0.141	0.646	0.290	0.336
Ramp PME (%)	-0.128	0.676	0.124	0.688

*Pearson Correlation is significant at the 0.05 level (2- tailed)
**Pearson Correlation is significant at the 0.01 level (2- tailed)
WUSPI= Wheelchair User Shoulder Pain Index

Average score of WUSPI was calculated by dividing the total score ranged from 0 – 150 on Visual analogue scale in WUSPI by the number of completed item out of 15 activities of daily living.

PME = Push Mechanical Effectiveness

Finally, as there was no significant main effect of group for weight normalized peak force, push frequency, push length and speed under different environmental conditions, we combined the groups to examine the relationships between pain and these four propulsion kinetics with the total sample. After combining the groups, we found a significant positive relationship between shoulder pain score on WUSPI scale and weight normalized peak force on tile (p= 0.048).

Figure 4.1 to 4.15 provide scatter plots for the correlation between shoulder pain and propulsion kinetics under each environmental condition for each group separately. The r and p values for correlation between shoulder pain and propulsion kinetics for all 26 participants have been shown under each figure.

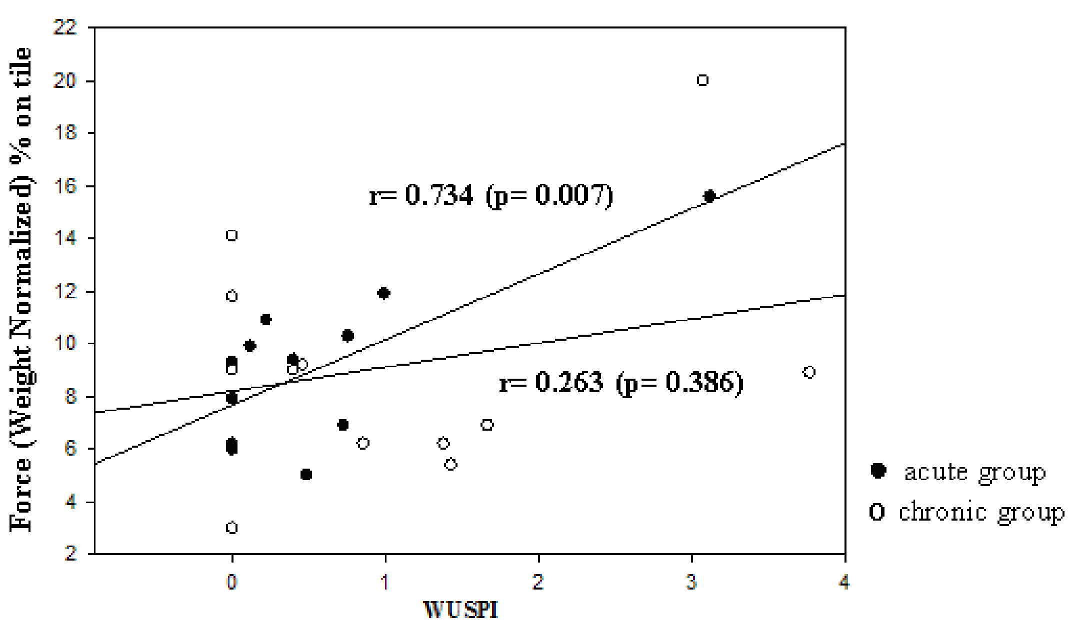

Figure 4.1: Correlation between force (Weight Normalized) % on tile and WUSPI score. Correlation for total sample (N= 25) is r= 0.399 (p= 0.048).

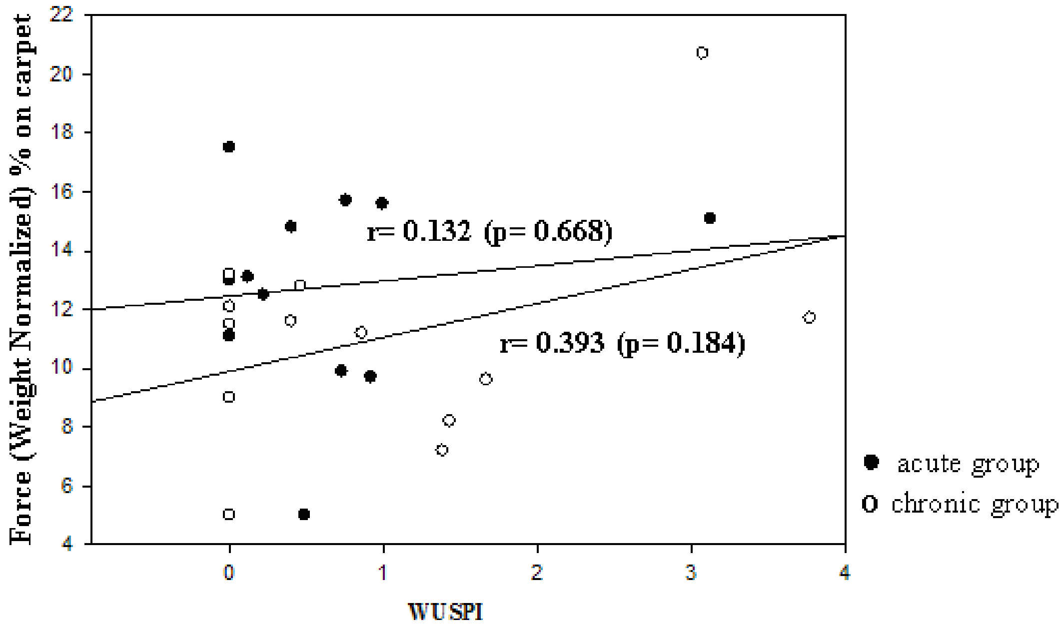

Figure 4.2: Correlation between force (Weight Normalized) % on carpet and WUSPI score. Correlation for total sample (N= 26) is r= 0.224 (p= 0.271).

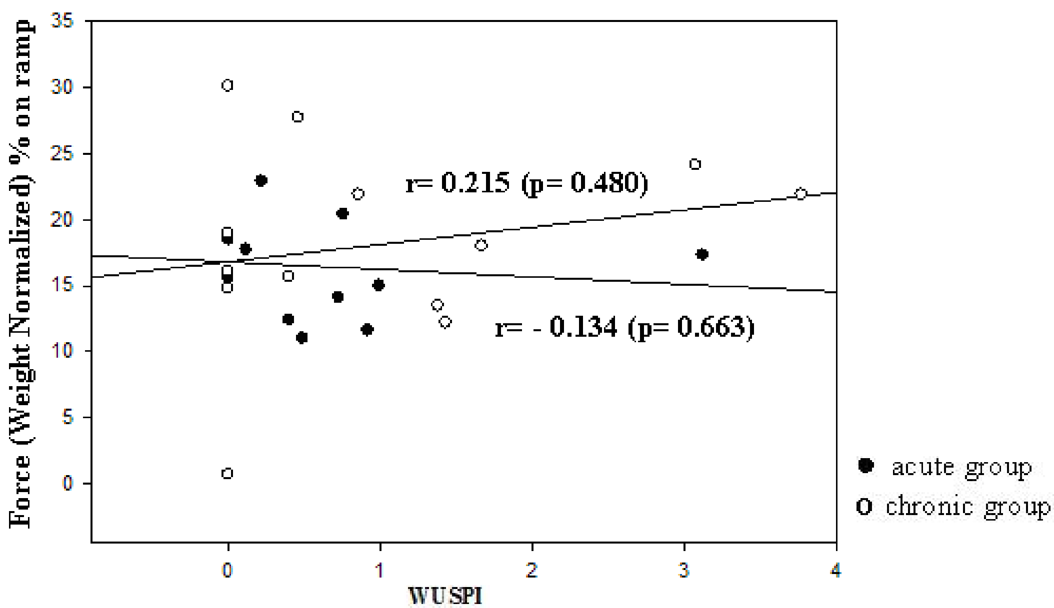

Figure 4.3: Correlation between force (Weight Normalized) % on ramp and WUSPI score. Correlation for total sample (N= 26) is r= 0.153 (p= 0.455).

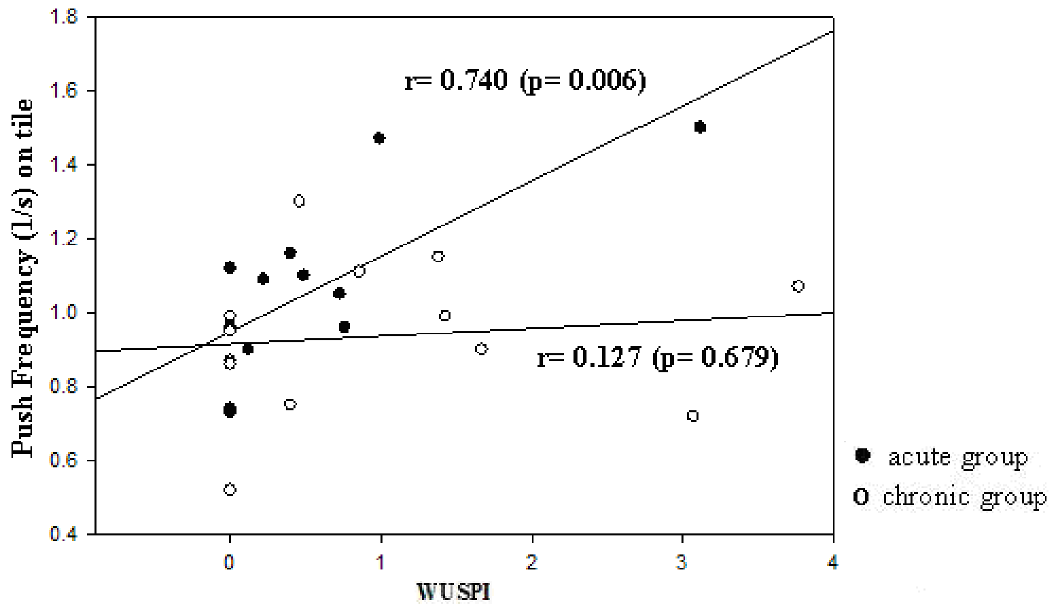

Figure 4.4: Correlation between push frequency on tile and WUSPI score. Correlation for total sample (N= 25) is r= 0.297 (p= 0.149).

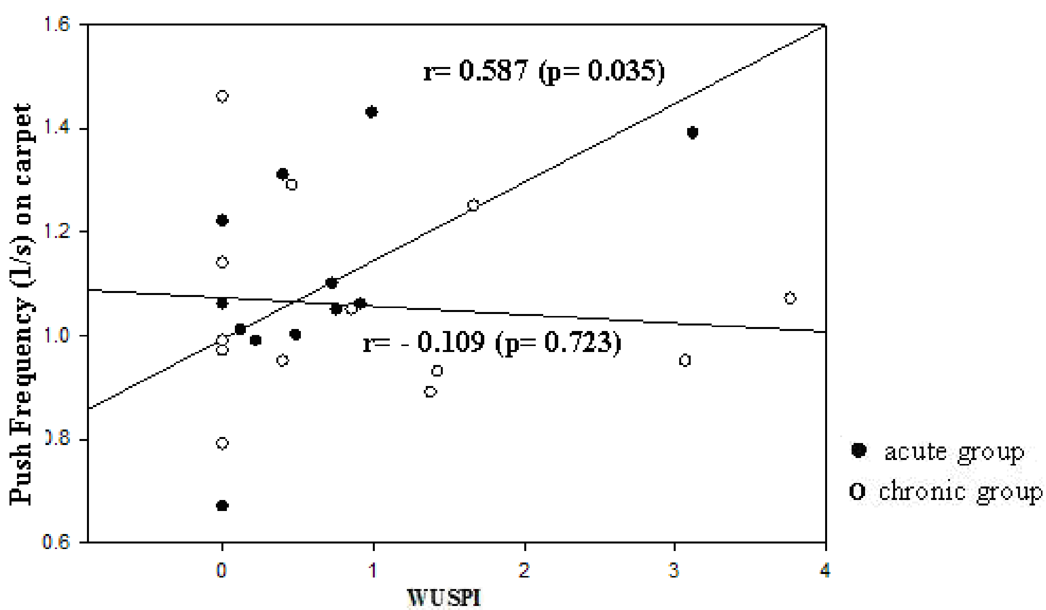

Figure 4.5: Correlation between push frequency on carpet and WUSPI score. Correlation for total sample (N= 26) is r= 0.175 (p= 0.393).

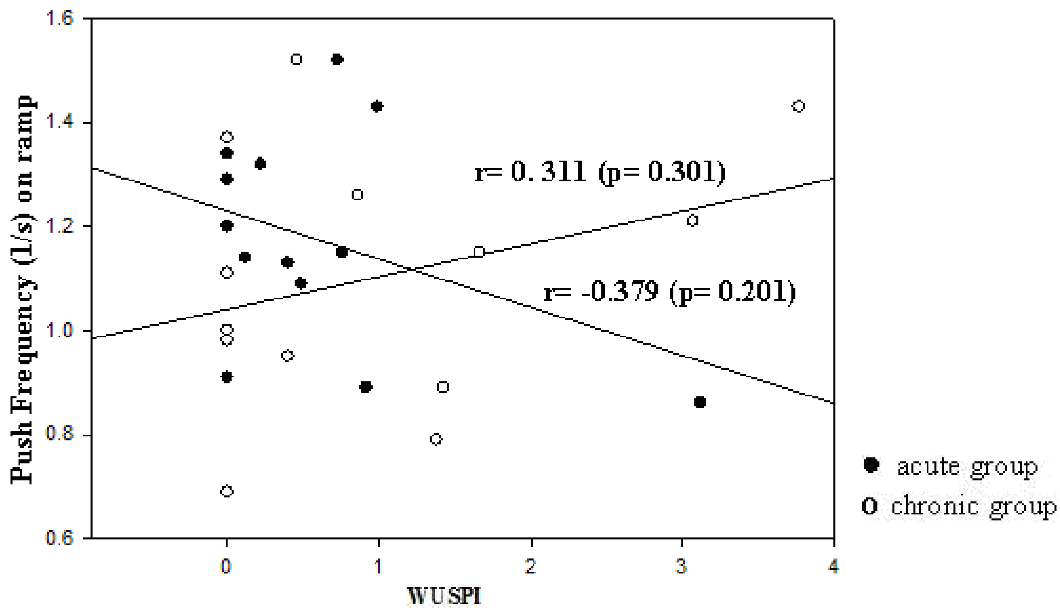

Figure 4.6: Correlation between push frequency on ramp and WUSPI score. Correlation for total sample (N= 26) is r= 0.030 (p= 0.883).

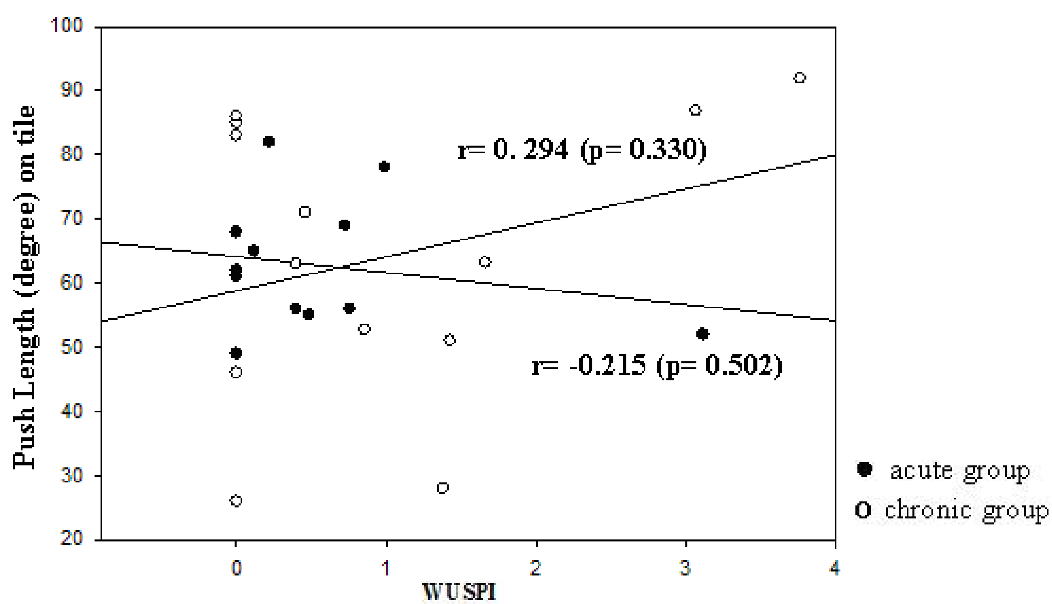

Figure 4.7: Correlation between push length on tile and WUSPI score. Correlation for total sample (N= 25) is r= 0.179 (p= 0.392).

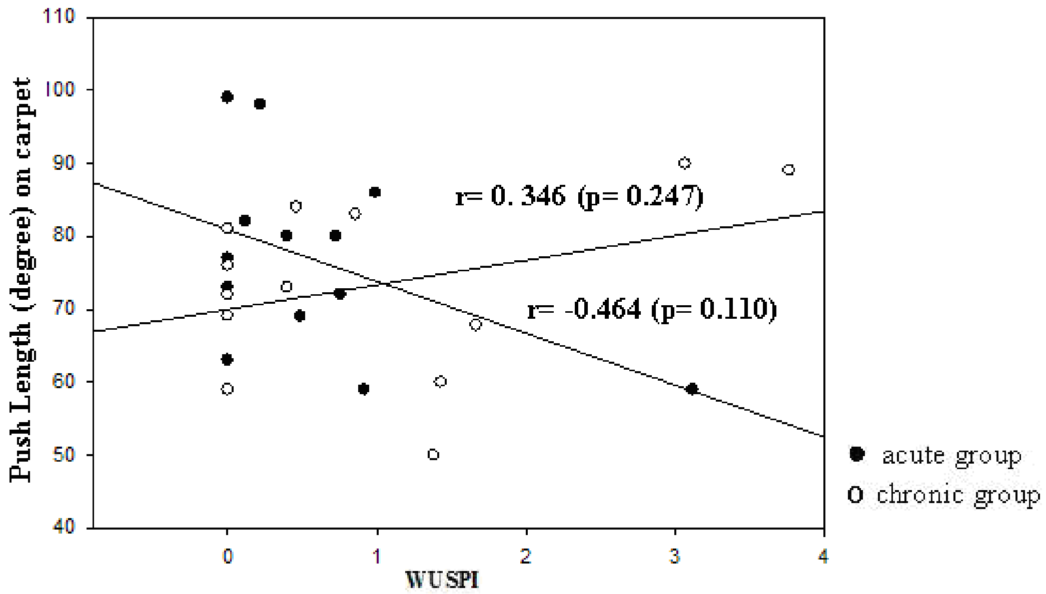

Figure 4.8: Correlation between push length on carpet and WUSPI score. Correlation for total sample (N= 26) is r= - 0.022 (p= 0.914).

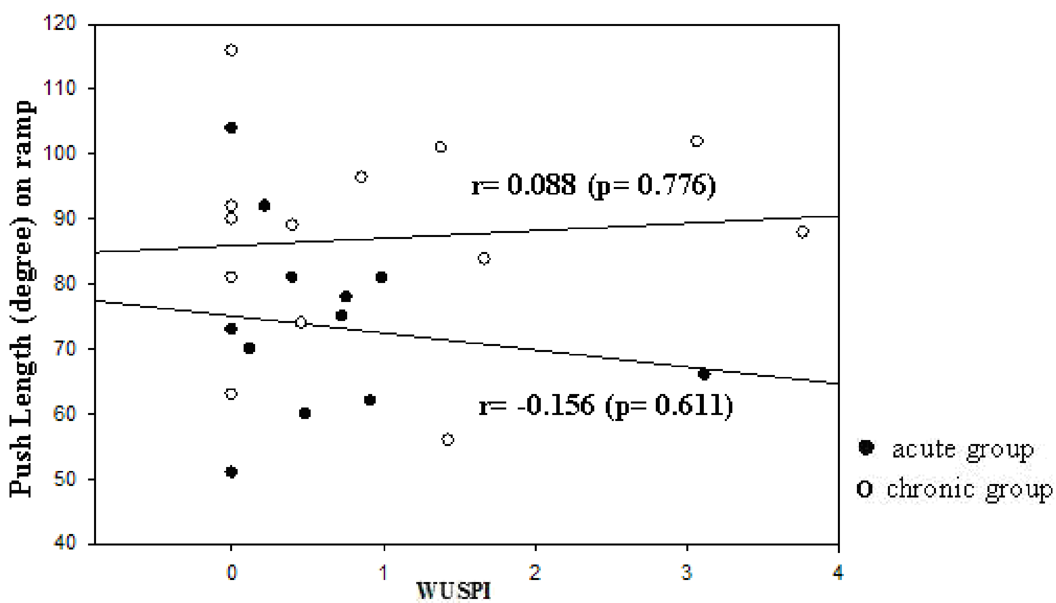

Figure 4.9: Correlation between push length on ramp and WUSPI score. Correlation for total sample (N= 26) is r= 0.080 (p= 0.699).

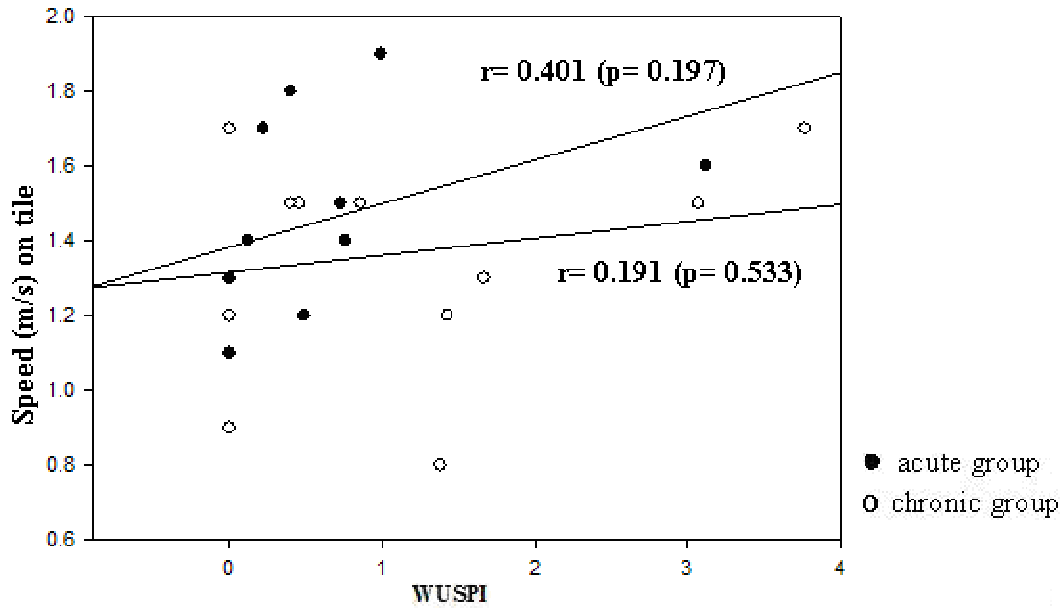

Figure 4.10: Correlation between speed on tile and WUSPI score. Correlation for total sample (N= 25) is r= 0.222 (p= 0.287).

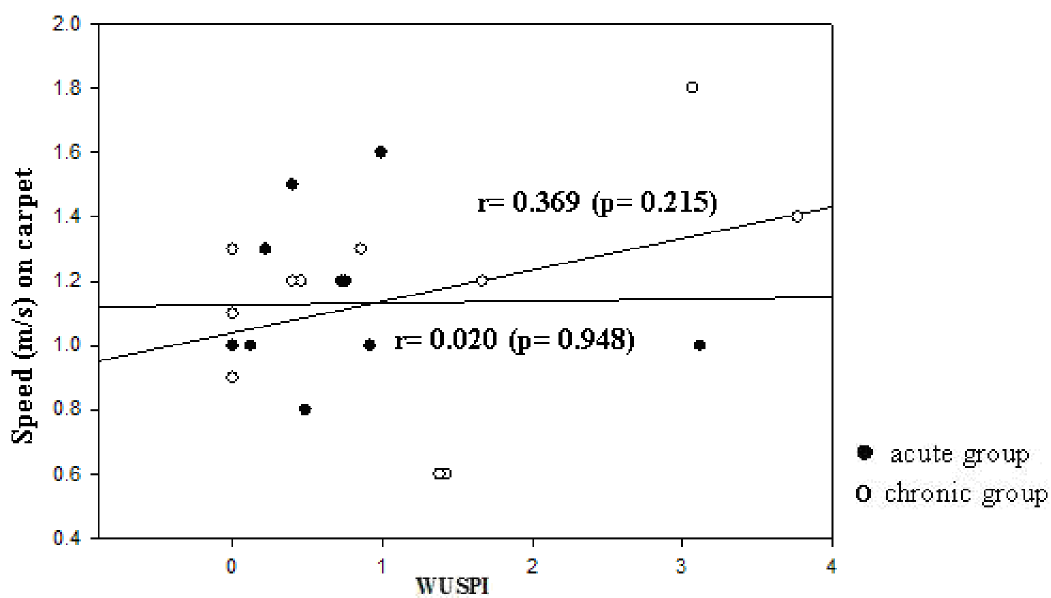

Figure 4.11: Correlation between speed on carpet and WUSPI score. Correlation for total sample (N= 26) is r= 0.254 (p= 0.210).

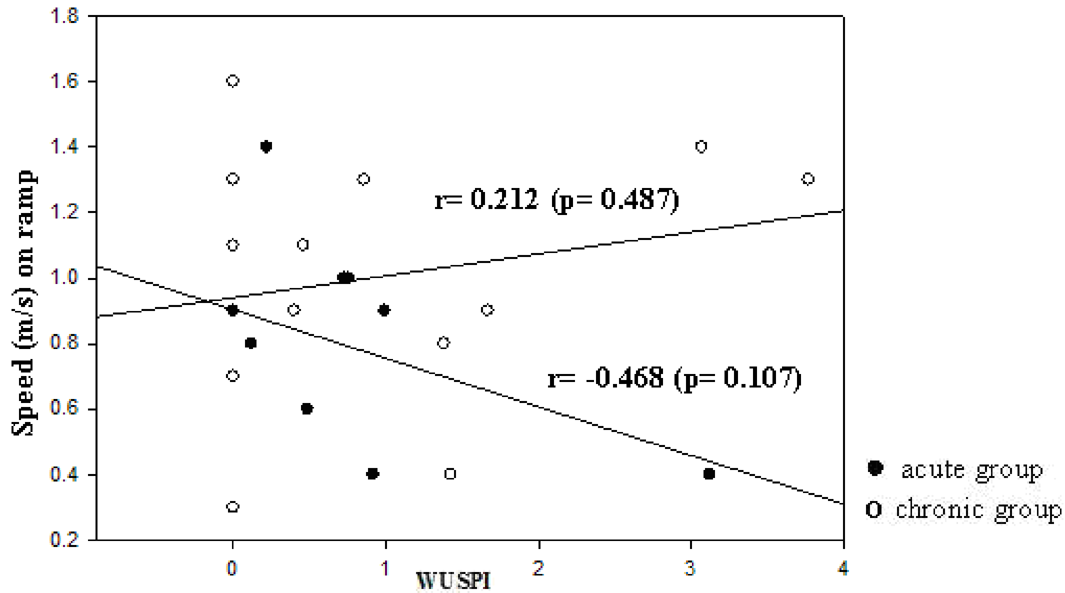

Figure 4.12: Correlation between speed on ramp and WUSPI score. Correlation for total sample (N= 26) is r= 0.052 (p= 0.802).

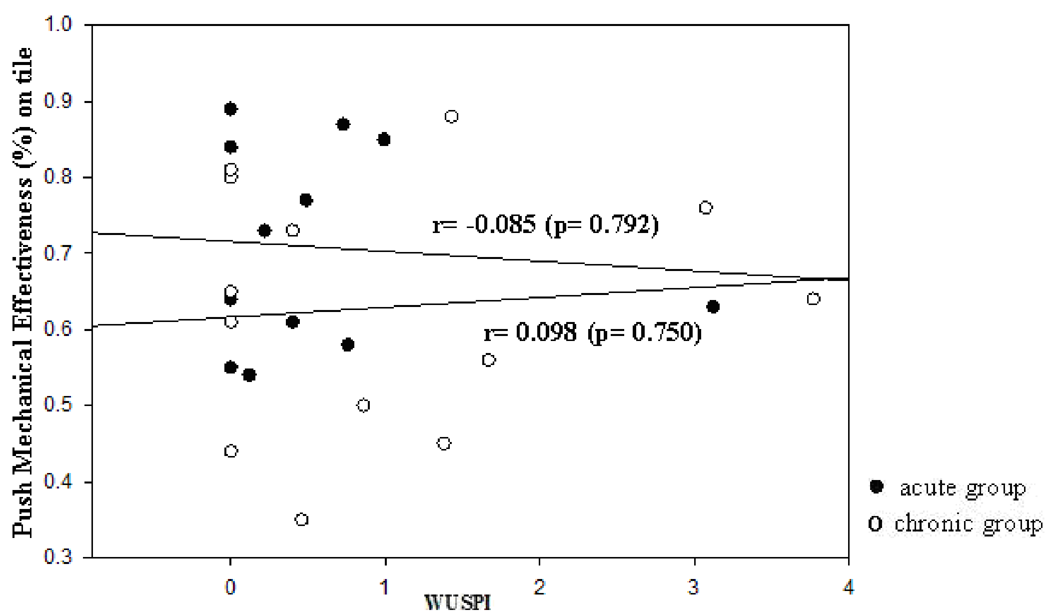

Figure 4.13: Correlation between push mechanical effectiveness on tile and WUSPI score.

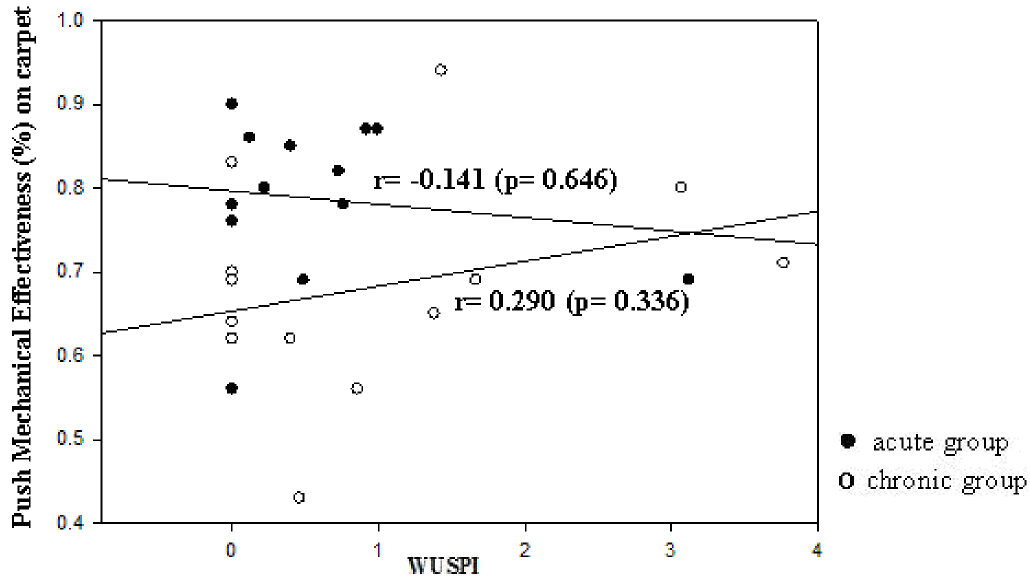

Figure 4.14: Correlation between push mechanical effectiveness on carpet and WUSPI score.

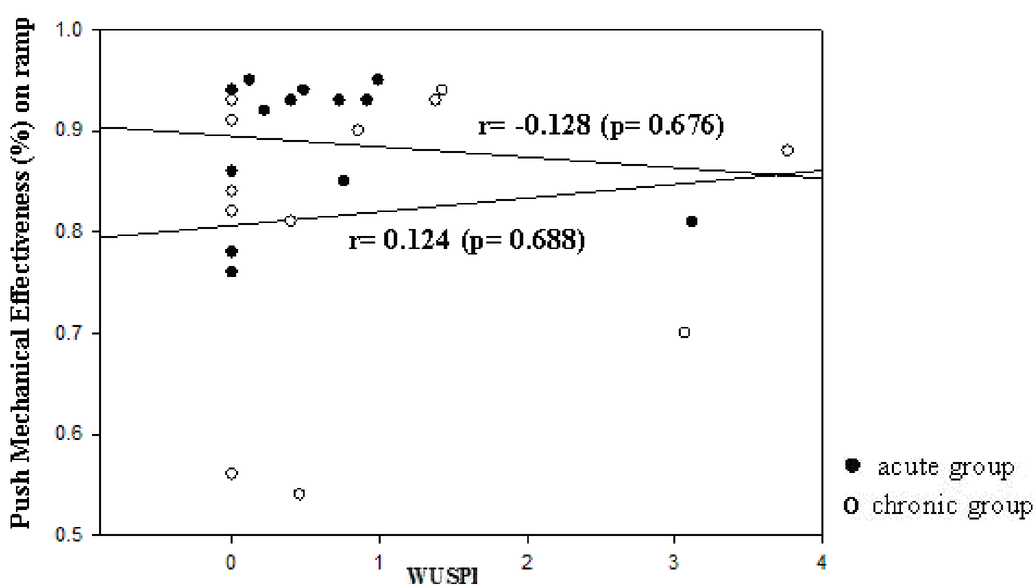

Figure 4.15: Correlation between push mechanical effectiveness on ramp and WUSPI score

CHAPTER FIVE

DISCUSSION

The main purpose of this study was to determine if there was a significant difference in wheelchair propulsion kinetics applied between people with acute and chronic SCI under different environmental conditions. We also wanted to determine if there was a relationship between propulsion kinetic outcomes and perceived shoulder pain while performing activities of daily living. We selected five pushrim variables, most relevant to wheelchair propulsion, including steady state peak force, push frequency, push length, speed and push mechanical effectiveness (PME).

5.1 Differences in propulsion kinetics applied between groups

We hypothesized that there would be a difference in the wheelchair propulsion kinetics applied between the groups under different environmental conditions such as tile, carpet and ramp. Our hypothesis was not fully confirmed by the results of present study. Specifically, for four propulsion kinetics variables we studied including peak force, push frequency, push length and speed there was no difference between the acute and chronic groups. Our findings with respect to these variables are different than previous research (Robertson et al., 1996; Kotajarvi et al., 2004).

Robertson et al. (1996) investigated pushrim forces applied between four experienced (2 out of 4 were people with SCI) and four non experienced manual wheelchair users under the laboratory settings. Participants were asked to propel a wheelchair fitted with a Smartwheel on a stationary wheelchair dynamometer at a fixed speed (Robertson et al., 1996). In this study the experienced group pushed with a longer push length and used lower peak forces at the pushrim on a level surface than non experienced group.

In an another study, Kotajarvi et al. (2004) asked 13 experienced manual wheelchair users with SCI and 20 non experienced manual wheelchair users to propel a Quickie II ultra lightweight sports wheelchair on level tile surface with the axle in 9 different horizontal and vertical positions. The main purpose of their study was to determine the effect of seat position on pushrim biomechanics. A wheel with instrumented pushrim (developed and validated in their lab) was mounted to the wheelchair to collect the kinetic data (Kotajarvi et al., 2004). In this study the experienced group pushed with a longer push length at a lower push frequency and used lower peak forces at a self selected speed on a level surface as compared to non experienced group.

Though there was no significant main effect of group for peak force, push frequency, push length and speed, we did find a significant difference between the groups for PME. This finding is similar to Kotajarvi and group's findings. PME characterizes how effectively individuals apply force to the pushrim which contributes directly to the forward motion. It is given as a ratio between tangential force and resultant force (Ft/F) (Smartwheel User's Guide, 2008). Kotajarvi et al., (2004) showed a significant difference between the groups for fraction of effective forces (FEF) i.e. Ft/F ratio. Their values for Ft/F ratio were 55 and 64%

in non experienced and experienced wheelchair users respectively. Conversely, Robertson et al. (1996) did not find any significant difference in PME in their groups. They calculated PME as a ratio between tangential force and resultant force squared (Ft^2/F^2). The Ft/F ratio is similar to Ft^2/F^2 but not identical (Boninger et al., 1997b). Ft^2/F^2 ratio in their groups ranged from 73-79%.

In the current study, the PME (Ft/F) values in our chronic and acute groups were of 60% and 70% respectively. We expected that due to greater experience in wheelchair propulsion our chronic group would show a higher PME ratio as compared to the acute group. Our finding that the acute group wheeled with greater mechanical effectiveness than the chronic group suggests that some of the gains made during acute rehabilitation related to propulsion, may be lost in the community. Nevertheless, our sample size is small and further study is required.

The discrepancies between our findings and previous research may be explained in several ways including differences in experimental set up, differences in samples, and differences in wheelchairs. Both previous studies were conducted within the laboratory setting. In Robertson's study, participants propelled a wheelchair fitted with Smartwheel on a stationary wheelchair dynamometer. In Kotajarvi's study, all participants propelled the same ultra light sports wheelchair in different axle positions on a 20m tile surface within the laboratory. The experimental set up in current study was different from the above mentioned studies because we quantified wheelchair propulsion effort under real world conditions.

Secondly, the non-experienced group in previous studies consisted of non-disabled individuals being tested in a wheelchair (Robertson et al., 1996; Kotajarvi et al., 2004). Though we examined experienced and new wheelchair users, all of our participants had an impairment that required them to use a wheelchair fulltime. Our new wheelchair user group was people with acute SCI who had 3.0± 1.0 months experience with the wheelchair propulsion due to their acute rehabilitation. Kilkens and colleagues conducted a research study with 121 people with SCI during their acute rehabilitation and concluded that wheelchair skill performance improved during inpatient rehabilitation as a consequence of practice and learning (Kilkens et al., 2005). In the current study the three months experience in wheelchair propulsion due to acute rehabilitation might have made the participants in acute group more like the participants in the chronic group.

Finally, the wheelchairs used in our study and previous studies differed. In the Robertson's study participants pushed a commonly used wheelchair fitted with a Smartwheel on a stationary wheelchair dynamometer (Robertson et al., 1996). In Kotajarvi's study, participants used an ultra light weighted sports wheelchair whose set up including pneumatic inner tube pressure, seat width, seat depth, and camber angle were kept same for all participants. Only horizontal and vertical axle positions were changed according to the testing protocol. The backrest and footrest heights were adjusted similar to participant's own wheelchair (Kotajarvi et al., 2004). In contrast, our participants used their own wheelchairs whose one wheel was replaced with a Smartwheel. Our participant's wheelchairs were similar in make across groups and were adjusted according to user's personal requirements. The majority of previous research shows that the type of wheelchair and its set up had an influence on the propulsion kinetic outcomes (Boninger et al., 2005; Cowan et al., 2009). Therefore, we believe that differences in wheelchairs and their set up might have influenced the propulsion performances in current and past studies. One past study, however, reported that there were no significant differences between the propulsion kinetic outcomes when the participants pushed their own wheelchair and a control wheelchair on tile and ramp surface (Ferguson-Pell et al., 2005). This study was performed with people with acute SCI just after their discharge from the hospital. The participants in Ferguson-Pell and colleague's study were new manual wheelchair users, the less experience in wheelchair propulsion may be a possibility that they did not show any difference in their performance in different wheelchairs.

5.2 Influence of different environmental conditions on propulsion kinetics

In the current study, we found a difference in wheelchair propulsion kinetics applied by people with SCI under different environmental conditions. This finding was expected and consistent with the largest Smartwheel study to date with people with SCI, where a difference in the propulsion kinetics was shown on different surfaces (Cowan et al., 2008). Cowan et al. (2008) conducted a study with 128 manual wheelchair users with SCI from multiple centers to describe a standard clinical protocol for the objective assessment of manual wheelchair propulsion. Participants in this study were asked to wheel their own wheelchairs fitted with a Smartwheel at a self selected speed across different environmental surfaces such as tile, carpet and a ramp. Cowan and colleagues established preliminary values for kinetic parameters including body weight normalized peak force, push frequency, push length and speed. Clinicians and researchers can compare their client's steady state propulsion kinetics with the normative values proposed in the national database.

Our values of peak force, push frequency and speed on different surfaces were similar to the values of the same proposed in the national database (see Table 4.3 in chapter 4). However, our participants used a significantly shorter push length (p= 0.001) on all three surfaces. Moreover, the national database found that push length was similar on different surfaces, which is contrary to our findings as our participants showed an increase in push length with the increase in the difficulty of the surfaces.

Cowan and colleague's study reported all the clinically important kinetic variables including peak force, push frequency, push length and speed, but they did not report PME under natural environmental conditions (Cowan et al., 2008). In the current study we compared the PME between people with SCI under commonly encountered environmental conditions. We showed that PME ratio increased with the increase in the difficulty with the surfaces. Our finding related to PME is similar to Koontz and colleague's finding where it was shown that mechanically effective force increased with the increase in the difficulty with the surfaces (Koontz et al., 2005).

In our study PME on ramp was significantly higher than tile and carpet surfaces (see Table 4.3 in chapter 4). Our finding infers that when environmental conditions became more demanding, the participants responded with a higher tangential force component to increase the PME ratio. Higher tangential force with increased task difficulty is not without its risks. In a previous study it was indicated that a high tangential force component may increase the shoulder joint kinetics and put more load on the front shoulder muscles (Desroches et al., 2008; Mercer et al., 2006). Therefore, our findings indicate that when the environmental condition became more challenging, more stress is born on the particular group of propulsive muscles which might be detrimental for shoulder joint in future.

5.3 Correlation between shoulder pain and propulsion kinetics under different environmental conditions

In the second part of the study, we hypothesized that there would be a negative relationship between history of perceived shoulder pain while performing different ADLs in past week and the propulsion kinetic outcomes such as peak force, push length, push frequency and speed and PME in each group under natural environmental conditions. Our hypothesis was partially confirmed by the results of the current study.

In the acute group, we found that higher shoulder pain was significantly associated with higher peak force on tile. We also found a significant association between higher shoulder pain and higher steady state average push frequencies on tile and on carpet surfaces in the acute group. However, in the chronic group there were not significant relationships between shoulder pain and wheelchair propulsion parameters.

Though there were no significant differences between groups for shoulder pain as reported on WUSPI scale, only the acute group demonstrated significant relationships between shoulder pain and selected propulsion performance. The disparate findings between groups may be due to differences in the level of experience in wheelchair propulsion. Participants in the acute group were new manual wheelchair users and they were learning the techniques of wheelchair propulsion with the unconditioned shoulder muscles at the acute rehabilitation center. Pushing the wheelchair under natural environmental conditions during the study was more demanding, which may be a possible explanation of significant associations only seen with the acute group.

Excluding the participants from the acute group who scored lowest for shoulder pain on WUSPI (see section 4.1 in chapter 4), we found that high PME was significantly associated with lower shoulder pain on ramp. This indicates that pushing up the ramp, participants in the acute group used a maximum amount of force which directly contributed to the forward motion of the wheelchair. Due to less wasted force on the handrim, participants felt lower shoulder pain, which may be due to their learning wheelchair propulsion skills during acute rehabilitation.

Our findings of no relationship between shoulder pain and propulsion performance in the chronic group is supported by previous research. Gutierrez et al., 2007 conducted a study with 80 manual wheelchair users with SCI with a mean duration of injury 20 years. The purpose of their study was to identify the relationship between shoulder pain intensity and quality of life in people with SCI. They concluded that shoulder pain intensity was not related to the involvement in general community activities. This study did not highlight the association between shoulder pain and mobility in the community specifically, but mobility was one of the factors related to community participation. In a more recent study, people with chronic SCI with mean duration of 14 years of injury were asked to push their wheelchairs at different speeds on a dynamometer under the laboratory settings (Collinger et al., 2008). The results of this study implied that shoulder pain did not interfere with the way a person propelled his wheelchair. Our study was different from previous studies because we mainly quantified wheelchair propulsion performance under different natural environmental conditions. The results of our study suggest that people with chronic SCI become habituated to living with shoulder pain and their pain does not interfere with the way they propel their wheelchair in the community.

Conversely, evidence suggests that wheelchair propulsion with higher forces at pushrim and higher velocities are related to higher shoulder joint kinetics and shoulder pathologies (Brose et al., 2008; Collinger et al., 2008; Morrow, Hurd, Kaufman, & An, 2009). Moreover, increased shoulder pain is associated with higher forces at the shoulder while pushing up inclined surfaces (Curtis et al., 1999; Morrow et al., 2009). In the current study the possible reasons for not finding a relationship between shoulder pain and wheelchair propulsion kinetics in chronic group may be due to the small sample size and small surfaces used for the wheeling test. Our small group may not be a representative of the overall population of manual wheelchair users with SCI living in the community. Moreover, the surfaces we used for wheeling test in the current study were short, that may be a reason for not showing any relationship between shoulder pain and propulsion kinetic outcomes. Therefore, future investigation is required using the longer surfaces and larger sample size to overcome the variability within the participants and their response to the shoulder pain on WUSPI scale.

5.4 Clinical Implications

We selected five clinically relevant propulsion kinetics for comparison between the groups and across different environmental conditions. We expected that the group that had more experience using a wheelchair would show better performance in propulsion. However, our chronic group was not different from the acute group. Moreover, the chronic group showed a lower PME ratio as compared to acute group. This finding is clinically important because pushing with lower mechanical effectiveness under various natural environmental conditions may lead to serious shoulder injuries in later life (Boninger et al., 1997). This finding infers that people with SCI who are living in the community, need continued care and education to maintain their wheelchair propulsion performance even after many years of their injury.

For people with acute injury, wheelchair propulsion training under natural environmental conditions from the beginning of acute rehabilitation is important. It is also important to initiate follow-up programs at discharge from the rehabilitation hospital. These follow- up programs allow the continued development and refinement of appropriate propulsion techniques as well as the implementation of shoulder rehabilitation interventions. An important resource for clinicians in rehabilitation and community settings is the clinical practice guideline from the Paralyzed Veterans of America (Consortium for Spinal Cord Medicine, 2005). In this guideline, 35 recommendations are given to reduce and prevent upper extremity impairments in people with SCI.

Our finding related to association between perceived shoulder pain and propulsion kinetic outcomes in people with acute SCI may encourage the rehabilitation specialists to individualize the therapeutic exercise programs to strengthen particular shoulder muscle groups which are involved in wheelchair propulsion. Furthermore, rehabilitation specialists can design home exercise programs as discussed by Nawoczenski and group (Nawoczenski et al., 2006) at the discharge from the rehabilitation centre. This might further help in preventing the people with SCI from far reaching deleterious effects of shoulder pain in the community locomotion.

Considerable research related to manual wheelchair biomechanics has been conducted. Most of this research has highlighted the importance of individual propulsion kinetics on the pushrim. Our participants had similar values of propulsion kinetics on different surfaces as proposed in the national database except for one variable i.e. push length (see Table 4.3 in chapter 4). Clinically, a longer and smooth push length is important for safe and effective propulsion. Moreover, it may influence the gross mechanical efficiency of wheelchair propulsion (i.e. a higher ratio between power output and energy expenditure) (de Groot, de Bruin, Noomen, & van der Woude, 2008; Knowlton, Fitzgerald, & Sedlock, 1981). Therefore, from our findings and the findings from past research we encourage clinicians to pay individual attention to each propulsion kinetic during their initial wheelchair propulsion training and/ or wheelchair adaptation in acute settings.

Clinicians can measure the propulsion performance of their clients before and after a therapeutic intervention using a commercially available tool called the Smartwheel (Cowan et al, 2008; Smartwheel User's Guide, 2008). A client's wheelchair propulsion performance can further be compared with the national database. If the Smartwheel is not available, there are other ways to measure propulsion kinetics (Cowan et al., 2008). Cowan et al. (2008) proposed a method to calculate client's push frequency and velocity without using the Smartwheel. With the knowledge of velocity and push frequency, clinicians can advise their clients to use long pushes to maintain a low push frequency with as low a force as possible to generate a functional velocity (Cowan et al., 2008; Minkel, 2009). This may be a step towards injury prevention and maintenance of functional abilities for long term manual wheelchair users.

5.5 Study limitations

1. Small sample size: The small sample size might be an explanation for not finding any significant difference in propulsion kinetics among the group. The variability in the participant's personal characteristics can be overcome with the large sample size.
2. Participant's own wheelchair: Our participants used their own wheelchairs during the study. Though the wheelchairs between groups

were similar in make, the difference in the wheelchairs' characteristics including weight of the system, frame material properties, caster size and type, camber and horizontal and vertical axle position might have influenced their mobility performance in general.

3. Self selected speed: We performed the study under natural environmental conditions; therefore, it was not possible to control the propulsion speed during the study. We also used self selected speed to ensure that our participants pushed at their most comfortable speed under natural environment. The problem with this approach is that how fast someone pushes is related to his other propulsion kinetics.
4. Type of surfaces: The types of surfaces used in the current study were limited to the Smartwheel clinical protocol. There are many more different surfaces like interlocking paves, cross slopes, different ramp grades, high pile carpets and soft surfaces like grass and sand which manual wheelchair users may come across during their community ambulation.
5. Fewer steady state pushes: We used on average 5 pushes in study state in comparison between both groups. People in the community spent a significant amount of wheelchair propulsion time in steady state. Fewer pushes might not have captured their real wheeling performance over different surfaces.

5.6 Strength of the study

1. Wheeling under natural conditions: We applied inferential statistics in this study to assess differences between the acute and chronic groups in terms of their wheeling under commonly encountered natural environmental condition. Therefore, our study might have shown the adequate wheeling performance by manual wheelchair users in the community.
2. Participants own wheelchair: We asked our participants to wheel in their own wheelchair. Though their wheelchair set ups were different from each other, wheeling in their own wheelchair might have captured their exact wheeling.

CHAPTER SIX

CONCLUSION

In the current study we quantified wheelchair propulsion kinetics under natural environmental conditions among people with acute and chronic SCI. We did not find any significant difference in clinically relevant propulsion kinetics applied between people with acute and chronic SCI. However, our acute group pushed with a small but significantly higher mechanical effectiveness as compared to chronic group. Beside that, we showed a positive relationship between perceived shoulder pain in the past week and selected propulsion kinetics applied by the acute group.

In spite of certain limitations our comparative study indicates that people with acute and chronic SCI show almost similar performance for wheelchair propulsion under real world conditions. Quantifying wheelchair propulsion demand under natural environmental conditions provides rehabilitation specialist with objective information to guide wheelchair propulsion training of patients adapting to manual wheelchair use. Our results highlight the importance of learning proper propulsion techniques under natural environmental conditions from the beginning of acute rehabilitation. Moreover, we infer that some of the learning during acute rehabilitation may be lost during community locomotion in everyday life in long term. Furthermore, our results may encourage clinicians to continue development and refinement of manual wheelchair propulsion strategies for the people with SCI who are living in the community long term after their injuries.

Future recommendations

The type of surfaces and the distance over which propulsion performance was measured were limited in the current study. We would encourage future investigators to incorporate a broader range of surfaces for a longer distance under natural environmental conditions. Moreover, we conducted the study with a small sample size, therefore, it may have insufficient statistical power. Therefore, future studies with a large and diverse sample are recommended to add strength to the study.

Past research has shown that experienced and non experienced manual wheelchair users adapt different stroke patterns (Chou et al., 1991). The type of stroke pattern adapted on the handrim is related with propulsion kinetic outcomes (Richter et al., 2007; Shimada et al., 1998). In the current study, we did not identify the different stroke patterns in our participants. Therefore, we encourage future researchers to determine the stroke patterns used by people with acute and chronic SCI under natural environmental conditions.

In the current study, we did not measure the performance capacity ratio between our groups. Performance capacity ratio is a functional outcome measure to look at individuals actual performance during their functional mobility compared to their capacity to perform (Ferguson-Pell et al., 2006). Clinicians may be further interested in knowing if people with SCI are wheeling within their capacity i.e. within their comfort level or extra effort is required to meet the demand under natural or built-in environmental conditions in the community. Therefore, we strongly encourage the future investigators to measure the performance capacity ratio between new and experienced manual wheelchair users with SCI over a range of natural surfaces.

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APPENDIX A ETHICS APPROVAL

Health Research Ethics Board

213 Heritage Medical Research Centre
University of Alberta, Edmonton, Alberta T6G 2S2
p.780.492.9724 (Biomedical Panel)
p.780.492.0302 (Health Panel)
p.780.492.0459
p.780.492.0839
f.780.492.7808

HEALTH RESEARCH ETHICS APPROVAL FORM

Date: March 2006

Name of Applicant: **Dr. Laura May**

Organization: **University of Alberta**

Department: **Physical Therapy**

Project Title: **Wheelchair Propulsion in Adults with Disabilities: A Pilot Study**

The Health Research Ethics Board (HREB) has reviewed the protocol for this project and found it to be acceptable within the limitations of human experimentation. The HREB has also reviewed and approved the subject information letter and consent form

The approval for the study as presented is valid for one year. It may be extended following completion of the yearly report form. Any proposed changes to the study must be submitted to the Health Research Ethics Board for approval. Written notification must be sent to the HREB when the project is complete or terminated.

Special Comments:

Dr. Glenn Griener, PhD
Chair of the Health Research Ethics Board
(B: Health Research)

APR 0 5 2006
Date of Approval Release

File Number: B-360306

UNIVERSITY OF ALBERTA   Capital Health   CARITAS HEALTH GROUP

Health Research Ethics Board

213 Heritage Medical Research Centre
University of Alberta, Edmonton, Alberta T6G 2S2
p.780.492.9724 (Biomedical Panel)
p.780.492.0302 (Health Panel)
p.780.492.0459
p.780.492.0839
f.780.492.7808

July 11, 2008

Dr. Trish Manns
Physical Therapy
2-50 Corbett Hall

File# B-360306

Re: Kinetic Analysis of Manual Wheelchair Propulsion Under Different Environmental Situations in Experienced and New Wheelchair Users with Spinal Cord Injury (SCI)

Dear Dr. Manns:

Thank you for your correspondence dated June 17th & 23rd, 2008, which requests approval of an amendment to the above-mentioned study. This change has been reviewed and approved on behalf of the Research Ethics Board. The following has been approved:

- Addition of a comparison group – community dwelling individuals with spinal cord injury.
- Revised title, as indicated above, to reflect this additional group.
- Appendix H: Recruitment Poster for community dwelling individuals
- Information Letter for community dwelling individuals
- Revised Information Letter for individuals undergoing active rehabilitation.
- Addition of Dr. Martin Ferguson-Pell as a co-applicant.

Thank you for keeping the Board informed. Best wishes for your study.

Sincerely,

Charmaine N. Kabatoff
Senior Administrative Coordinator
Health Research Ethics Board (Health Panel)

UNIVERSITY OF ALBERTA

Capital Health
Edmonton and area

CARITAS HEALTH GROUP

APPENDIX B

INFORMATION LETTER

(Community participants)

Kinetic analysis of manual wheelchair propulsion under different environmental situations in experienced and new wheelchair users with spinal cord injury (SCI)

PRINCIPAL INVESTIGATOR: Dr Trish Manns Ph.D., Assistant Professor, Department of Physical Therapy, Telephone 780-492-7274 or Email: trish.manns@ualberta.ca

Background: People with spinal cord injury (SCI) who use manual wheelchairs often have shoulder pain. Most of the studies done so far have found that the way a person wheels might have something to do with why a person gets shoulder pain. We do not know much about how the forces applied on the pushrim differ in new and experienced wheelchair users with SCI in different environmental conditions.

We are giving you this letter to invite you to participate in this research study. You do not have to participate if you do not want.

Purpose: We want to compare a number of factors related to wheelchair propulsion in people with SCI living in the community to the people with SCI doing active rehabilitation

Procedure: The study will be conducted at Corbett Hall (Department of Physical Therapy) University of Alberta. The study includes two parts that will take place on the same day. We will use a special wheel called Smartwheel that records information about how a person wheels. The Smartwheel (please see the picture) measures pushing force, frequency and stroke length.

Part 1: You will be asked to fill out a questionaire that will ask you about any medical history of shoulder pain and shoulder pain in performing different activiities of daily living.

Part 2: Next we will ask you to move from your own wheelchair to a different lightweight wheelchair. One wheel on that wheelchair will be the SmartWheel. The SmartWheel will be on the same side as your dominant hand. We will then ask you to wheel around for about 5 minutes to get used to the Smartwheel fitted wheelchair. After you are used to wheeling with this new wheelchair, we will ask you to complete 4 wheeling tasks including: 1) 10m of straight line wheeling over a smooth, level, tile floor; 2) 8m of straight line wheeling over a smooth, level, carpeted floor; 3) figure-8 wheeling on a smooth, level, tile floor; 4) wheeling up a 5m ramp. The ramp is in a different building (a short 5 minute wheel from Corbett Hall). After you have finished the wheeling tasks you can move back to your own wheelchair.

The SmartWheel (http://www.3rivers.com/swhome.php)

In all, the above tasks will take about 90 minutes to complete.

Possible Benefits: You will learn about your wheeling abilities and how that may be associated with the pain in your shoulders. We will give you a copy of your SmartWheel results. We will also teach you about how your wheeling style compares to a national database.

Possible Risk: There are no risks beyond those that may happen with every day wheeling such as arm pain and falling. You will be watched closely at all times when you are doing the wheelchair skills. If you have shoulder pain which increases during the study, the test will be stopped.

Confidentiality: All your records for this study will be kept private. You will be free to withdraw from the study at any point. Any research data collected about you during this study will not use your name. Any report published as a result of this study will not use your name. All data will be stored in a locked filing cabinet. Only the researcher will have access to the confidential data. Study data will be retained for at least 7 years. If any secondary analysis is done in the future on this data, further ethics approval will be required.

Voluntary Participation: Taking part in this study is voluntary. You may refuse to answer any questions or withdraw from the study any time. If you choose to participate, we will pay for your parking at Corbett Hall.

If you have concerns about this research study, whom may you contact?

If you have questions about your rights as a research participant, please contact the Health Research Ethics Board (HREB) at 780- 4920302.

IF YOU ARE INTERESTED IN PARTICIPATING, PLEASE CONTACT THE PRINCIPAL INVESTIGATOR Trish Manns at email: trish.manns@ualberta.ca or 780-492-7274 OR THE STUDY COORDINATOR, **Manu Singla at e-mail: singlamanupt@gmail.com, or contact at 780- 492-7785.**

APPENDIX C CONSENT FORM

Kinetic analysis of manual wheelchair propulsion under different environmental situations in experienced and new wheelchair users with spinal cord injury (SCI)

Name of Principal Investigator: Dr Trish Manns

Contact Information: Phone: (780) 492-7274, Email*: trish.manns@ualberta.ca*

Name of Co-Investigator: Dr Martin Ferguson-Pell

Contact Information: Phone: (780) 492-0329, Email*: martin.ferguson-pell@ualberta.ca*

	Yes	No
Do you understand that you have been asked to participate in a research study?	☐	☐
Have you received and read a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in the study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to refuse to participate or withdraw from the study at any time, without having to give reason, and that your information will be withdrawn at your request?	☐	☐
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records/ information?	☐	☐

This study was explained to me by: ______________________________

I agree to take part in this study. Yes ☐ No ☐

___________________________ _____________ _______________________

Signature of Research Participant Date Witness

________________________________ ______________________________

Printed Name Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

____________________________ _______________

Signature of Investigator or Designee Date

APPENDIX D

SMARTWHEEL REPORT PARAMETER DEFINATIONS

Client & Session Information

Name	The Subject's Name
Age [y]	The Subject's Age
Gender	The Subject's Gender
Weight [kg]	The Subject's Weight (not including the Wheelchair)
Height [cm]	The Subject's Height
Primary Diagnosis	The Subject's Primary Diagnosis
Additional Information	Any other information that's relevant to know about the Subject.
Date & Time	The date and time of the SmartWheel session.
Notes	Any notes specific to the particular SmartWheel Session.

Protocol	The Activity performed, which is often a clinical protocol, such as Tile-Protocol.
Time [s]	The total elapsed time of the session.
Distance [m]	The total distance traveled by the SmartWheel during the session.
Number of Pushes	The number of complete pushes detected by the SmartWheel over the entire session.

Key Data from Client Session & Comparison to Database Averages	
Speed [m/s]	The steady state average speed of the session.
Push Frequency [1/s]	The average number of times per second the Subject pushes on the SmartWheel.
Push Length [degree]	The average length of the Subject's push, in degrees.
Force (Weight Normalized) %	The average force the Subject applies to the SmartWheel handrim, averaged over all steady-state pushes and normalized using the Subject's bodyweight

Session Results- Start up **These parameters are calculated from the first 3 pushes.**	
Peak Force Push 1 [N]	This is the peak force the Subject applied to the SmartWheel handrim during the first push. (note: this force is the total force applied)
Peak Force Push 2 [N]	This is the peak force the Subject applied to the SmartWheel handrim during the second push. (note: this force is the total force applied)
Peak Force Push 3 [N]	This is the peak force the Subject applied to the SmartWheel handrim during the third push. (note: this force is the total force applied)
Distance after 2nd Push [m]	This is the distance covered by the SmartWheel during the first two pushes.
Distance After 3rd Push [m]	This is the distance covered by the SmartWheel during the first three pushes.
Speed After 2nd Push [m/s]	This is the speed that was achieved after the 2nd push.

Sessions Results- Steady State **These parameters are averages calculated from all pushes except for the first 3.**	
Peak Force [N]	For each steady-state push (all pushes in the session except for the first three), the peak force is measured. This is average peak force of all the steady-state pushes. (note: this force is the total force applied)
Average Push Force [N]	This is the average force the Subject applies to the SmartWheel handrim, averaged over all steady-state pushes.
Peak Backwards Force [N]	For each steady-state push (all pushes in the session except for the first three), the peak backwards force is measured. This is average peak backwards force of all the steady-state pushes. This shows the extent to which the client is effectively braking the wheelchair with every push. This parameter is only valid in this sense if the Subject is not actually trying the brake. (note: this force is a tangential force)
Speed [m/s]	This is the average speed of the SmartWheel during steady state (the time after the first 3 pushes).
Avg. distance / push [m]	This ratio is the average steady-state speed divided by the average steady-state push frequency. It provides an indication of how many pushes per second are being used to achieve the average speed.
Push Length [deg]	This is the average length of the Subject's push, in degrees.
Push Frequency [1/s]	This is how many times per second, on average, the Subject pushes on the SmartWheel.
Peak/Average Force Ratio	This is the ratio between the peak force during a push, and the average force during a push. It is averaged across all steady-state pushes. It provides an indication of how smoothly pushes are applied the SmartWheel's handrim. A lower ratio indicates the peak force is more close to the average force, that can indicate a smoother push.
Push Mechanical Effectiveness	This indicates the approximate ratio of applied force which is directed such that the SmartWheel is accelerated. For example, if much of the applied force is down or outward, this value will be lower, because pushing inwards toward the hub, or pushing outward do not actually make the Wheelchair accelerate. This parameter is only intended to provide a red flag for abnormally inefficient pushing.

APPENDIX E

SAMPLE SIZE CALCULATION

Dependent variables

Five propulsion kinetics including; peak force, push frequency, push length, speed and push mechanical effectiveness.

Independent Variables

1.) Two groups of people with SCI; people with SCI undergoing their acute rehabilitation and people with chronic SCI living in the community at least one year post injury.

2.) Environmental conditions including; tile, carpet and ramp

Effect size calculation

$$\text{Cohen effect size (d)} = \frac{m_A - m_B}{\Sigma\,\sigma}$$

Where $m_A - m_B$ is the difference between means in two groups and σ is the standard deviation of either group.

Mean of peak tangential force (main force responsible for the forward motion of the wheelchair) in new wheelchair users = 94.6

Mean of peak tangential force in experienced wheelchair users = 66.2

Standard deviation (σ) = 14.4 (Robertson et al., 1996).

Putting the values in the above equation:

$$d = \frac{94.6 - 66.2}{14.4} = 1.97$$

Sample Size: At effect size 1.98, at power .80 and significance level of $p < .05$, 13 people were needed in each group (Cohen, 1988).

APPENDIX F

WHEELCHAIR USERS SHOULDER PAIN INDEX

WUSPI- MEDICAL HISTORY: (circle the appropriate response below)

1. Did you have shoulder pain prior to wheelchair use?	1. Yes 2. No	If yes, which shoulder (s)?	1. Left 2. Right 3. Both
2. Have you had shoulder pain during the time you have used a wheelchair?	1. Yes 2. No	If yes, which shoulder (s)?	1. Left 2. Right 3. Both
3. Have you had shoulder surgery?	1. Yes 2. No	If yes, which shoulder (s)?	1. Left 2. Right 3. Both
4. Do you currently have shoulder pain?	1. Yes 2. No	If yes, which shoulder (s)?	1. Left 2. Right 3. Both

5. Have you sought medical attention for a shoulder problem? 1. Yes 2. No

if yes, who did you see?
1. Physician
2. Physical Therapist
3. Chiropractor
4. Other:

6. Circle all the following if you have used to relieve shoulder pain:
1. Ice
2. Heat
3. Exercise
4. Medication
5. Rest
6. None
7. Other:

7. . Has shoulder pain limited you from performing your usual activities during the past week? 1. Yes 2. No

8. Have you experienced hand or elbow pain or injuries? during the time you have used a wheelchair? 1. Yes 2. No

WUSPI@ Kathleen A. Curtis

APPENDIX F WHEELCHAIR USERS SHOULDER PAIN INDEX (WUSPI)

Place an "X" on the scale to estimate your level of pain with the following activities. Check box at right if the activity was not performed **in the past week.**

Based on your experiences in the past week, how much shoulder pain do you experience when:

			NOT Performed
1. transferring from a bed to a wheelchair?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
2. transferring from a wheelchair to a car?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
3. transferring from a wheelchair to the tub or shower?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
4. loading your wheelchair into a car?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
5. pushing your chair for 10 minutes or more?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
6. pushing up ramps or inclines outdoors?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
7. lifting objects down from an overhead shelf?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
8. putting on pants?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
9. putting on a t-shirt or pullover?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
10. putting on a button down shirt?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
11. washing your back?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
12. usual daily activities at work or school?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
13. driving?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
14. performing household chores?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]
15. sleeping?	No Pain [ ]______	Worst Pain Ever Experienced	[ ]

Appendix G

SMARTWHEEL GENERAL QUESTIONAIRE

Age __________ **Gender:** Male Female

Height _____ (measured/reported) Weight _____ (measured/reported)

Dominant Hand: ______________________________

Primary Diagnosis ______________________________

Secondary Diagnosis ______________________________

Date of Primary Diagnosis/Injury: ______________________________

Wheelchair Model /Manufacture: ______________________________

Month /Years of Wheelchair Use: ______________________________

Hours per day of wheelchair Use ______________________________
(as prime mode of mobility

Method of Transfer: ______________________________

Clinician's overall perception of the user's ability in the chair over multiple surfaces (1-5)
1-Low; 5= High ______________________________

Accessory Equipment:
Type of cushion: ______________________________

Custom Seating? (describe) ______________________________

Use of Gloves for Wheeling? Yes ________ **No** ________

Use of chest strap for Wheeling? Yes ________ **No** ________

Use of seat belt for Wheeling? Yes ________ **No** ________

Rear Tire Pressure (day of testing): Smartwheel ________ **Other** ________

APPENDIX H

SMARTWHEEL STANDARD CLINICAL EVALUATION PROTOCOL

Purpose

The SmartWheel Standard Clinical Evaluation Protocol is intended to facilitate the development of normative standards for wheelchair propulsion. The Protocol is a result of the efforts of the SmartWheel User Group and is reviewed and updated by the SmartWheel User Group on a periodic basis.

Components of the SmartWheel Clinical Evaluation Protocol

Tile Protocol

Carpet Protocol

Ramp Protocol

Figure 8 Protocol

Each component of the SmartWheel Standard Clinical Evaluation Protocol is specifically described in the following pages.

Each component of the clinical protocol is designed as an independent evaluation. While it is important to attempt completion of the entire protocol, the information obtained from each protocol component is important. Therefore, completion of a single component trial provides valuable information, regardless of the completion of all the other protocol components

If possible, it is helpful to include a digital picture as part of the SmartWheel Standard Clinical Evaluation Protocol. How to take the digital picture is also described in the following pages.

SmartWheel Standard Clinical Evaluation Protocol
Tile Protocol

Trial Setup

This trial requires the completion of 10 meters or 10 seconds of propulsion, whichever occurs first.
You will need approximately 12 meters of smooth, level tile for this trial so the Client can propel through the 10 meter finish without braking. The final two meters of the space are for stopping the wheelchair. Designate a starting line for this evaluation. If the Auto Start & Stop function is activated (highly recommended for clinical applications), the SmartWheel will start and terminate data collection. If the Auto Start & Stop feature is not used then you are responsible for starting and terminating data collection.

Tile Trial Administration

1. Line casters of WC within three inches of the marked start line for the Tile Surface trial.

2. Ask Client to place their hands in their lap

3. Insure the SmartWheel is ready to start data collection

4. Using the script below, instruct the Client to begin pushing

During the data collection period do not offer ANY encouragement to the client while they are pushing.

Tile Protocol Script

"This test is designed to see how you push on a smooth floor. When I tell you to 'GO' I want you to push your wheelchair in a straight line. Push at a comfortable speed, as if you were pushing from a parking lot to the grocery store. Keep pushing until I tell you to stop. Do not brake or slow down until I tell you. Do you have any questions?" *PAUSE* "Place your hands in your lap. GO."

5. Since the SmartWheel will terminate data collection when the client reaches 10 meters or 10 seconds of propulsion (with the Auto Start & Stop function activated), the clinician should only ask the client to stop pushing once they are certain 10 seconds have passed or 10 meters have been covered.

Trial Setup

This trial requires the completion of 10 meters or 10 seconds of propulsion, whichever occurs first.

You will need approximately 12 meters of smooth, level carpeted floor for this trial so the Client can propel through the 10 meter finish without braking. The final two meters of the space are for stopping the wheelchair. Designate a starting line for this evaluation. If the Auto Start & Stop function is activated (highly recommended for clinical applications), the SmartWheel will start and terminate data collection. If the Auto Start & Stop feature is not used then you are responsible for starting and terminating data collection.

Carpet Trial Administration

1. Line casters of WC within three inches of the marked start line for the Carpet Surface trial.

2. Ask client to place their hands in their lap

3. Insure the SmartWheel is ready to start data collection

4. Using the script below, instruct the Client to begin pushing

During the data collection period do not offer ANY encouragement to the client while they are pushing.

Script for Carpet Protocol

"This test is designed to see how you push across carpet. When I tell you to 'GO' I want you to push your wheelchair in a straight line. Push at a comfortable speed, as if you were pushing down a familiar carpeted hall. Keep pushing until I tell you to stop. Do not brake or slow down until I tell you. Do you have any questions?" *PAUSE* "Place your hands in your lap. GO."

5. Since the SmartWheel will terminate data collection when the client reaches 10 meters or 10 seconds of propulsion (with the Auto Start & Stop function activated), the clinician should only ask the client to stop pushing once they are certain 10 seconds have passed or 10 meters have been covered.

SmartWheel Standard Clinical Evaluation Protocol

Ramp Protocol

Trial Setup

The ideal ramp will be ADA compliant, surfaced with smooth tile. An ADA ramp has a maximum slope of 4.7 degrees or an 8% grade. *You need to document the slope of the ramp in the clinical protocol.* You may do this by recording the Rise & Run of the ramp. If you are not able to record the Rise because the ramp is imbedded, you will need to use an electronic level to determine the slope. Additionally, you will need to document the type of surface found on the ramp, carpet, tile, concrete, etc.. The base of the ramp is designated as the starting line for the purpose of this trial.

You will need a ramp of at least 5 meters in length or long enough for the person to complete 3 strokes.

If 3 strokes are completed, then trial is considered successful. If an individual requires a rest during the trial, the therapist can support the wheelchair while the client rests. While the client is allowed to rest multiple times during the trial, no more than 20 seconds can elapse between strokes.

If a person is unable to complete 3 strokes, or must rest for longer than 20 seconds between strokes, the trial is considered unsuccessful

Prior to beginning the ramp protocol, modify the Auto Stop function to indicate 5 meters or 60 seconds. With the Auto Start & Stop functions activated, of the SmartWheel will start and terminate data collection. If the Auto Start & Stop feature is not used then you are responsible for starting and terminating data collection.

Ramp Trial Administration

1. Line casters of WC within three inches of the designated start line for the Ramp trial.

2. Ask Client to place their hands in their lap

3. Insure the SmartWheel is ready to start data collection

4. Using the script below, instruct the Client to begin pushing

   During the data collection period do not offer ANY encouragement to the client while they are pushing.

   Script for ramp protocol:

   "This test is designed to see how you push up a ramp. When I tell you to 'GO' I want you to push your wheelchair up this ramp. Push at a comfortable speed, as if you were pushing from a parking lot to the grocery store. You may rest if needed. Do you have any questions?" *PAUSE* "Place your hands in your lap. GO."

SmartWheel Standard Clinical Evaluation Protocol

Figure 8 Protocol

Trial Setup

Place three cones on a smooth tile surface, each 1.5 meters apart. *There should be an additional 1.5 meter space beyond the first and third cone*. The first cone designates the start and finish lines for the figure 8 trial. The starting line is located on the right side of the first cone. The finish line is located on the left side of the first cone. The client will push in the shape of an 8 around the other 2 cones. This is a timed trial. The auto-start function should be utilized. The auto-stop function should be disabled as you will need to terminate data collection in the software when the client crosses the finish line.

A trial is considered successful if the course is completed without hitting a cone. If the client hits a cone, they should continue the trial. A second attempt is permitted. If the person is unable to complete the second trial without hitting a cone, do not record the time.

Figure 8 Trial Administration

1. Line casters of WC within three inches of the marked start line for the Figure 8 trial. This line should be to the right of the first marker.

2. Ask Client to place their hands in their lap

3. Insure the SmartWheel is ready to start data collection
3. Using the script below, instruct the Client to begin pushing. Use the Auto Start function of the SmartWheel then manually stop timing when the casters cross the marked finish line. The finish line is on the opposite side of the marker from the starting line.

During the data collection period do not offer ANY encouragement to the client while they are pushing.

Script for Figure 8 Protocol:

"This test is designed to see how quickly you can complete a figure 8. When I tell you to 'GO' I want you to push your wheelchair around these cones. This is the path you take (*demonstrate path*). Do not slow down until you get all the way past this line (*indicate line*). Push as fast as you can, but do not touch any of the cones. If you do hit a cone, do not stop, keep pushing. When you cross the finish line, stop the chair. Do you have any questions?" *PAUSE* "Place your hands in your lap. GO."

4. Terminate data collection in the clinical software when the client crosses the finish line.

5. Ask the client to stop pushing after they cross the finish line

Digital Picture

This picture serves as documentation of the axle position of the wheelchair used for testing purposes. The picture will be from the neck down of the individual sitting in the wheelchair with the Smart^{Wheel} attached. The individual should have their hands placed at top center of the pushrim. As much as possible, the picture should be taken at a right angle to the client. You may need to kneel when taking the picture to ensure the lens of the camera is at a right angle to the individual. An example is included below.

5.