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BIOMECHANICAL ANALYSIS OF STROKE PATTERNS AND FUNCTIONAL OUTCOMES IN PEDIATRIC MANUAL WHEELCHAIR USERS

by

Paige Aschenbrener

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Partial Fulfillment of the
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ABSTRACT

BIOMECHANICAL ANALYSIS OF STROKE PATTERNS AND FUNCTIONAL OUTCOMES IN PEDIATRIC MANUAL WHEELCHAIR USERS

by

Paige Aschenbrener

The University of Wisconsin-Milwaukee, 2020
Under the Supervision of Dr. Brooke A. Slavens, PhD

Approximately 88,0000 manual wheelchair (MWC) users are under the age of 21 in the United States (Kaye, LaPlante, & Kang, 2000). More than half of pediatric MWC users with spinal cord injury (SCI) report shoulder pain later in life and are at higher risk for developing upper extremity (UE) overuse injuries (Vogel & Zebracki, 2015). During MWC propulsion, a stroke pattern is the path the hand follows with respect to the pushrim (Boninger et al., 2002). Current clinical guidelines for adults recommend sole use of the semicircular stroke pattern as best practices because a MWC user is able to spend more time recovering and propel with less forceful, frequent pushes (Paralyzed Veteran's Association, 2005). No clinical guidelines specific to pediatric MWC users exist. The biomechanical data from adult-based studies cannot be accurately scaled down to children because the size of their body segments is proportionally different (Schnorenberg et al., 2014). The characterization of stroke patterns amongst pediatric MWC users is needed in order to develop appropriate recommendations for this population. Twenty-two (22) participants, 13 males and 9 females between the ages of 7 - 21 years old (13.9 ± 4.49) participated at the Motion Analysis Laboratory at Shriners Hospitals for Children – Chicago. The average positions of the 3rd metacarpal phalangeal reflective markers were tracked by a 14-camera Vicon MX Motion Analysis system and captured three-dimensional UE kinematics during each trial of steady-state MWC propulsion. Data was converted into a visual representation of each stroke cycle from the sagittal perspective via MATLAB. Three-hundred-eighty-three (383) stroke cycles were classified as one of six different types of stroke patterns. A two-stage protocol was used and confirmed good to very good ($\kappa = 0.932$) inter-rater agreement across all data. Most subjects alternated between two and four different types of stroke patterns. Among them were two novel pediatric stroke patterns that were identified in this study. A Multivariate Analysis of Covariance (MANOVA) tested for statistically significant differences in six glenohumeral (GH) joint dynamics between the different types of stroke patterns. The semicircular stroke pattern was characteristic of the largest average peak GH joint superior force ($p < 0.01$). The biomechanical characteristics of the two novel stroke patterns were significantly different than that of the other four types ($p < 0.001$). A One-Way T-Test was used to test for statistically significant differences between the scores of the sample and the normative population on the Short-Form Health Questionnaire for health-related quality of life. The average physical composite score (PCS) was significantly lower, while the mental health composite score (MCS) was significantly higher than that of the average healthy individual ($p < 0.001$). A MANOVA was conducted to determine if there were statistically significant differences in average PCS and MCS between groups stratified by use of 1 – 4 or more different types of stroke patterns. The PCS of subjects who used two stroke patterns during steady-state MWC propulsion was significantly less than those who performed one, three, or four ($p < 0.05$). The Visual Analog Scale was used to assess bodily pain; a small number of subjects indicated mild (6) and moderate (1) symptoms. This study is an important first step towards the development of pediatric-specific clinical guidelines for practitioners who are involved in life care planning for children and adolescents with SCI.

I would like to dedicate my thesis to my incredible family and friends who have celebrated each milestone of this project along with me. To my advisor Dr. Brooke Slavens, thank you for your continuous encouragement and guidance. To Alyssa Schnorenberg, I would not have made it through my thesis journey without your help. To Professor Dana Washburn, thank you for helping me grow as a researcher and a future occupational therapist.

TABLE OF CONTENTS

II. MANUSCRIPT

III. CONCLUSION

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADL	Activity of Daily Living
AOTA	American Occupational Therapy Association
ARC	Arcing
ATP	Assistive Technology Professional
DLOP	Double Looping Over Propulsion
GH	Glenohumeral
HRQoL	Health Related Quality of Life
IADL	Instrumental Activity of Daily Living
MCS	Mental Health Composite Score
MRI	Magnetic Resonance Imaging
MWC	Manual Wheelchair
OT	Occupational Therapy
PCS	Physical Composite Score
PEO-P	Person-Environment-Occupation Performance
PT	Physical Therapy
PVA	Paralyzed Veteran’s Association
ROM	Range of Motion
SC	Semicircular
SCI	Spinal Cord Injury
SF-12	Short Form Health Questionnaire
SLOP	Single Looping Over Propulsion
UE	Upper Extremity
VAS	Visual Analog Scale

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I. Introduction

Spinal Cord Injury (SCI)

In the past decade, the annual incidence of spinal cord injury (SCI) under the age of 21 has risen from 2,947 to 3,863 in the United States (National Spinal Cord Injury Statistical Center (NSCISC), 2019). Youth and adolescents accounted for approximately half (50.3%) of all SCI hospital admissions between October 2016 and September 2018 (NSCISC, 2018**.** Motor vehicle accidents are the leading cause of SCI in adolescents and youth under the age of 15 (36.8%). The second leading cause is falls for younger children and sports-related injuries for adolescents (Falavigna et al., 2018). Other causes include complications during birth, medical procedures, and violence (NSCISC, 2019).

Diagnoses & Prognoses

A SCI is diagnosed and graded via The International Standards for the Neurological Classification of Spinal Cord Injury (ISNCSCI) Exam (American Spinal Injury Association (ASIA), 2018). Diagnoses are determined by the neurological level of injury which is the lowest segment of the spinal cord with intact sensation and anti-gravity muscle motion. Tetraplegia is an injury to the cervical spine (C1 – C7) resulting in paralysis, to some degree, of all four limbs (Roberts, Leonard, & Cepela, 2017). An injury is considered paraplegic if it is located between the first thoracic (T1) and last lumbar (L5) vertebrae. The upper extremities (UE) are intact while sensation and motion of the trunk and lower extremities varies, as does bowel-bladder control. Grades indicate the severity of the SCI (ASIA, 2018). An SCI is considered complete (Grade A) if there is no sensorimotor function present at the lowest (S4-S5) level of the spinal cord. Incomplete injuries are grossly divided between sensory (Grade B) and motor (Grade C & D).

Grade E indicates minor weakness, spasticity, and/or pain secondary to an otherwise undetectable SCI. The potential for neurological recovery following an incomplete SCI is dependent on the severity of the injury, individual characteristics, and participation in rehabilitation. A systematic review noted functional improvements in 64% of children under the age of 18 with an incomplete SCI (Wang et al., 2004).

Manual Wheelchair

Manual wheelchairs (MWC) are considered the primary mode of functional, home, and community mobility for individuals with lower extremity dysfunction and adequate UE range of motion (ROM) (Nas et al., 2015). Approximately 88,000 MWC users in the United States are under the age of 21 with diagnoses of, but not limited to, spastic hemiplegia, multiple sclerosis, cerebral palsy spina bifida, and SCI (Kaye, LaPlante, & Kang, 2000; Patel, Patel, & Jadeja, 2015). The mobility device is low-weight and components are adjustable for optimal ergonomic positioning (Model Systems Knowledge Translation Center (MSKTC), 2011). MWC propulsion is a form of physical activity and shown to decrease users' risk of chronic cardiopulmonary conditions (Patel et al., 2015).

Despite their benefits, the MWC is not a universal device. Independent propulsion requires a user to have adequate shoulder, elbow, forearm and wrist ROM. For injuries at the C5-C6 level, MWC use is possible but requires the implementation of gloves, knobs, and/or battery power for longer distances (Nas et al., 2015). Second, the adjustable components are not designed to accommodate for the rapid growth of a child. The cost of a replacement MWC is only covered once every five years under Medicare (Groah et al., 2014). To compensate, insurance providers will often argue that a larger MWC be ordered for children and adolescents

(Vogel & Zebracki, 2015). Improper positioning can lead to permanent lower and upper body postural changes. Lastly, wheelchair propulsion fits the definition of a repetitive activity and places strenuous loads on users' UEs (National Institute of Occupational Safety and Health (NIOSH), 1997). The biopsychosocial consequences of long-term MWC use include shoulder pain, disease, decreased UE function, and poor health related quality of life (HRQoL) (Patel et al., 2015).

Shoulder Anatomy & Biomechanics

Shoulder Complex

The shoulder complex is an interdependent system of bones, joints, nerves, and muscles working together to produce functional UE ROM (Neumann, 2017). The four joints are the sternoclavicular, acromioclavicular, scapulothoracic, and glenohumeral (GH) (Figure 1). The shoulder complex sacrifices its stability for the mobility needed to accurately position the elbow, forearm, wrist, and hand during functional reaching activities.

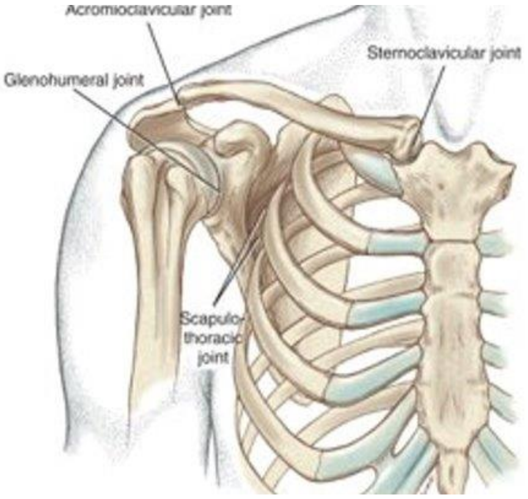


Figure 1. *Shoulder joints (Neumann, 2017).*

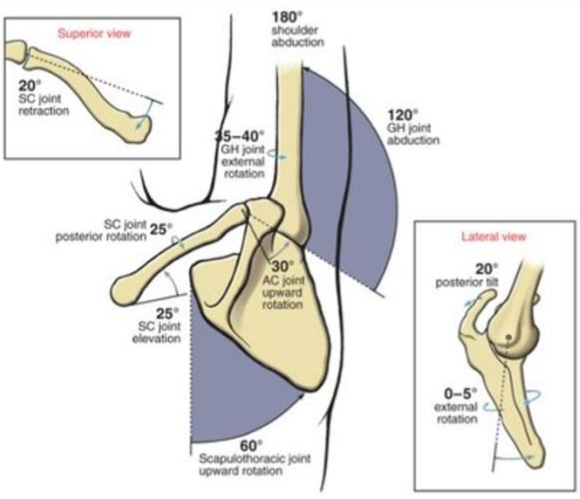


Figure 2. *Scapulohumeral rhythm (Neumann, 2017).*

The sternoclavicular is the most proximal joint and the only direct connection to the axial skeleton. The acromioclavicular joint serves as an extension to the sternoclavicular, positioning the scapula in appropriate relation to the thorax. Both facilitate motion of the scapulothoracic pseudo joint where contact is made between the anterior scapula and posterior rib cage. These movements include elevation/depression, upward/downward rotation, protraction/retraction in relation to the spinal column, and anterior/posterior tilt. Lastly, the GH joint is the articulation between the scapula's concave glenoid fossa and the convex humeral head. The joint's three degrees of freedom include flexion/extension (sagittal plane), abduction/adduction (frontal plane), and internal/external rotation (transverse plane). Full-range shoulder motion is dependent on the alignment of all four joints, muscle function, and structural support (e.g. labrum, ligamentous) (Figure 2).

Musculature

Dynamic stability during functional shoulder ROM is sustained by a grouping of four muscles known as the rotator cuff. The subscapularis is responsible for internal rotation, the supra and infraspinatus for abduction, and the teres minor for external rotation (Figure 3). Their specific role for the GH joint is to maintain alignment between the glenoid fossa and humeral head. The rotator cuff muscles are coupled into the inferior, anterior, posterior cuffs in order to control rotational forces produced by the GH joint. Superior moments and forces in the frontal plane are controlled by the inferior (infraspinatus, teres minor, subscapularis). The anterior (subscapularis) and posterior (infraspinatus, teres minor) cuff balance one another and moments produced in the transverse plane. UE elevation via the shoulder complex is supported by accessory muscles (Figure 3). The three segments of the trapezius are coupled with a periscapular muscle that, when activated together, facilitate scapular motion. Elevation is the combined efforts of the upper trapezius, rhomboid, and serratus anterior. Upward rotation is powered by the serratus anterior, upper and lower trapezius. Downward rotation is a combination of lower trapezius, latissimus dorsi, and pectoralis minor activation. For GH abduction, a force couple exists between the deltoid, supra and subscapularis (Neumann, 2017).

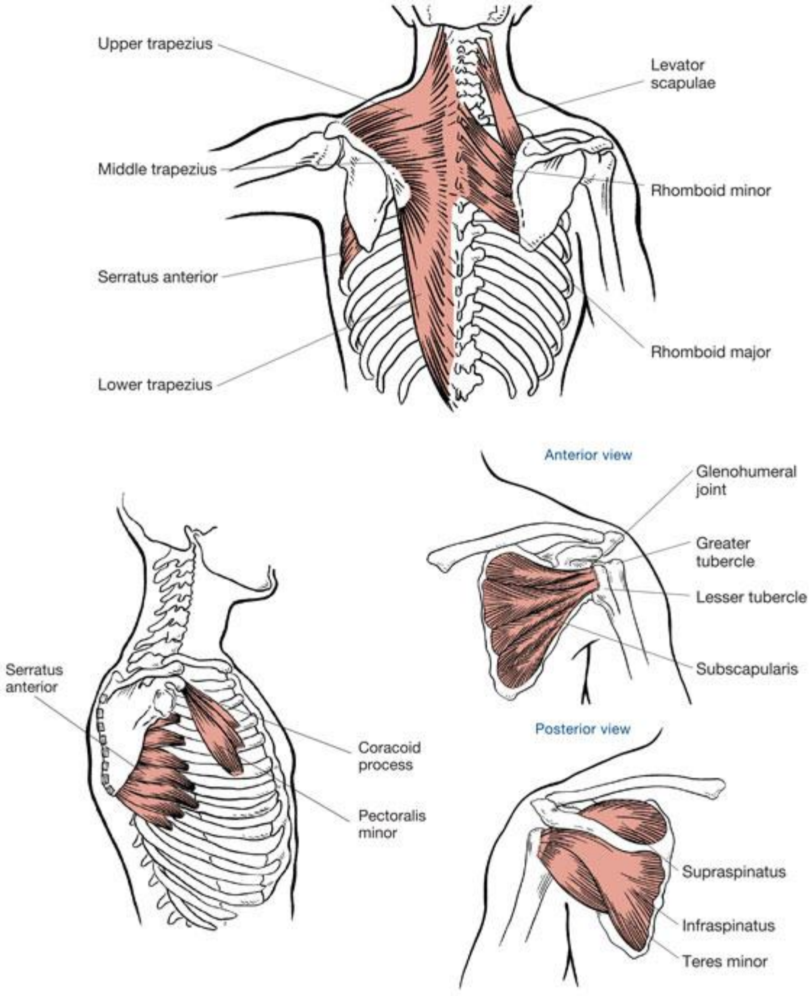


Figure 3. *Rotator cuff and accessory shoulder muscles (Houglum, 2005).*

Scapulohumeral Rhythm

Scapular upward rotation and GH joint abduction/flexion occur in tandem to produce scaption, a motion performed 30 to 45 degrees anterior to the frontal plane and used for functional reaching tasks (Neumann, 2017). There are three phases for achieving full ROM: initial, middle or critical, and final (Figure 2). The GH joint facilitates the majority of the initial phase (0 – 60 degrees). After the first 30 degrees, the RC shifts from stabilizing to mobilizing the shoulder. The rhythm, a consistent 2:1 ratio begins; for every 2 degrees of GH joint abduction/flexion there is 1 degree of ST upward rotation (Neumann, 2017). The muscles of the RC actively mobilize the scapula during the middle (60-140 degrees) and return to GH joint stabilization during the final (140-180 degrees) phase. The accessory, periscapular muscle compensate for weakness and support proper UE posture.

Occupational Performance & Participation

Functional shoulder ROM is crucial to independence with activities of daily living (ADL), the basic self-cares that are fundamental to one’s survival and well-being (American Occupational Therapy Association (AOTA), 2014). Upper extremity dressing and grooming require a combination of shoulder flexion, abduction, and external rotation. Extension and internal rotation are essential for reaching back during toileting or to shift the body during a functional transfer. ADLs are one of eight types of occupations, the intrinsically meaningful and purposeful activities an individual engages in to fill their time. Instrumental activities of daily living (IADL), education, work, play, leisure, social participation, rest and sleep are the others and equal contributors to health-related quality of life (HRQoL). HRQoL describes how an individual perceives their health status to impact their ability to engage in valued occupations and fulfill meaningful roles (AOTA, 2014; Patel et al., 2015). Occupational performance is produced by dynamic interactions between the multi-dimensional person, environment, and occupation (AOTA, 2014). The Person-Environment-Occupation Performance (PEO-P) Model is one of several theoretical models that illustrate what intrinsic, extrinsic, and task-related factors are at play (Baum, Christiansen, & Bass, 2005) (Figure 4). The model emphasizes the importance in considering how dysfunction in one domain will impact others which include an individual's physical health, psychological well-being, environmental supports and barriers.

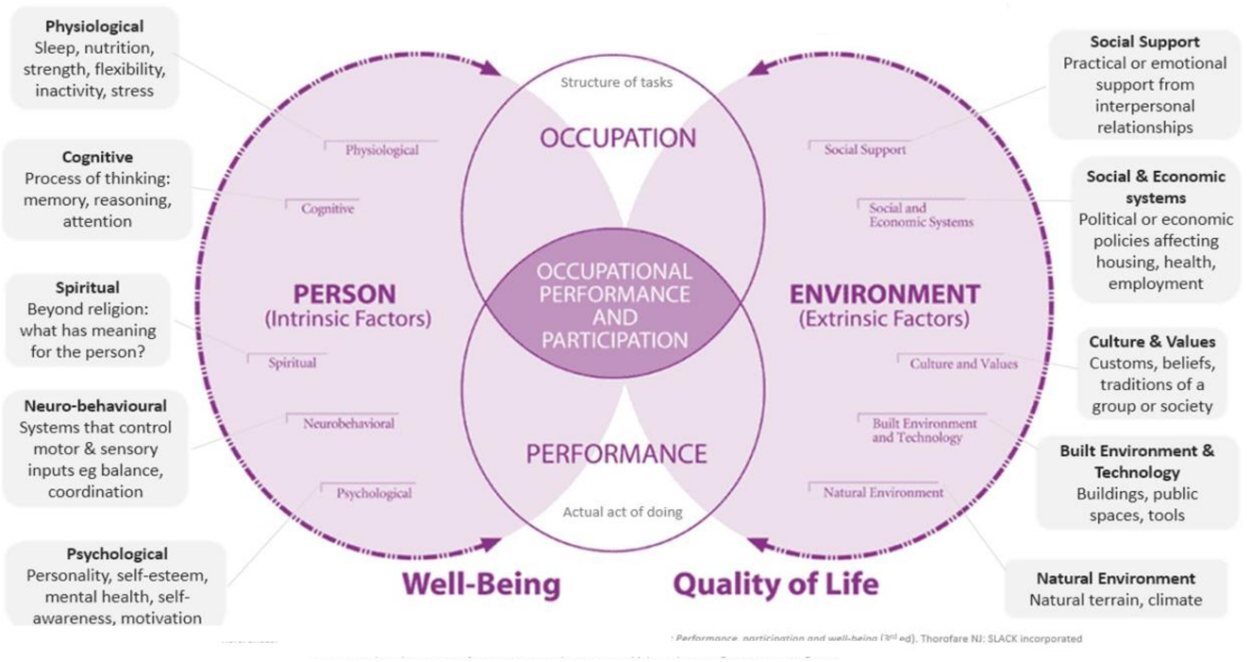


__Figure 4.__ Person-Environment-Occupation Performance Model (Baum, Christiansen, & Bass, 2005).

Sequelae of Shoulder Dysfunction

Adult MWC Users

Chronic shoulder pain has been reported by up to 84% of MWC users with adult-onset SCI (Silvestri, 2017). This may result from many factors including poor MWC positioning, user body weight, choice in propulsion technique, and/or underlying pathological conditions (Morrow et al. 2014). Magnetic resonance imaging (MRI) studies have detected a high prevalence of disease within the bones, muscles, and neurological supply to the shoulder joint amongst MWC users with SCI (Boninger et al., 2001). Symptoms of subacromial bone spurs or impingement, rotator cuff enthesis, advanced clavicular osteoporosis, coracoacromial ligament edema and acromioclavicular ligament thickening have been indicated as severe by up to 50% of adult MWC users with SCI. (Boninger et al., 2001; Mercer et al., 2006). Chronic impingement of the supraspinatus tendon between the humeral head and acromion process can result in musculoskeletal pain, weakness, poor posture, and/or disease (Neumann, 2017). Shoulder muscle deficiencies significantly reduce the available ROM and functional use of the entire UE. Increased challenges with ADLs due to UE impairments have been shown to lead to mental strain and poor HRQoL amongst individuals with SCI (Silvestri, 2016; Walford et al., 2019). Depression is reported by one in three adults with SCI, particularly within the first six months following the onset of injury (Rivers et al. 2018). Other reported stressors and contributors to poor mental health in adults with SCI include financial burden, lack of community accessibility, and navigating new occupational barriers (Nas et al., 2015; Patel et al., 2015; Rivers et al., 2018).

Pediatric MWC Users

Evidence on shoulder pain in childhood, after the transition into young adulthood, and beyond is mixed. One study noted that 1 out of 14 participants experienced minimal bodily pain (13%) amongst youth and adolescents with SCI (Slavens et al., 2015). However, despite reporting significantly less than those with adult-onset SCI, up to 52% of individuals with pediatric-onset SCI report shoulder pain later in life (Sawatzky et al., 2005; Vogel & Zebracki, 2015). This may be because children and adolescents with SCI are at high risk for accelerated aging due to UE overuse and relatively sedentary lifestyles (e.g. obesity, cardiopulmonary disorders) (Vogel & Zebracki, 2015). Further, pediatric MWC users are susceptible to complications with their physical development. Scoliosis affects 100% of those who have not yet reached their growth spurt and 67% of adolescents already at full musculoskeletal maturity (Kwarciak et al., 2009). Consequences of a poorly fit MWC include hip dysplagia in 93% to 100% of children injured at or under the age of 10 and pressure sores with risk for skin breakdown or infection (Parent et al., 2011). Additionally, kyphotic posture has been found to be another residual effect of incomplete SCI. Poor physical health and long-term barriers to functional independence can be determinental to HRQoL (Behrman & Trimble, 2012). Depression is reported by 38% of adults with pediatric-onset SCI (Vogel & Zebracki, 2015). The same longitudinal study (n=457) found that 41% of the group had graduated college, yet less than half (47%) had attained employment in adulthood (Vogel & Zebracki, 2015). Other notable determinants of HRQoL amongst adolescents and youth with SCI include academic success, parental support, accessible recreation or leisure, independence in I/ADLs and wheelchair mobility (Behrman & Trimble, 2012; Vogel & Zebracki, 2015).

MWC Propulsion

MWC mobility is a major step towards functional independence amongst users with SCI (Boninger et al., 2002). MWC propulsion is divided into different task components. A stroke cycle, beginning with the hand in contact with the pushrim and ending at the next point of contact, is comprised of two phases. First is the propulsive: the period of contact between the user's hand and pushrim during which force is being applied to manipulate the chair's motion (Kwarciak et al., 2009). The magnitude and duration of the push directly influences the cadence, speed, and amount of time spent in recovery during the stroke cycle. Next is the recovery phase, the time after the hand releases the pushrim before regaining contact. This second phase of a stroke cycle describes the pattern in which the hand moves. From a sagittal plane perspective, four stroke patterns have been identified, defined, and characterized in adult MWC users with SCI (Boninger et al., 2002) (Figure 5). First, a distinct tracking motion along the edge of the pushrim is known as arcing. The single looping over rim (SLOP) pattern is characterized by the user's hand raising back and above the pushrim. Conversely, the hand rising to meet the pushrim but falling below in order to make another loop is known as the double looping over rim (DLOP) pattern. Lastly, a semicircular pattern is followed if the user's hand remains under the pushrim for the entirety of the recovery phase. Studies specific to pediatric MWC users have note stroke patterns that have a different appearance than thatof any of the four previously mentioned (Slavens et al., 2014, Slavens et al., 2015).

Biomechanical Analysis

The sequelae of shoulder pain, disease, and poor upper extremity function is thought to be the result of repetitively used muscles involved in the propulsive phase as compared to those stabilizing the glenohumeral joint during recovery (Patel et al., 2015). Shoulder muscles involved in the propulsive phase are those that internally rotate, adduct, and flex the arm. These become stronger while the rotator cuff, deltoid, and biceps brachii long head activate for joint stability during recovery and strength is unchanged. The National Institute of Occupational Safety and Health's (NIOSH) definition of a repetitive activity includes cyclicial GH flexion-extension, abduction, and interal rotation (1997). In combination, these kinematics reduce glenoid alignment and volume within the subacromial space. Superior force is a GH kinetic known to cause chronic impingement of the suprapsinatus between the humeral head and acromion process of the scapula. The supraspinatus tendon is highly susceptible to pain, inflammation, and eventual tear secondary to chronic impingement. With the resulting weakness, reliance on accessory periscapular muscles increases. Maladaptive compensatory movement patterns have been observed amongst adults with SCI during functional activities such as MWC propulsion (Slowik et al., 2016).

Certain GH motions, moments, and forces have become biomechanical risk factors for the development of shoulder pain and overuse injuries. Each of these metrics have been used to characterize the four classic stroke patterns (Boninger et al., 2002; Kwarciak et al., 2009; Kwarciak, Turner, Guo, & Richter, 2012). The ARC and SLOP patterns require more frequent pushes, or cadence, via GH extension, abduction, and internal rotation moments (Boninger et al., 2002). Shoulder extension, or anterior translation of the humeral head, has a found to be moderately correlated to rounded shoulder posture (Choi et al., 2017). Comparatively, the SC and DLOP patterns have significantly longer and more effective application of forces at the pushrim and less required to stop the chair (Boninger et al., 2002; Kwarciak et al., 2009).

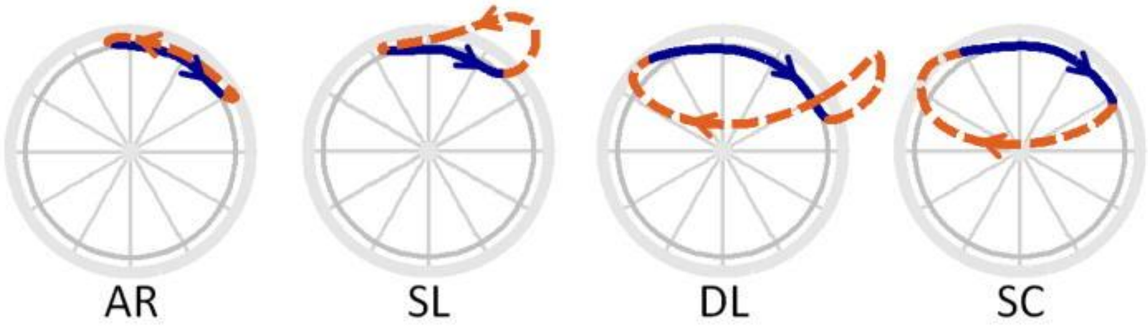


Figure 5. *Four, classic stroke patterns during steady-state MWC propulsion The purple line represents the path of the hand during the propulsive phase. The orange, dotted line represents follows the hand once it releases the pushrim and until completion of the stroke cycle (Slowik et al., 2016).*

Clinical Guidelines

The Preservation of Upper Limb Function Following a Spinal Cord Injury are clinical guidelines developed by the Paralyzed Veteran's Association and provide recommendations for environmental adaptations, pain management, MWC ergonomics and best practices for MWC use (2005). The guidelines emphasize sole use of the SC stroke pattern to minimize UE overuse and dysfunction (PVA, 2005) (Figure 6). The SC stroke pattern follows a smooth elliptical path and requires a less abrupt motion in order for the MWC user to regain hand contact with the pushrim (Boninger et al., 2002). However, these recommendations are derived from adult-based MWC studies and have not been updated in over a decade. Sawatzky and colleagues published a position paper that spoke to the importance of updating current clinical guidelines (2015). The group identified the need for updated recommendations to include that new MWC users practice the different types of stroke patterns more frequently during wheelchair skills training as well as urging practitioners to better consider individual and environmental factors.

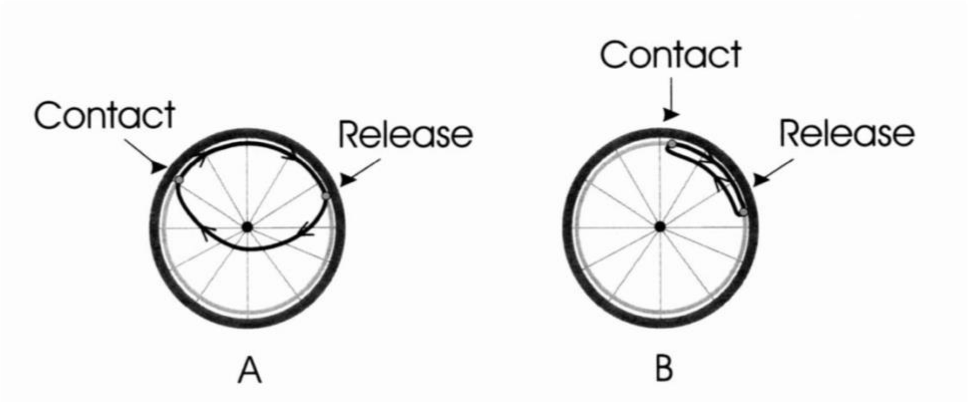


Figure 6. *The recommended propulsion pattern (SC) is represented by 'A' versus "an example of a poor propulsion pattern" is 'B' (ARC) (PVA, 2005).*

The goal of clinical guidelines is to enhance treatment planning for practitioners involved in MWC training and SCI rehabilitation. These include, but are not limited to, an interdisciplinary team of neurologists, nurses, occupational/physical/speech/recreation therapists, psychologists, social workers, and assistive technology professionals (Vogel & Zebracki, 2015; PVA, 2005). The preservation, remediation, and/or adaptation for functional use of the UEs is at the forefront of occupational therapy intervention. Occupational therapists possess clinical skills to address short-term and/or chronic pain (Lagueux, Depelteau, Masse, 2018). Consideration for home set up and environmental factors is shared by physical therapists who are more directly involved in wheelchair mobility (Morgan, Engsberg, & Gray, 2017). An assistive technology professional is responsible for set up of a newly received MWC and training on the components. An assistive technology professional must pass a board examination, but the required education and hours of work-related experience vary depending on a candidates highest attained degree (Rehabilitation Engineering and Assistive Technology Society of North American (RESNA), 2012). These range from a high school diploma to a master’s in a rehabilitation science

Literature Review

There are no current clinical guidelines for pediatric MWC users and limited investigation of UE joint dynamics during propulsion tasks (Slavens et al., 2014; Slavens et al., 2015). The biomechanical data from adult-based studies cannot be accurately scaled down to a pediatric MWC user. Children's bodies are not yet fully developed and the segments are proportionally different than that of an adult (Schnorenberg et al., 2014). As a result, there are specialized considerations to be made with pediatric versus adult MWC users with SCI. This includes biopsychosocial needs, the prescription of, and training on best practices for MWC use (Vogel & Zebracki, 2015). Defending the need for individualized seat dimensions and physical supports are vital in limiting the effects of gravity on poor posture and UE dysfunction (Behrman & Trimble, 2012; Nas et al., 2015).

There is no current protocol for how long an occupational therapist, physical therapist, and assistive technology professional must spend on wheelchair skills training during SCI rehabilitation. The degree of training on strategies for MWC propulsion is inconsistent amongst the SCI population. A study found 77% of all inpatient occupational therapy treatments for patients with SCI were geared towards ADL re-training while an average of one hour was spent addressing MWC mobility for participants with paraplegic injuries grades A – C. (Foy et al., 2011). A focus-group study conducted by Morgan and colleagues identified priorities, skills to be taught, and future needs for and future needs for wheelchair skills training during inpatient rehabilitation for patients with SCI (2017). Comparisons were made among the perceptions of MWC users, assistive technology professionals, occupational and physical therapists. Consistent with previous literature, more than half the participants indicated the level of training given was one of two extremes: none or extensive education (Boninger et al., 2002; Morgan, Engsberg, &

Gray, 2017). Users expressed that while stroke patterns were introduced, there was little explanation and practice of the four during therapy sessions. Consideration for physical, social, cultural, personal, temporal, virtual supports and barriers is imperative to the SCI rehabilitation process (AOTA, 2014) (Appendix A & Figure 7). For pediatric patients, this includes their individual learning preferences, the identification of occupations valued by the child and family as a whole, set up of the home and school, transportation methods, and relevant functional transfers.

Purpose

The purpose of this study is to support the development of MWC training guidelines for pediatric patients as none such exist. This long-term objective will be achieved through three aims. These are to identify stroke patterns used by pediatric MWC users with SCI, characterize via GH joint dynamics, and assess physical and mental HRQoL. The data could help determine which propulsion technique(s) and GH joint dynamics are at lesser risk for shoulder pain, disease, and dysfunction with long-term MWC use. These findings may support interdisciplinary teams involved in creating a life care plan, prescribing mobility devices, training on MWC propulsion techniques, and educating adolescents and youth with SCI on joint protection strategies during I/ADLs. The results may benefit pediatric MWC users with other diagnoses such spastic hemiplegia, multiple sclerosis, muscular dystrophy, cerebral palsy, and spina bifida.

Aims and Hypotheses

Aim I: To identify stroke patterns being used in pediatric MWC users.

Hypothesis A: It is expected that a pediatric MWC user with an SCI will use two different stroke patterns during steady-state propulsion.

Aim 2: Compare glenohumeral joint motions, forces and moments between the different types of stroke patterns.

Hypothesis A: It is expected that there will be statistically significant differences in average peak GH joint extension moment among the different types of stroke patterns.

Hypothesis B: It is expected that there will be statistically significant differences in average peak GH joint abduction moment among the different types of stoke patterns.

Hypothesis C: It is expected that there will be statistically significant differences in average peak GH joint internal rotation moment among the different types of stroke patterns.

Hypothesis D: It is expected that there will be statistically significant differences in average peak GH joint superior force among the different types of stroke patterns.

Hypothesis E: It is expected that there will be statistically significant differences in average peak GH joint flexion/extension range of motion (ROM) among the different types of stroke patterns.

Hypothesis F: It is expected that there will be statistically significant differences in average peak GH joint abduction angle among the different types of stroke patterns.

Aim 3: To correlate pediatric MWC users' self-perceived physical, social, and emotional function and role fulfillment to number and type of stroke pattern(s) used.

Hypothesis A: Average SF-12 PCS and MCS will be significantly different than that of the average healthy individual.

Hypothesis B: Physical and mental health composite scores for HRQoL will be correlated to the number of stroke patterns used by pediatric MWC users with SCI.

II. Manuscript

Introduction

Approximately 88,000 MWC users in the United States are under the age of 21, including children and youth diagnosed with SCI (Kaye, LaPlante, & Kang, 2000; Patel, Patel, & Jadeja, 2015). Long term MWC use and propulsion has been defined as a repetitive activity due to the cyclical moments, forces, and motions it places on the shoulder (NIOSH, 1997). Compared to adults, there has been limited investigation of UE joint dynamics during propulsion tasks (Slavens et al., 2014; Slavens et al., 2015). Functional shoulder ROM is crucial to independence with activities of daily living (ADL), the basic self-cares that are fundamental to one's survival and well-being (AOTA, 2017). The pediatric population is at increased risk for accelerated aging due to UE overuse and complications with physical development (Vogel & Zebracki, 2015). There are no guidelines specific to pediatric MWC users. There is no standardized protocol for how long occupational therapists, physical therapists, and/or assistive technology professionals must devote to wheelchair skills training. The purpose of this study is to identify stroke patterns used by pediatric MWC users with SCI, characterize each type via GH joint dynamics, and to report on the multiple domains of HRQoL. It is hypothesized that pediatric MWC users with SCI will perform two or more types of stroke patterns during steady-state propulsion. It is hypothesized that there will be statistically significant differences in average peak GH joint moments, forces, and motions between the different types of stroke patterns. It is hypothesized that there will be statistically significant differences between the number of stroke pattern types used and the average HRQoL assessment scores among pediatric MWC users with SCI.

Methods

2.1 Subjects. Data was collected retrospectively; All thirty-nine (39) participants were MWC users under the age of 21 and diagnosed with either a quadriplegic or paraplegic SCI. Subjects with secondary neurological conditions or upper extremity joint contractures were excluded because of the potential for limited participation in functional mobility tasks. Medical interventions, specifically botulinum toxin type-A or orthopedic procedures within the past year, were further grounds for exclusion. Data collection involved temporary installation of a SmartWheel (Out Front, Mesa, AZ) on the dominant side, meaning, qualified subjects were required to have a MWC with a quick release axle feature.

This study included a subset of twenty-two (22) of the participants, 13 males and 9 females between the ages of 7.2 - 20.9 years old (13.85 ± 4.49) (Table 1). Errors experienced during data collection (e.g. poor placement of UE reflective markers) or large gaps during processing were grounds for subject exclusion. However, the entire sample (n=39) was included summarizing HRQoL outcome scores for Aim 3.

2.2 Data Collection. All data was collected in the Motion Analysis Laboratory at Shriners Hospital for Children – Chicago. Twenty-seven reflective markers were applied to specific anatomical landmarks on each subject (Figure 7). Anthropometric measurements were taken prior to and included body weight, length of each upper extremity segment, and circumference of joints. A 14-camera Vicon MX motion analysis system (Oxford Metric Group, Oxford, UK) was used to capture three-dimensional UE kinematics during steady-state, MWC propulsion. Kinetic data was collected at the pushrim of a SmartWheel outfitted to the dominant side of each participants' personal MWC. Each trial was performed along 15 meters of flat, tile floor.

Subjects were permitted time to acclimate to the task and setting prior to data collection. Both systems were calibrated prior to data collection, including a static baseline trial in which the participant did not move.

Table 1 – Subject Demographics

Subject	Age (Years)	Limb dominance	Gender	Time since injury (Years)	SCI Level (Cervical/ Thoracic)	AISA Grade	Height (cm)	Weight (kg)
1	18	R	M	0.2	C	AIS A	181.6	65.8
2	17.7	L	M	16.4	C	AIS C	172.1	49.0
3	18	R	M	2.21	T	AIS B	185.4	61.2
4	9	R	M	4.2	C	/	145.0	64.0
5	17.8	L	M	7.5	C	AIS A	152.4	41.3
6	11.3	R	M	1.6	T	AIS A	154.2	34.2
7	11.1	R	M	2.9	T	AIS A	137.1	31.7
8	18	L	F	0.3	T	AIS A	178.0	90.3
9	16.5	R	M	0.2	C	AIS B	170.2	63.1
10	8	R	F	3.6	T	AIS B	124.4	31.7
11	17.9	R	F	5.2	C	AIS A	160.0	52.9
12	20.9	L	F	3.8	T	AIS A	167.6	51.1
13	7.2	L	M	5.8	C	AIS C	121.9	26.5
14	11.5	R	M	10.4	T	AIS C	151.9	63.0
15	10.2	R	F	8.1	T	AIS A	121.9	24.0
16	19	R	M	6.5	T	AIS A	178.3	76.0
17	19.9	R	M	3.8	C	AIS C	177.8	67.3
18	14.5	R	F	14	T	AIS A	139.7	42.5
19	13	R	F	3.1	C	AIS B	153.4	44.0
20	7.8	R	F	4.1	T	/	118.1	22.6
21	8.4	R	M	3.4	C	/	135.0	22.1
22	9	R	F	1.2	T	/	130.0	27.6
Average ± SD	13.85 4.49			4.93 4.15			152.55 21.3	47.92 18.65

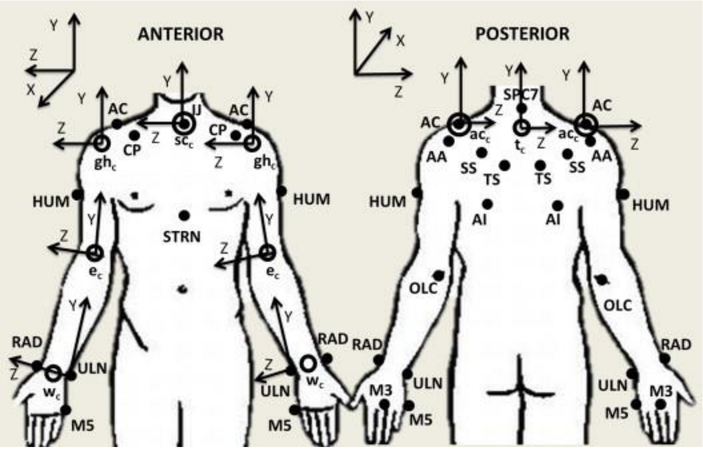


Figure 8. *Upper extremity marker set used for shoulder kinematic data collection and analysis (Schnorenberg et al., 2014).*

Functional outcome measures were chosen because of their clinical use and familiarity with participants regularly treated at Shriners Hospital for Children – Chicago. Pain outcomes were collected through use of the Visual Analog Scale (VAS) (Figure 8), a reliable and valid measure of pain intensity in adults and children between the ages of 8 and 17 (Wewers & Lowe, 1990). Subjects were asked to select, on average, their level of daily bodily pain. Results were recorded as a number between 0 and 100.

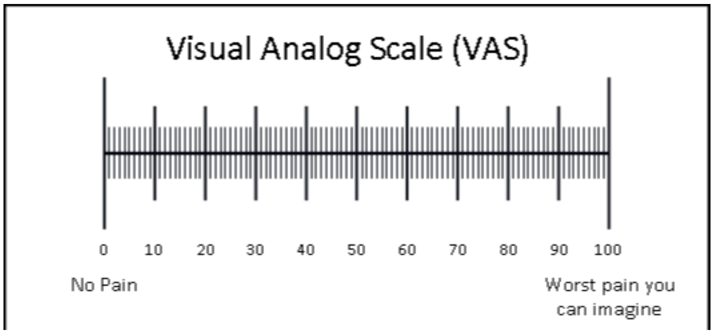


Figure 9. *Visual Analog Scale (VAS) for pain (Wewers & Lowe, 1990)*

Assessment of health-related quality of life (HRQoL) was completed via the Short-Form Health Questionnaire (SF-12) v2 (Appendix B & Figure 10). The eight domains include self-perceptions of physical (PF) and social functioning (SF), fulfillment of physical (RP) and emotional roles (RE), bodily pain (BP), general (GH) and mental health (MH), and vitality (VT) (National Institute of Neurological Disorders and Stroke (NINDS), 2019). Developers created an algorithm to score the twelve questions into a physical (PCS) and mental health (MCS) composite scores. A guide to interpret the results, ranging between 0 – 100 with the average healthy individual being 50, was used (Utah Department of Health, 2001). The SF-12 has been strongly validated and is one of the six most commonly used objective HRQoL measures for the SCI population (Hawkins, Henry, Crandell, Nguyen, 2014). A longitudinal study published SF-12v2 PCS (45.0) and MCS (53.3) averages for a population of adults ages 19 – 48 years old who had sustained a SCI in childhood or adolescence (0 – 18 years) (Vogel & Zebracki, 2015).

2.3 Data Processing & Analysis. Motion analysis data captured during steady-state MWC propulsion was compiled into MATLAB. The average positions of the left (LM3) and right (RM3) 3rd metacarpal phalangeal reflective markers were tracked throughout each trial. MATLAB was used to convert the data into visual representations of each stroke cycle from the sagittal perspective (Figure 9). Symbols to distinguish the point of hand contact and release from the pushrim were denoted. A custom pediatric inverse dynamics model was applied to quantify the motions, moments, and forces at the UE joints (Schnorenberg et al., 2014). It was developed to account for the different segmental lengths of the extremities in pediatric subjects. ROM was calculated by subtracting the minimum angle from the maximum angle. Peak forces were adjusted by percent body weight (%BW). Peak moments were adjusted by percent body weight times height (%BWxH). Scores for the SF-12v2 and VAS were compiled into Microsoft Excel (Microsoft, Redmond, WA).

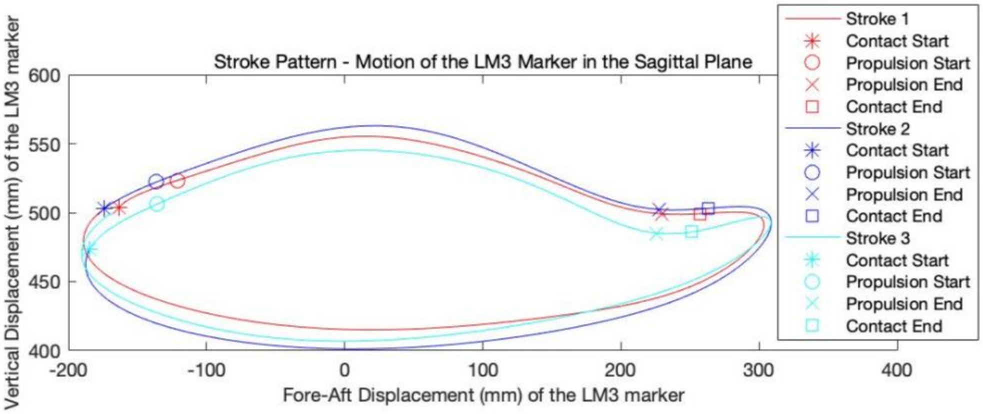


Figure 11. *One trial of three stroke cycles modeled via MATLAB*

Stroke Pattern Classification. Recent adult-based studies have opted to use more complex objective methods for the classification of stroke patterns including biomechanical variables and machine-based learning (Slowik et al., 2015). Our research group has been the only to attempt to characterize MWC propulsion variables and classify stroke patterns in pediatric users with SCI (Slavens et al., 2014, Slavens et al., 2015, Aurit et al., 2015). This study followed in suite; stroke patterns (n=383) were classified with respect to the widely recognized definitions developed for the SC, DLOP, SLOP, and ARC stroke patterns in adult-based literature (Boninger et al., 2002). Prior to, two novel stroke patterns consistently presented themselves during the classification process. Neither entirely matched the appearance of any of the four classic stroke patterns. The definitions for the two types of novel stroke patterns novel are as follows.

Semicircular (SC). The hand remains entirely under the pushrim. The pattern shows no looping (Figure 12).

Double Loop-Over Rim (DLOP). After release, the hand raises above the pushrim and then returns below to reconnect with the pushrim. The pattern shows two proportionally sized loops, one above and one below the pushrim (Figure 13).

Single Loop-Over Rim (SLOP). After release, the hand rises and makes a neutral run in the posterior direction to reconnect with the pushrim. The pattern shows one loop entirely above the wheel (Figure 14).

Arcing (ARC). The hand moves in a repetitive, antero-posterior direction along the upper edge of the pushrim. The pattern shows no looping (Figure 15).

Novel "Bean". (Figure 16). After release, the hand rises and follows the curvature of the upper edge of the pushrim. The pattern shows one loop entirely above the wheel.

Novel "Tiny Loop". (Figure 17). The hand makes the same motion as the DLOP pattern. However, the loop made above the pushrim is notably smaller in proportion to that loop below the pushrim.

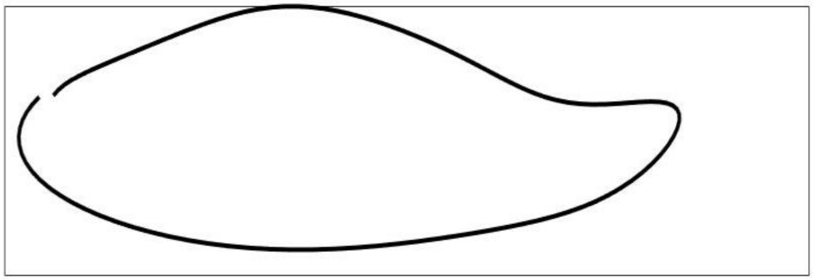


Figure 72. *Semicircular (SC)*

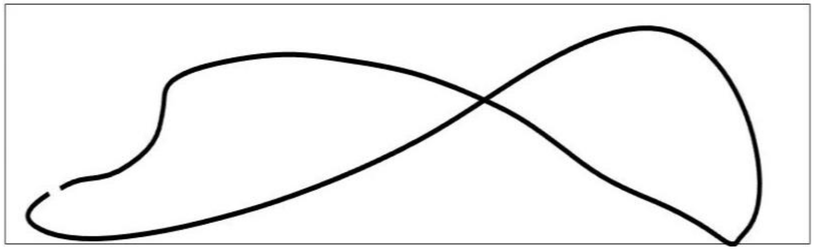


Figure 13. *Double Loop-Over Propulsion (DLOP)*

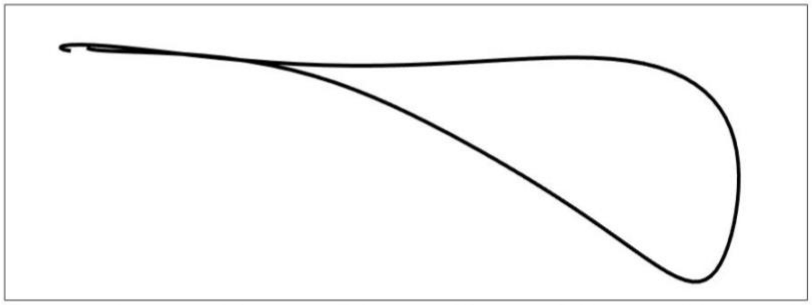


Figure 14. *Single Loop-Over Propulsion (SLOP)*

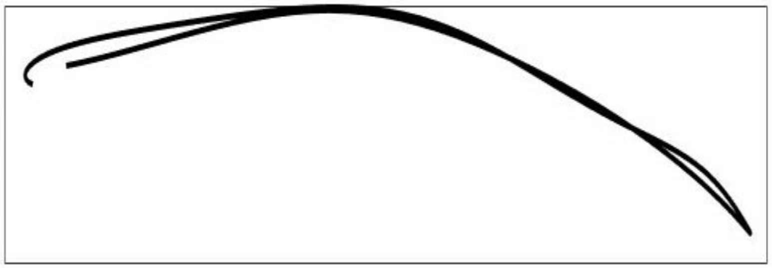


Figure 15. *Arcing (ARC)*

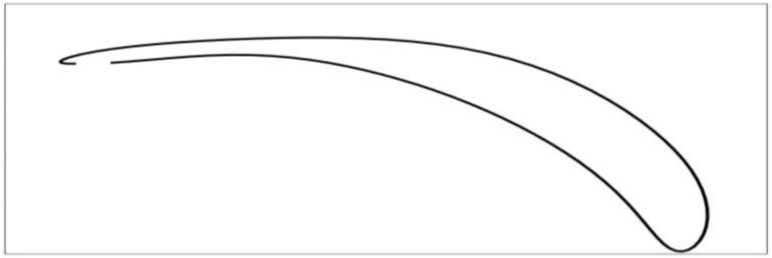


Figure 16. *Bean*

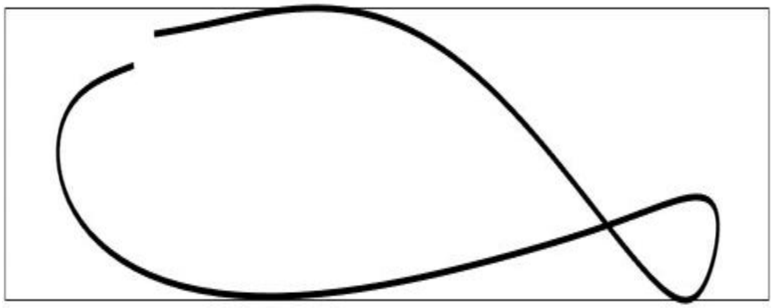


Figure 17. *Tiny Loop*

2.4 Statistical Analyses. This study included three aims and associated hypotheses to be tested. All statistical tests were computed using Statistical Package for Social Sciences (SPSS) (IBM, Armonk, NY). Graphs and tables were created in Microsoft Excel (Microsoft, Redmond, WA).

Stroke Pattern Classification. A two-stage protocol was used to confirm good inter-rater agreement (IRA) of stroke pattern classification into six different categories (Tarima & Flournoy, 2019) (Figure 18). IRA indicates the level of agreement that exists between raters and is often evaluated by Cohen’s Kappa (κ) (Cohen, 1960). The goal for this study was to establish good ($\kappa = 0.61 – 0.8$) to very good ($\kappa > 0.8$) inter-rater agreement. The null hypothesis (H_0) was set at $\kappa = 0.6$. The chance of this is incorrectly assumed to be false, a Type I error, is 0.05 ($=0.0253 + 0.0253*(1-0.0253)$) or $\alpha = 0.0253$ for each stage. This and excellent 83% statistical power were ensured by the sizes of both randomized samples. Stage I ($n_1 = 25$) was completed by two raters both a part of the same research team with at least one year of involvement in pediatric mobility research and adequate exposure to stroke patterns. If Cohen's κ at stage I was > 0.83, good IRA was established and the protocol was complete. If $\kappa < 0.83$, Stage II was initiated. Stage II followed the same procedures with a critical value (CI) of 0.74. If $\kappa > 0.74$, the null hypothesis would be rejected and IRA determined to be good.

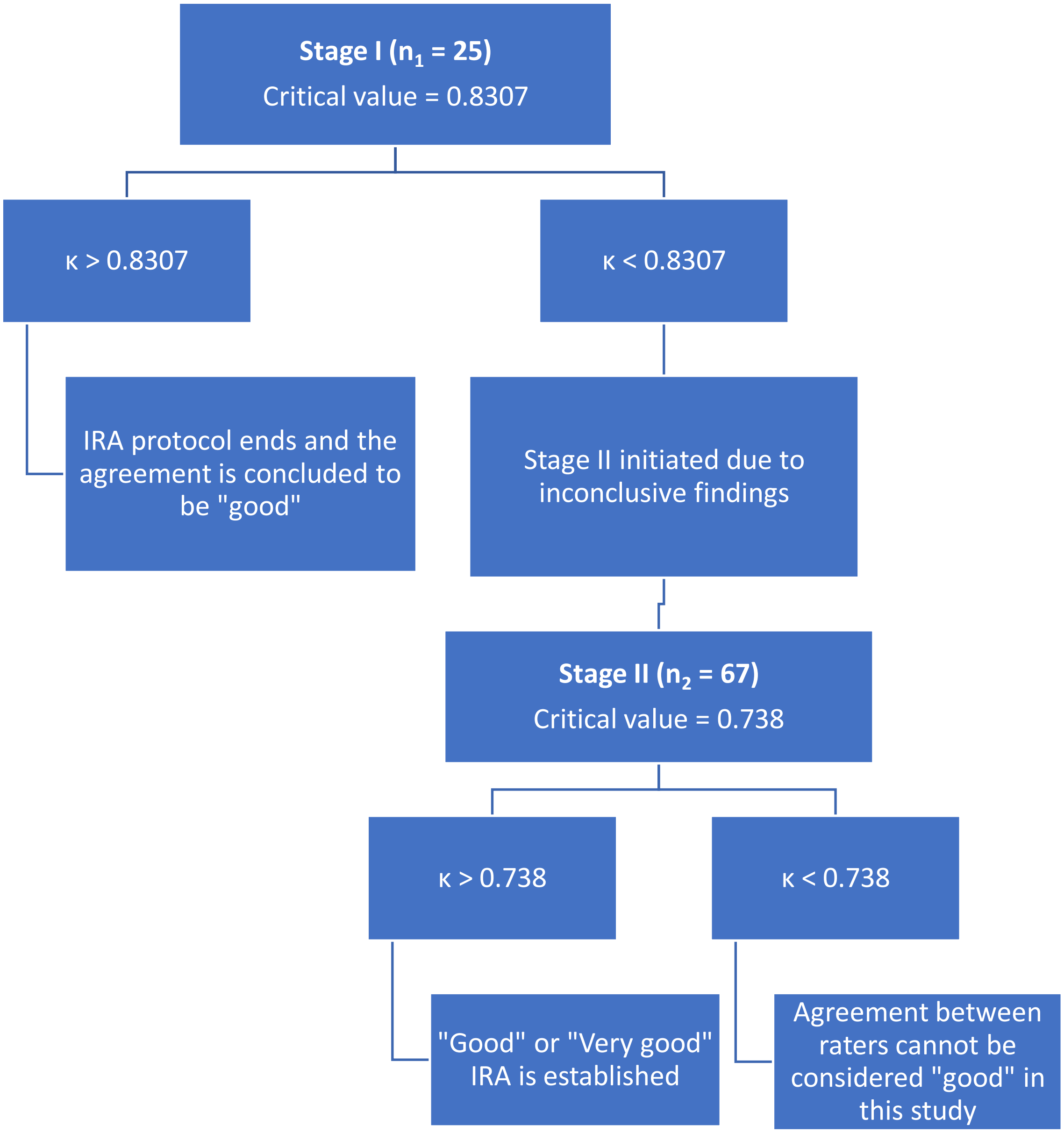


Figure 18. *Two-stage inter-rater agreement protocol (Tarima & Flournoy, 2019) for classification of stroke patterns.*

GH Joint Dynamics. Data for GH joint peak extension moment, peak abduction moment, peak internal rotation moment, peak superior force, flexion/extension ROM, and peak abduction angle for each stroke cycle were compiled into SPSS for statistical analyses. A multivariate Analysis of Covariance (MANOVA) was conducted to test for statistically significant differences between six average peak GH joint dynamics between groups stratified by type of stroke pattern. A Tukey post-hoc test was included to determine between which specific groups, if any, the statistically significant differences existed. A Bonferroni Correction, an adjustment made to the p-value to account for the number of comparisons being tested, was applied ($p < 0.01$).

Functional Outcomes. Bodily pain reported by the sample via the VAS was calculated as a frequency (%). SF-12v2 scores were stratified by PCS and MCS. All were compiled into SPSS for statistical analyses. Two one-sample T-tests were conducted to determine if there were statistically significant differences between the sample's PCS and MCS scores and a normative score ($p < 0.05$). These included the score that the SF-12 measure published as that of an average healthy individual (50) and others specific to a sample of adults with pediatric-onset SCI (PCS = 45.0, MCS = 53.3) (Utah Department of Health, 2001; Vogel & Zebracki, 2015). A MANOVA was conducted to determine if there were statistically significant differences in average PCS and MCS between groups stratified by use of 1 – 4 or more different types of stroke patterns. A Tukey post-hoc test was included to determine between which specific groups, if any, the statistically significant differences existed ($p < 0.05$). The average and standard deviation of scores for each of the eight domains was reported.

Results

3.1 Stroke Pattern Classification. Out of all 383 trials for steady-state MWC propulsion, participants used the SC stroke pattern (117) most often (Figure 18). The DLOP stroke pattern (86) and Tiny Loop (84) stroke patterns were used of similar frequency to one another. The SLOP (52) and Bean (34) stroke patterns were used minimally. The ARC stroke pattern (10) was classified least often. The majority of subjects used two (n = 5) or four (n = 5) different types of stroke patterns throughout multiple trials of the steady-state MWC propulsion task (54%). The three subjects (14%) who adhered to one type of stroke pattern solely used the semicircular (SC) stroke pattern. The IRA between both raters was determined to be good or very good (Cohen's $\kappa > 0.6$). The interim IRA following Stage I ($n_1 = 25$) did not provide enough statistical power to make a conclusive decision ($\kappa = 0.793 < 0.832$). An additional 48 stroke cycles were included as part of Stage II ($n_2 = 73$). The resulting, combined IRA ($\kappa = 0.911 > 0.738$) was great enough to reject the null hypothesis ($H_0 = K \leq 0.6$). The accuracy on all data was calculated ($\kappa = 0.932$).

Aim 1, Hypothesis A: It is expected that a pediatric MWC user with SCI will use two different stroke patterns during steady-state propulsion.

Summary of Aim 1, Hypothesis 1. More than half of all stroke patterns were classified as SC. The majority of subjects used multiple types of stroke patterns during a steady-state MWC propulsion task. Subjects who used a single type adhered to the SC stroke pattern across each of their respective data collection trials.

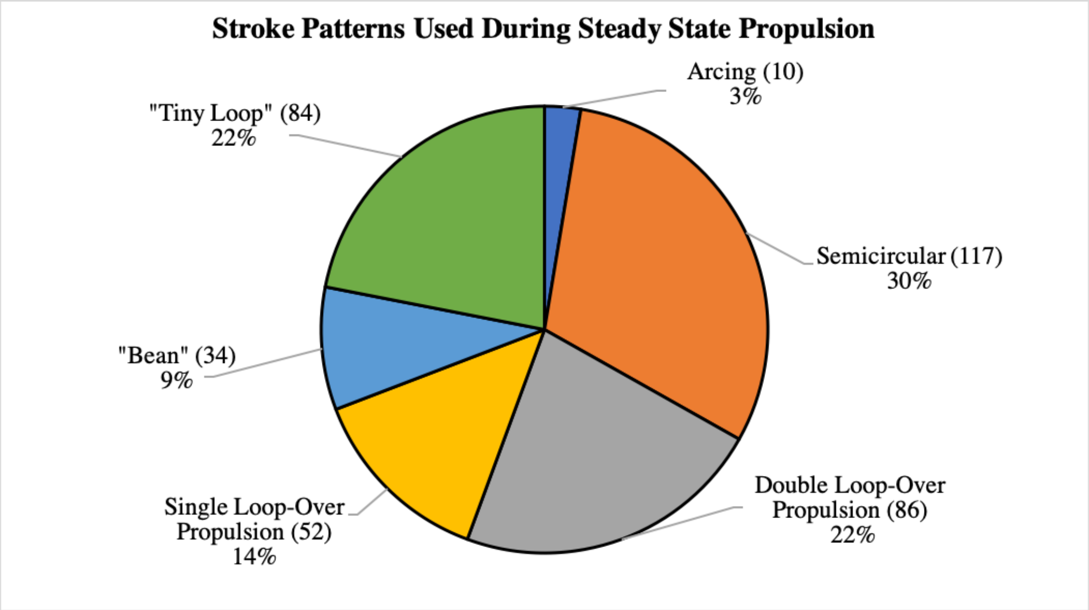


Figure 19. *Frequency of semicircular (orange), DLOP (grey), SLOP (yellow), ARC (dark blue), bean (light blue), and tiny loop (green) stroke pattern use across all stroke cycles during steady state propulsion (n = 383). Reported by number in parentheses as a percentage.*

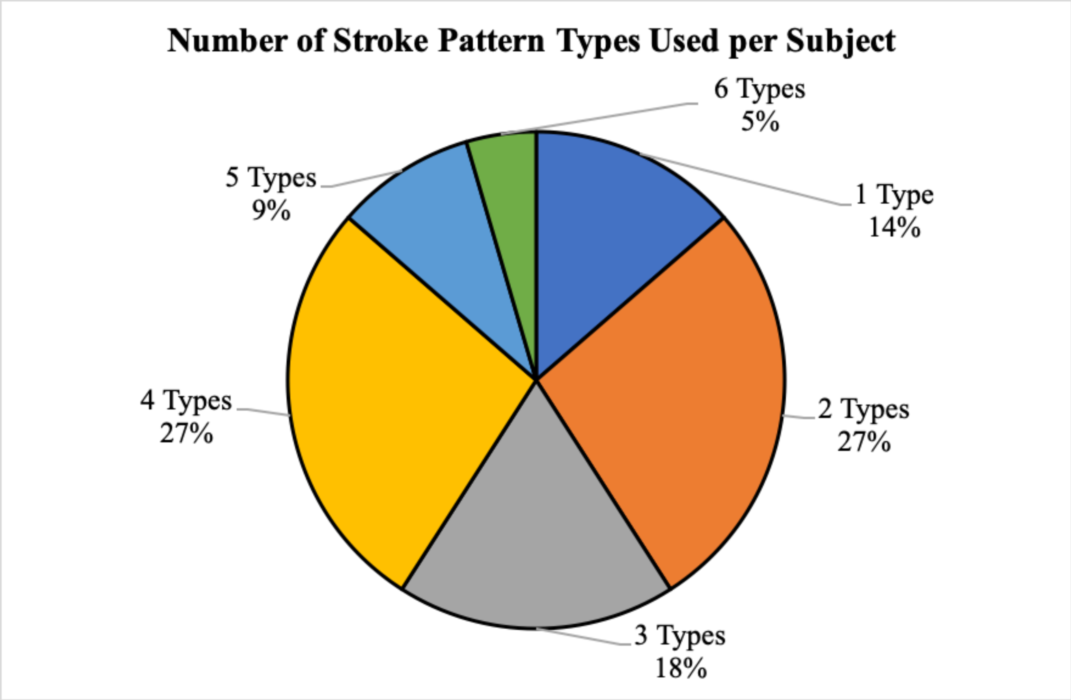


Figure 20. *Number of stroke patterns types (1 - 6) used by each subject (n = 22) during steady state MWC propulsion trials. Frequency was reported by percentage.*

3.2 GH Joint Dynamics. There were statistically significant differences in peak GH joint moments, forces, and motions between the different types of stroke patterns (Table 2). Large standard deviations may indicate greater variability in GH joint dynamics between subjects performing the same type of stroke pattern (Figure 20 -22). The average peak extension moments for SLOP (-1.73 %BWxH) and DLOP (-1.67 %BWxH) were significantly larger than those of SC and Tiny Loop ($p < 0.001$). The ARC (1.23 BW%xH), SLOP (.98 BW%xH, and Tiny Loop (.82 BW%xH) stroke patterns yielded significantly larger average peak internal rotation moments than the SC stroke pattern ($p < 0.01$). The average peak abduction moments for Bean (-1.66 %BWxH) and SLOP (-1.32 %BWxH) were significantly larger than those of SC, DLOP, and Tiny Loop ($p < 0.001$). The same differences were found to be statistically significant for average peak GH abduction joint angles; the largest was the difference between the SLOP and Tiny Loop stroke patterns (20°) ($p < 0.001$). SC, DLOP, and Tiny Loop stroke patterns were characteristic of significantly lower average GH flexion/extension ROM in comparison to Bean (57°) and SLOP (53°) ($p < 0.01$). The SC stroke pattern required the least flexion/extension ROM (42°); the differences between those of DLOP (7°), Tiny Loop (5°), and SLOP (11°) were found to be statistically significant in addition to Bean ($p < 0.001$). The SC stroke pattern yielded the largest average peak GH superior force (7.37 %BW) and was significantly different in comparison to SLOP (6.29 %BW) and Bean (5.99 %BW) ($p < 0.01$). A statistically significant difference existed between the average peak GH superior force between the Tiny Loop and Bean stroke patterns as well ($p < 0.01$).

Aim 2, Hypothesis 1: It is expected that maximum GH joint extension, abduction, internal rotation moments, superior force, flexion/extension ROM, and peak abduction angle will be significantly different between all six stroke pattern categories.

Summary of Aim 2, Hypothesis 2. There were statistically significant differences in average peak GH joint moments, forces, and motions between the different types of stroke patterns. The SLOP stroke pattern was characteristic of significantly larger GH extension, internal rotation and abduction moments. The Bean stroke pattern was characteristic of significantly larger average GH joint flexion/extension ROM, peak abduction moment and angle. Conversely, the SC stroke pattern was characteristic of significantly lower average peak GH joint moments and motions. However, the SC stroke pattern yielded the largest average peak superior force. The aforementioned and a larger average peak internal rotation moment were the only difference found to be significant for the ARC stroke pattern. The DLOP and Tiny Loop stroke patterns shared some, but not all characterizing GH joint moments, forces, and motions. The same applied to SLOP with respect to the Bean stroke pattern.

Table 2 - Mean Peak GH Joint Moments, Forces, and Motions in Dominant Limb During Steady-State MWC Propulsion

Stroke Pattern	Peak GH Joint Moments (%BWxH)			Peak GH Joint Force (%BW)	Peak GH Joint Angles and ROM (degrees)	
	Extension (-)	Internal Rotation (+)	Abduction (-)	Superior (+)	Flexion (+)/ Extension (-) ROM	Abduction (-) Angle
SC	-1.01 ± .53	.58 ± .42	-.63 ± .42	7.37* ± 1.31	41.93 ± 5.99	-23.06 ± 13.33
DLOP	-1.67** ± 1.06	.68 ± .44	-0.94* ± .66	6.75 ± 2.12	49.14** ± 14.39	-22.38 ± 18.87
SLOP	-1.73** ± 1.39	.98** ± .69	-1.32** ± .63	6.29 ± 1.26	52.63** ± 9.49	-36.13** ± 10.39
ARC	-1.13 ± .36	1.23** ± .43	-1.07 ± .64	5.66 ± 1.66	44.92 ± 7.70	-27.04 ± 6.34
Bean	-1.32 ± .48	.60 ± .42	-1.66** ± .73	5.99 ± 1.55	57.07** ± 11.16	-35.1** ± 12.58
Tiny Loop	-1.09 ± .71	.82* ± .50	-0.84 ± .39	7.21* ± 1.77	47.31** ± 11.30	-16.39 ± 16.71
Average ± SD	-1.30 ± .91	.73 ± .51	-.94 ± .62	6.89 ± 1.77	47.61 ± 11.44	-24.39 ± 16.35

Mean peak GH joint dynamics stratified by type of stroke pattern during steady steady-state MWC propulsion. Moments as percent body weight x height (%BWxH) and forces as percent body weight (%BW). ROM and joint angles were reported in degrees.

$*p < 0.01$ $**p < 0.001$. The asterisk indicates the significantly larger average that was found to be different from that of one or more other types of stroke patterns.

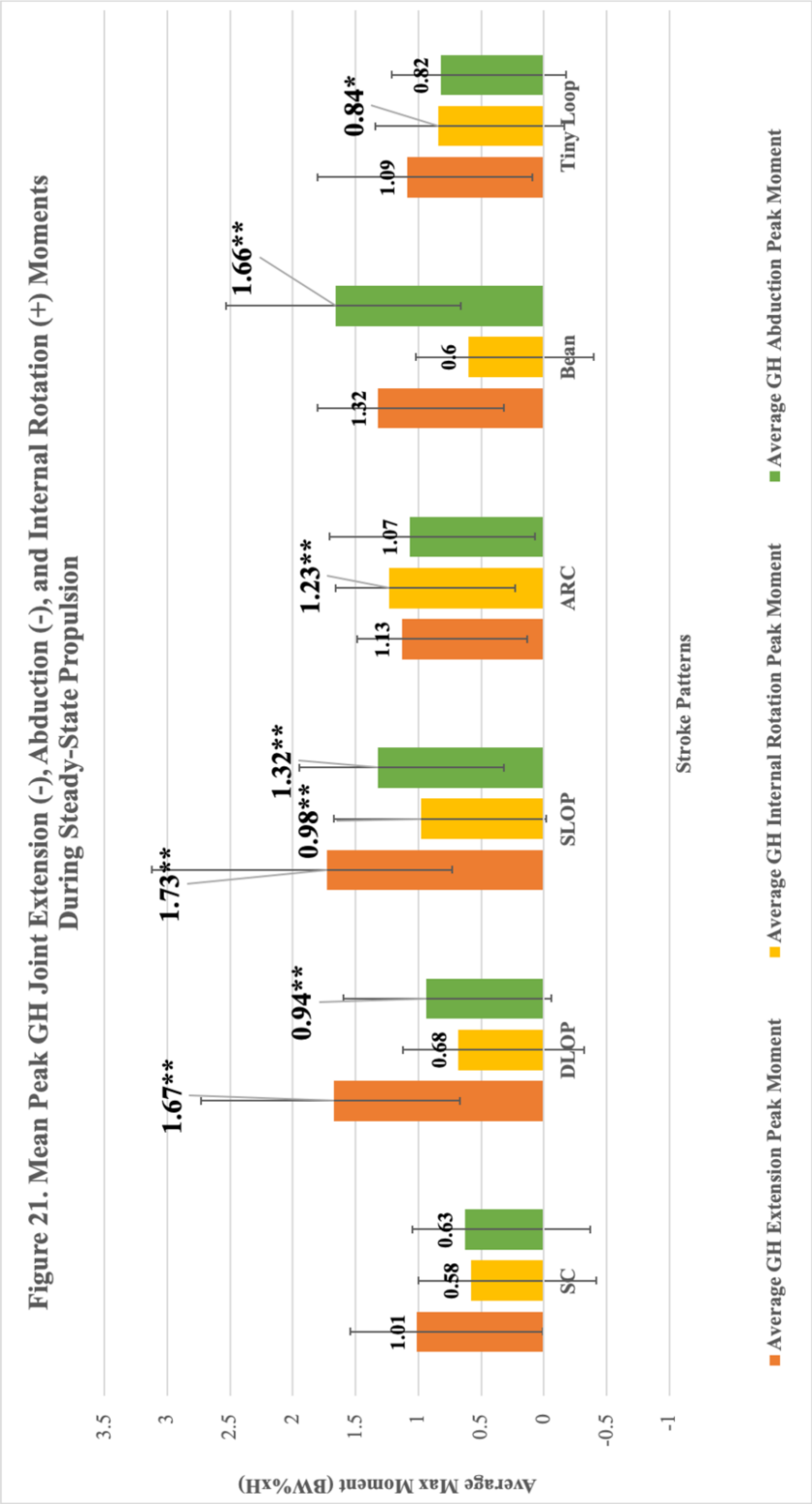
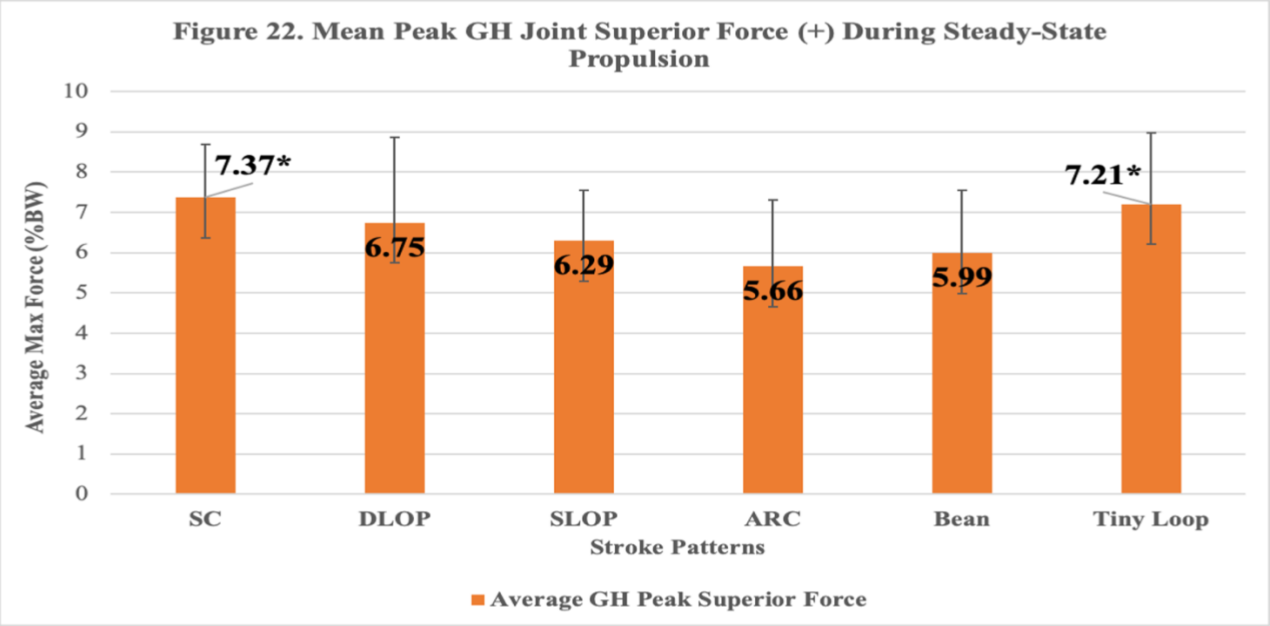


Figure 21. Mean Peak GH Joint Extension (-), Abduction (-), and Internal Rotation (+) Moments During Steady-State Propulsion



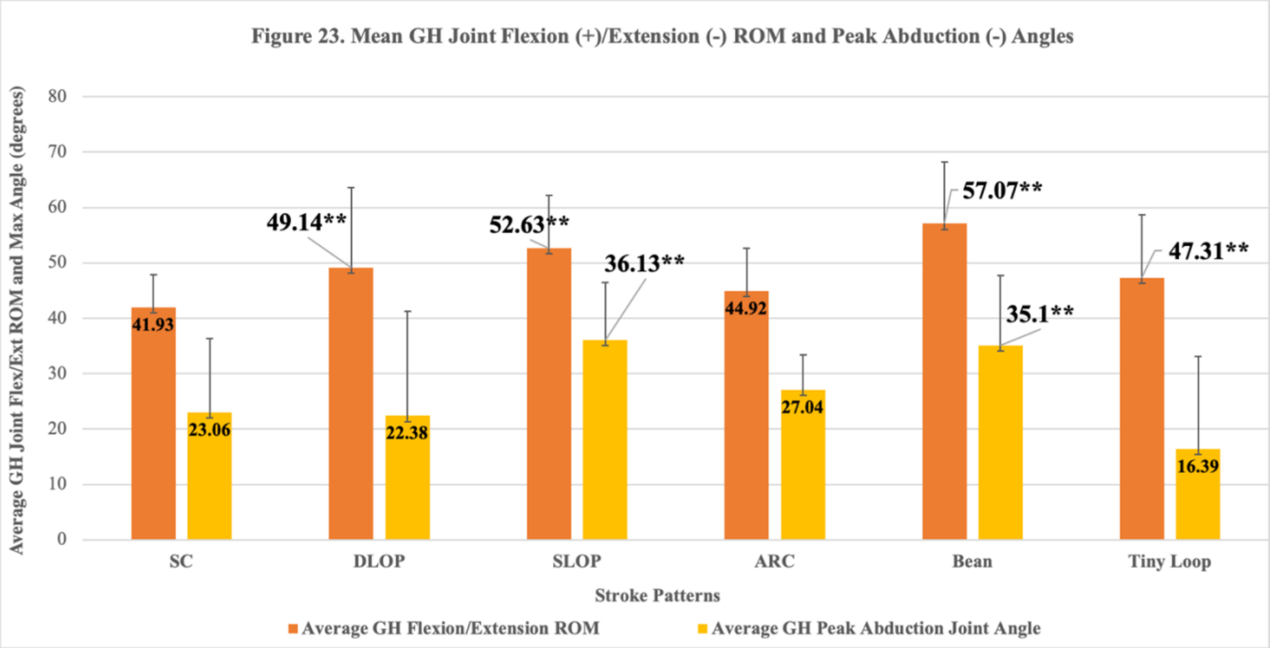


Figure 21 - 23. *Mean peak GH joint dynamics stratified by type of stroke pattern during steady steady-state MWC propulsion. Moments (Figure 21) were reported as percent body weight x height (%BWxH). Forces (Figure 22) were reported as percent body weight (%BW). ROM and joint angles (Figure 23) were reported in degrees.*
** $p < 0.001$ * $p < 0.01$

3.3 HRQoL. The average PCS of the group was significantly less than the normative scores for the average healthy individual (PCS = 50) and characteristic of an adult with a pediatric-onset SCI (PCS = 45) ($p < 0.01$). There was a statistically significant difference in the average PCS of subjects who performed two different types of stroke patterns compared to those who used one, three, or four during the steady-state MWC propulsion task. The average MCS of the group was significantly greater than the normative scores for the average healthy individual (MCS = 50) and characteristic of an adult with a pediatric-onset SCI (MCS = 53.3) ($p < 0.001$). There were no statistically significant differences in average MCS between groups of subjects who used one, two, three, or four different stroke patterns during steady-state MWC propulsion. Only 18% of the sample indicated bodily pain via the VAS (20.72 ± 10.97).

Table 5 - Average SF-12 Scores

	Average ± SD	Average SF-12 scores for pediatric MWC users with SCI. The physical (PCS) and mental health (MCS) composite scores are reported. The eight domains including physical (PF) and social functioning (SF), fulfillment of physical (RP) and emotional roles (RE), bodily pain (BP), general (GH) and mental health (MH), and vitality (VT) are reported.
PF	32.05 ± 29.22	
RP	66.67 ± 26.65	
BP	75.00 ± 34.89	
GH	78.08 ± 19.92	
VT	70.77 ± 24.08	
SF	83.33 ± 25.86	
RE	87.50 ± 15.97	
MH	77.24 ± 16.93	
PCS	42.56 ± 8.95	
MCS	58.06 ± 8.18	

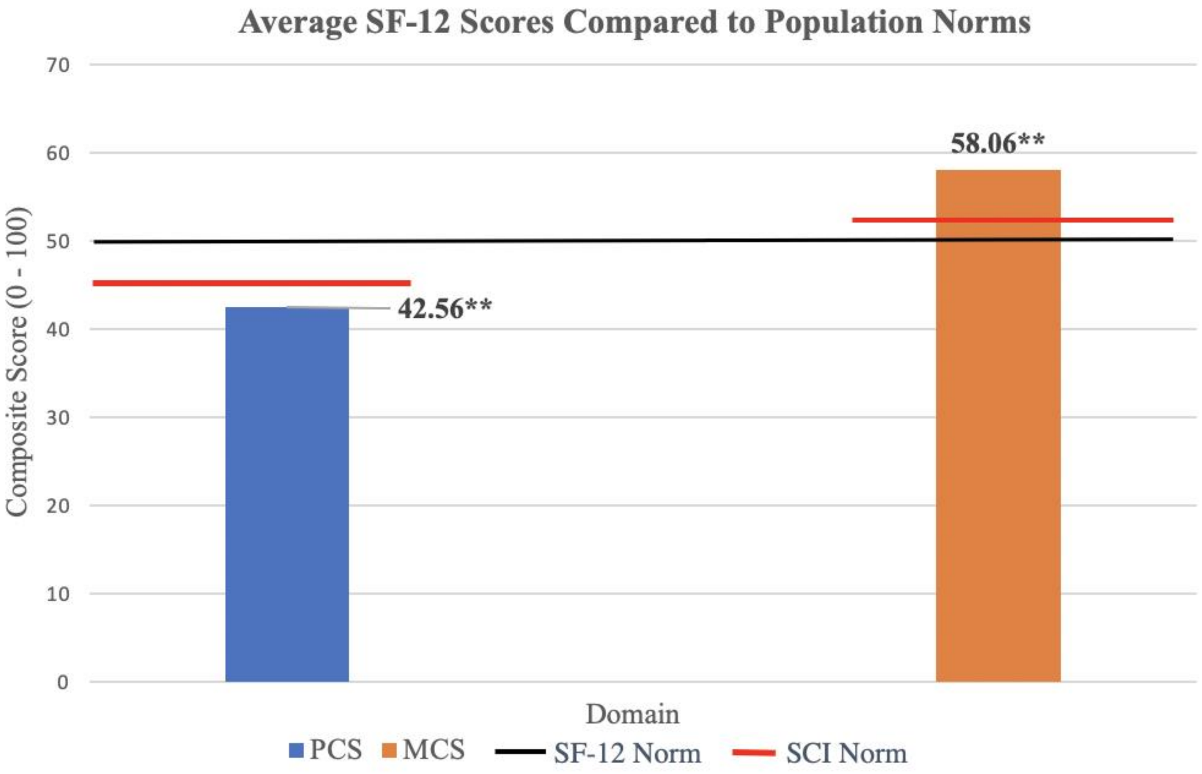


Figure 24. *Average Short Form 12 Health Questionnaire (SF-12) scores of pediatric MWC users with SCI (n = 39). The average physical (PCS) and mental health (MCS) composite score is reported. The normative score for the average healthy individual (50) is denoted by the bold black line. The scores with shared demographic features (e.g. adult with pediatric-onset SCI) are denoted by the bold red lines (PCS = 45, MCS = 53.3).*
$** = p < 0.001$ $* = p < 0.01$

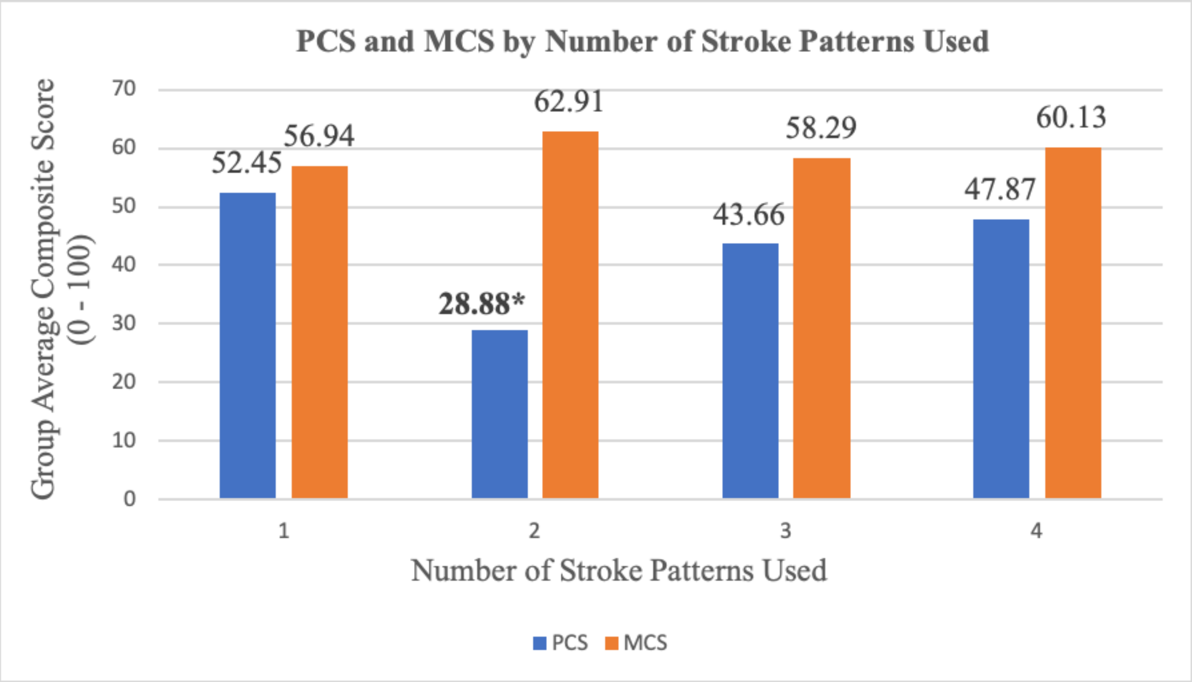


Figure 25. *Average Short Form 12 Health Questionnaire (SF-12) scores of pediatric MWC users with SCI (n = 19). The average physical (PCS) and mental health (MCS) composite scores are stratified by the number of stroke patterns used during steady-state MWC propulsion.*
$* = p < 0.05$

Aim 3, Hypothesis A: Hypothesis A: Average SF-12 PCS and MCS will be statistically significant and greater than the score (50) recognized for the average healthy individual

Summary of Aim 3, Hypothesis A. There were statistically significant differences between the average PCS and normative scores for both the general population and adults with pediatric-onset SCI. There were statistically significant differences between the average MCS and normative scores for both the general population and adults with pediatric-onset SCI

Aim 3, Hypothesis B: Physical and mental health composite scores for HRQoL will be correlated to the number and type of stroke patterns used by pediatric MWC users with SCI.

Summary of Aim 3, Hypothesis B. The PCS of subjects who used two stroke patterns during steady-state MWC propulsion was significantly less than those who performed one, three, or four. There was no statistically significant difference in MCS between these groups. A small number of subjects indicated mild (6) and moderate (1) bodily pain.

Discussion

Aim 1. Stroke Pattern Classification

This study is the first to classify stroke patterns with good to very good IRA amongst pediatric MWC users with SCI ($\kappa = 0.932$). Our methods were developed in response to positive findings from other studies that had used two-rater protocols (Koontz et al., 2009; Slowik et al., 2015). The classification process included two types of stroke patterns that are novel to this group of pediatric MWC users, Bean and Tiny Loop. Other studies have identified stroke patterns with mixed characteristics and emphasized the need for continued research to determine whether creating another type of stroke pattern all together is warranted. For example, Benson (2018) made note that even slight extension of the wrist upon release of the pushrim can result in what appears to be either the DLOP or ARC stroke pattern (Benson, 2018). Accurate classification and characterization of stroke patterns is an important step towards developing clinical guidelines and recommendations specific to the pediatric population.

We hypothesized and found the majority of subjects alternated between two and four different types of stroke patterns during steady-state MWC propulsion. Studies have identified individual, environment, task-related factors that significantly influence the type of stroke pattern(s) chosen. The use of DLOP (25 – 60%), SLOP (24% - 45%), and SC (8-16%) has proven highly variable amongst adults during steady-state propulsion whereas the ARC stroke pattern is used most frequently (73%) during to start-up, surface friction, and incline tasks (Boninger et al., 2002; Richter, Rodriguez, Woods, & Axelson, 2007; Koontz, Roche, Collinger, Cooper, & Boninger, 2009; Kwarciak et al., 2012; Slowik et al., 2015). Trends based on subject characteristics, such as the level of SCI, were difficult to observe for in this study because the majority did not identify with a preferred stroke pattern. Only three (3) of the twenty-two (22) adhered to a single type of stroke pattern which, for all, was SC. Choice in stroke pattern has been found to be dependent on body posture (Aissaoui & Desroches, 2008; Boninger et al., 2002). Proper positioning of the shoulder joint in relation to the wheel axle limits repetitive and extraneous shoulder loading during MWC propulsion. However, less than 90% of MWC users receive a customizable version with the exception of Worker’s Compensation and Veteran’s Affairs beneficiaries (Groah et al., 2014). For children, the adjustable components of a MWC are not designed to accommodate for three to five years of physical growth until they qualify for a replacement. Research addressing the relationship between proper MWC fit and developmental outcomes in pediatric users is needed.

Aim 2. GH Joint Dynamics

This study applied a validated custom pediatric inverse dynamics model to accurately quantify the motions, moments, and forces at UE joints amongst children and youth with SCI.

We hypothesized and found that there were statistically significant differences in all six average peak GH joint moments, forces, and motions of interest between the different types of stroke patterns. The SLOP stroke pattern was characteristic of significantly larger average peak GH joint extension moments, abduction moments, internal rotation moments, flexion/extension ROM, and abduction angles. Four out of the five are recognized as risk factors for chronic subacromial impingement (NIOSH, 1997). A study by Shelby Walford and colleagues found that higher average shoulder rotation angles were significant predictors of pain among 102 adult MWC users with SCI who were asymptomatic at baseline (2019). To promote long-term preservation of shoulder function, clinical guidelines should recommend MWC users avoid use of the SLOP stroke pattern. The same study found another significant predictor of pain was large positive forces at the shoulder joint during the recovery phase of MWC propulsion (Walford et al., 2019). The highest average peak GH joint superior force was characteristic of the SC out of all six types of stroke patterns. Current clinical guidelines for adults recommend use of SC because a MWC user is able to spend more time in recovery and propel with less forceful, frequent pushes (Boninger et al., 2002; Kwarciak et al., 2012; Slowik et al., 2016). This discrepancy affirms the need to assess UE biomechanics in children in order to make accurate recommendations for propulsion training. Lastly, biomechanical analyses revealed statistically significant differences in the GH joint dynamics between both Tiny Loop/DLOP and Bean/SLOP, indicating they should be considered in future studies involving stroke pattern classification and/or biomechanical analyses.

Aim 3. HRQoL

It was hypothesized that average PCS and MCS would differ significantly from that of the average healthy individual. We hypothesized and found that the average PCS was significantly lower, while the MCS was significantly higher than normative scores for an average healthy individual and an adult with pediatric-onset SCI. This may be due to the wording of the questions related to the PCS (NINDS, 2019). For example, the household chores (e.g. vacuuming) provided as examples for the Physical Functioning domain are less frequently participated in by children and youth with SCI (Mulcahey et al., 2010; Vogel & Zebracki, 2015). The higher average MCS may be more representative the play-based occupations and school functions the subjects have positive perceptions of self-efficacy for and participate in.

It was hypothesized that PCS and MCS would be correlated to the number of stroke patterns used. The PCS of subjects who used two stroke patterns during steady-state MWC propulsion was significantly less than those who performed one, three, or four. There was no statistically significant difference in MCS between these groups. There was no consistent pattern between which subjects reported bodily pain and the respective number of stroke patterns used. Only 18% of subjects indicated bodily pain, six (6) considered mild and one (1) moderate per the VAS. This may indicate that children are more resilient to the repetitive stress of MWC propulsion. However, the VAS does not ask for a specified location of pain. These findings may imply that while there may not be an ideal number of stroke patterns for pediatric MWC users to alternate between during steady-state propulsion, two may not be optimal.

Conclusions

The goal of this study was to identify stroke patterns used by pediatric MWC users with SCI. Biomechanical analyses were conducted to characterize stroke patterns by GH joint moments, forces, and moments using a validated custom pediatric inverse dynamics model. The purpose of the results is to help determine which propulsion technique(s) may be at lesser risk for the development of shoulder overuse injuries and dysfunction in children due to long-term MWC use. The different domains of HRQoL were discussed and explored as they related to the number of stroke patterns used. Pediatric MWC users alternated between multiple types of stroke patterns during steady-state MWC propulsion. Semicircular was most commonly classified across the entire sample of stroke patterns. Two stroke patterns novel to the pediatric population were identified and defined during the classification process. A two-stage inter-rater agreement protocol was used to enhance the reliability of the results. The calculated agreement between the two raters for all the classified stroke patterns was confirmed to be good or very good. There were statistically significant differences found in all six average peak GH joint moments, forces, and motions of interest. The average PCS was found to be significantly lower, while the MCS was found to be significantly higher than the average healthy individual. The average PCS was significantly lower amongst subjects who alternated between two different stroke patterns during steady-state propulsion in comparison to those who used one, three, or four. The results of this study may support interdisciplinary teams involved in training pediatric MWC users on propulsion techniques and educating adolescents and youth with SCI on joint protection strategies during I/ADLs. It is important that occupational therapists, physical therapists, and assistive technology professionals collect information and collaborate on pediatric patients' secondary health conditions, pain specific to location, mental health, and supports or barriers to functional independence. Future studies related to this research should explore quantitative methods for the classification of pediatric stoke patterns, investigate other UE joint biomechanics required of each type of stroke pattern, and use pediatric-validated outcomes measures to assess functional outcomes in children and youth with SCI.

III. Conclusion

Summary

This thesis addressed several research questions related to pediatric MWC users with SCI for the first time. This study was the first to classify stroke patterns with good to very good IRA amongst pediatric MWC users with SCI. It identified and defined two types of stroke patterns novel to the pediatric population, Tiny Loop and Bean. More than half of all stroke patterns were subjectively classified as SC, but the majority of pediatric MWC users with SCI alternated between two and four different types of stroke patterns. Establishing good to very good inter-rater agreement added strength to these results. These findings may indicate that pediatric MWC users find benefit in using other types of stroke patterns in addition to SC during steady-state propulsion. There were statistically significant differences found in all six average peak moments, forces, and motions of interest between different types of stroke patterns. Musculoskeletal maturity may explain for differences in stroke patterns' biomechanical characteristics when comparing adults and children. The significantly lower PCS may be due to limited engagement in household chores and work-related tasks. The significantly higher MCS may be due to pediatric-MWC users finding fulfillment in forms of play and academics.

Significance for OT

The results of this study may provide evidence to establish a more consistent protocol for therapists to train pediatric MWC users on best practices. Further, this is one among many aspects of SCI rehabilitation that would benefit from skilled occupational therapy intervention. A goal of the practice is to preserve, remediate, and/or adapt the environment to promote functional use of the UEs. An occupational therapy evaluation would address physical, social, cultural, personal, temporal, virtual supports and barriers (Appendix A & Figure 7). Occupational therapists possess and use knowledge of UE biomechanics to offer joint protection strategies. This is one of several approaches taken in addressing clients' pain and limiting long-term functional impairments. Occupational therapists would bring value to interdisciplinary collaboration. With a physical therapist, discussion may pertain to home set up for training on functional transfers and mobility. With assistive technology professionals, the occupational therapist can support efforts to advocate for a properly fitting MWC that promotes improved posture and body mechanics.

Limitations

This study is limited by the number of participants (22 subjects) included in statistical analyses. However, it was an acceptable size for the purposes of this exploratory study. Twenty-two subjects were sufficient for finding significant statistical differences between GH joint motions, forces, and moments. Another limitation is the range of subjects' ages, years since injury, and subsequent years of MWC experience. The study did not control for any MWC characteristics (e.g. type, dimensions, etc.) other than the quick axle release function for the SmartWheel. Only a few subjects reported the level of training they received on MWC propulsion during their rehabilitation process. All were recruited from and patients at Shriners Hospital for Children – Chicago. A major limitation was the task environment was not representative of true community-based mobility. It is reasonable to wonder whether subjects would have used different stroke patterns had they been able to continue to propel there MWC past the 15 feet of flat tile floor. Further, each subject had a different number of trials and stroke cycles included in data and statistical analyses. This was in the interest of accuracy and eliminated trials with improper placement of reflective makers or large gaps in biomechanical data. Lastly, neither outcome measure, the SFv2 and VAS, was developed specifically for children and youth. However, both chosen due to their regular use at Shriner's Hospital for Children – Chicago and familiarity with patients.

Future Directions

This research provides the first step towards an understanding of the variability amongst pediatric MWC users and stroke patterns. It addressed several research questions that would be beneficial to include in the development of clinical guidelines for pediatric MWC users with SCI. There are other topics that warrant further investigation before recommendations for best practice are determined.

First, future studies should include quantitative methods for classifying pediatric stroke patterns. For example, an adult-based study developed algorithm to determine the total radial thickness (TRT) of a stroke pattern, an indicator of how drastically a MWC user has to adjust their UEs with respect to the pushrim (Slowik et al., 2015). Second, future studies should simulate daily environments, such a home with a transition from carpet to tile flooring. Third, the biomechanical demands of different types of stroke patterns should be investigated at other UE joints. Common overuse injuries in MWC users include lateral/medial epicondylitis at the elbow and carpal tunnel syndrome at the wrist joint (Mercer et al., 2006; Patel et al., 2015). Additionally, it would be interesting to expand upon the shoulder complex. There are four involved joints that produce their own moments, forces, and motions and are essential to full shoulder ROM. Muscle activation and strain via electromyography would provide valuable information that may inform clinical guidelines as well. Another consideration for future studies that focus on the shoulder joint would be to use an outcome measure that assesses localized pain.

The Wheelchair User’s Shoulder Pain Index (WUSPI) is a self-report of shoulder pain experienced during a range of functional activities and transfers (Brose et al., 2008).

Fourth, future studies should incorporate functional outcome measures that are geared towards, reliable, and validated for the pediatric population. The Adolescent Pediatric Pain Tool (APPT) has been recommended for children with spinal cord injury and is one of few, multidimensional assessments that can effectively distinguish nociceptive from neuropathic pain in children (NINDS, 2019) (Appendix C). The Adolescent Scale of Participation (CASP) has been recommended for and answered directly by pediatric patients with SCI (NINDS, 2019) (Appendix D). Lastly, future research should evaluate the efficacy of MWC training protocols in pediatric MWC users with SCI. A study by Rice and colleagues found an immediate improvement in functional transfer skills among pediatric MWC users with SCI (2017).

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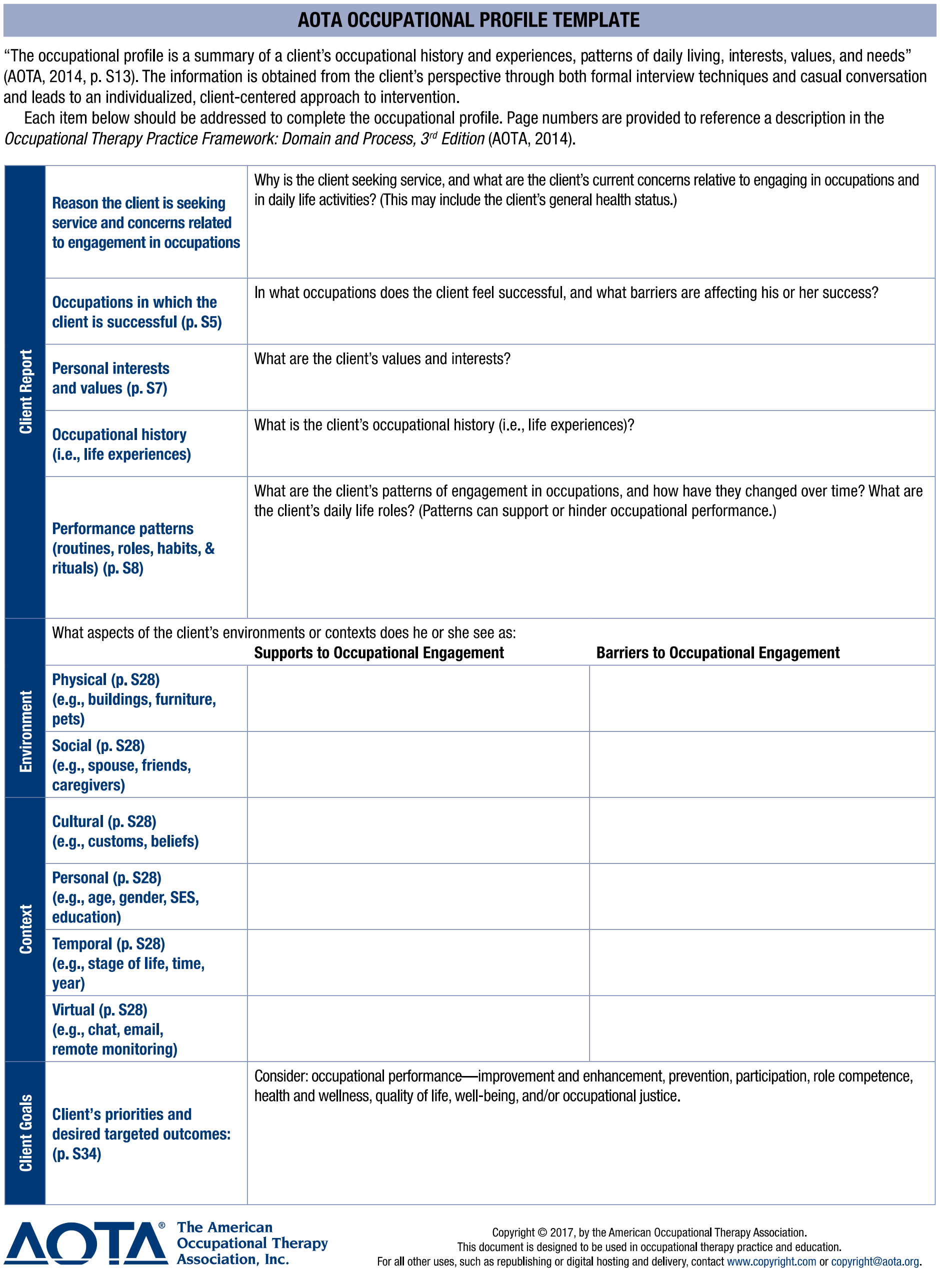
Appendices

Appendix A: American Occupational Therapy Association (AOTA) Occupational Profile



AOTA OCCUPATIONAL PROFILE TEMPLATE

"The occupational profile is a summary of a client's occupational history and experiences, patterns of daily living, interests, values, and needs" (AOTA, 2014, p. S13). The information is obtained from the client's perspective through both formal interview techniques and casual conversation and leads to an individualized, client-centered approach to intervention.

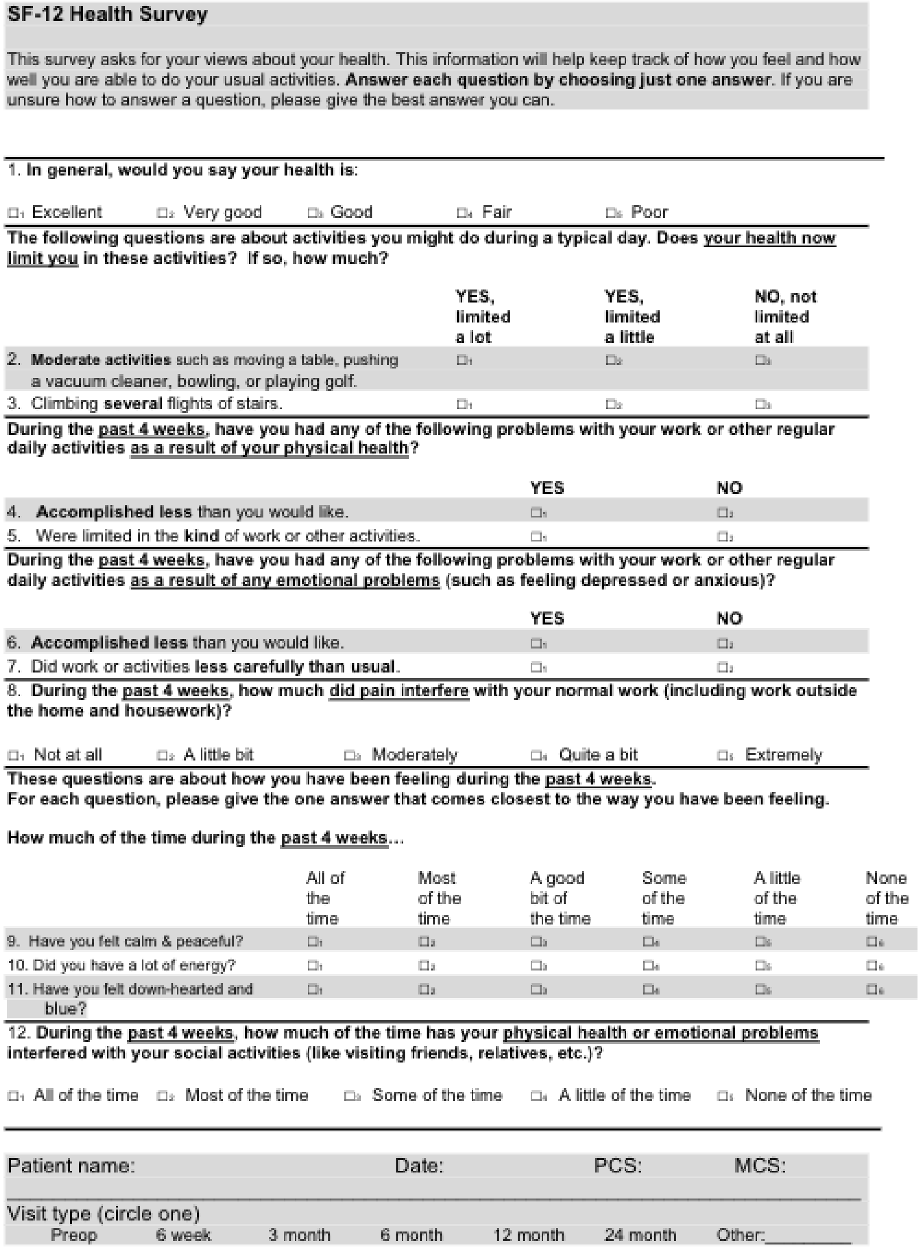
Each item below should be addressed to complete the occupational profile. Page numbers are provided to reference a description in the *Occupational Therapy Practice Framework: Domain and Process, 3rd Edition* (AOTA, 2014).

Client Report	**Reason the client is seeking service and concerns related to engagement in occupations**	Why is the client seeking service, and what are the client's current concerns relative to engaging in occupations and in daily life activities? (This may include the client's general health status.)	
	Occupations in which the client is successful (p. S5)	In what occupations does the client feel successful, and what barriers are affecting his or her success?	
	Personal interests and values (p. S7)	What are the client's values and interests?	
	Occupational history (i.e., life experiences)	What is the client's occupational history (i.e., life experiences)?	
	Performance patterns (routines, roles, habits, & rituals) (p. S8)	What are the client's patterns of engagement in occupations, and how have they changed over time? What are the client's daily life roles? (Patterns can support or hinder occupational performance.)	
Environment	What aspects of the client's environments or contexts does he or she see as:	**Supports to Occupational Engagement**	**Barriers to Occupational Engagement**
	Physical (p. S28) (e.g., buildings, furniture, pets)		
	Social (p. S28) (e.g., spouse, friends, caregivers)		
Context	**Cultural (p. S28) (e.g., customs, beliefs)**		
	Personal (p. S28) (e.g., age, gender, SES, education)		
	Temporal (p. S28) (e.g., stage of life, time, year)		
	Virtual (p. S28) (e.g., chat, email, remote monitoring)		
Client Goals	**Client's priorities and desired targeted outcomes: (p. S34)**	Consider: occupational performance—improvement and enhancement, prevention, participation, role competence, health and wellness, quality of life, well-being, and/or occupational justice.	

AOTA® The American Occupational Therapy Association, Inc.

Figure 8. *The AOTA Occupational Profile Template used to assess occupational history and experiences, patterns of daily living, interests, values, and needs of a client (AOTA, 2014).*

Appendix B. Short-Form Health Questionnaire (SF-12) v2



SF-12 Health Survey

This survey asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. **Answer each question by choosing just one answer**. If you are unsure how to answer a question, please give the best answer you can.

1. **In general, would you say your health is:**

☐1 Excellent ☐2 Very good ☐3 Good ☐4 Fair ☐5 Poor

The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	YES, limited a lot	**YES, limited a little**	**NO, not limited at all**
2. **Moderate activities** such as moving a table, pushing a vacuum cleaner, bowling, or playing golf.	☐1	☐2	☐3
3. Climbing **several** flights of stairs.	☐1	☐2	☐3

During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

	YES	**NO**
4. **Accomplished less** than you would like.	☐1	☐2
5. Were limited in the **kind** of work or other activities.	☐1	☐2

During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

	YES	**NO**
6. **Accomplished less** than you would like.	☐1	☐2
7. Did work or activities **less carefully than usual**.	☐1	☐2

8. **During the past 4 weeks, how much did pain interfere with your normal work (including work outside the home and housework)?**

☐1 Not at all ☐2 A little bit ☐3 Moderately ☐4 Quite a bit ☐5 Extremely

These questions are about how you have been feeling during the past 4 weeks.
For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the past 4 weeks…

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
9. Have you felt calm & peaceful?	☐1	☐2	☐3	☐4	☐5	☐6
10. Did you have a lot of energy?	☐1	☐2	☐3	☐4	☐5	☐6
11. Have you felt down-hearted and blue?	☐1	☐2	☐3	☐4	☐5	☐6

12. **During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?**

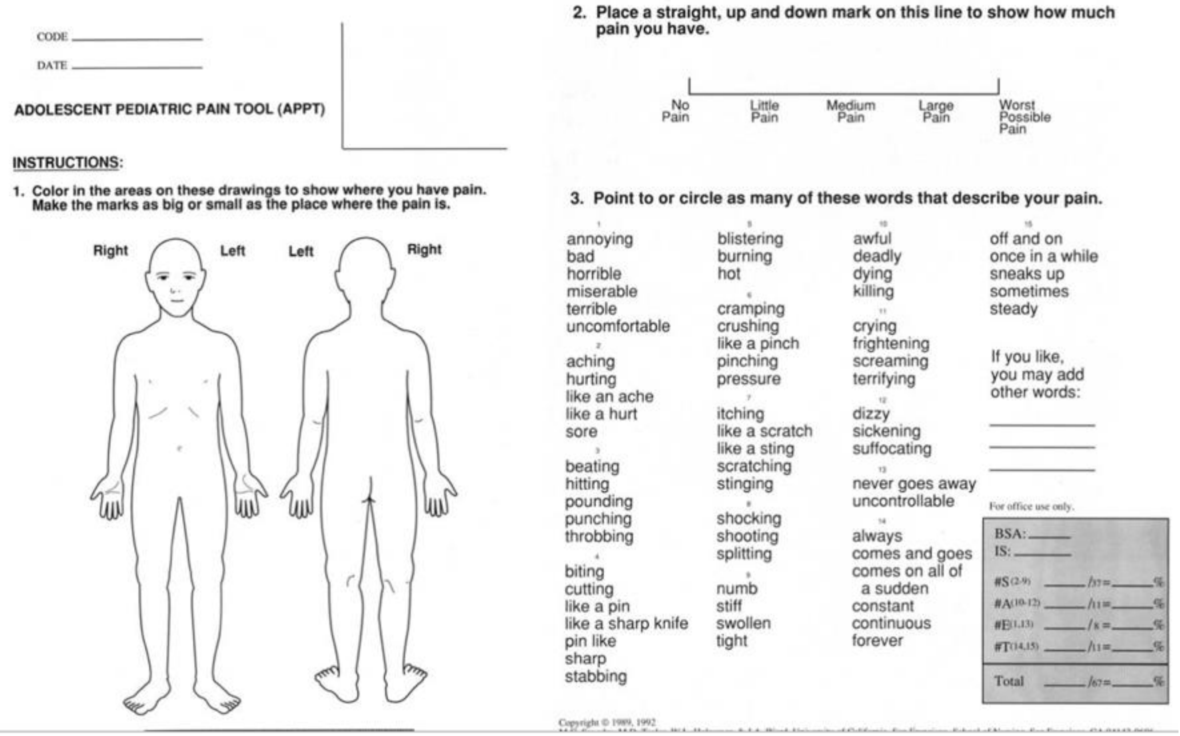
☐1 All of the time ☐2 Most of the time ☐3 Some of the time ☐4 A little of the time ☐5 None of the time

Patient name: Date: PCS: MCS:

Visit type (circle one)
Preop 6 week 3 month 6 month 12 month 24 month Other:_________

Figure 9. *The Short-Form (SF-12) for health-related quality of life (NINDS, 2019).*

Appendix C: Adolescent Pediatric Pain Tool (APPT) Form



CODE ______________

DATE ______________

ADOLESCENT PEDIATRIC PAIN TOOL (APPT)

INSTRUCTIONS:

1. Color in the areas on these drawings to show where you have pain. Make the marks as big or small as the place where the pain is.

2. Place a straight, up and down mark on this line to show how much pain you have.

3. Point to or circle as many of these words that describe your pain.

1
annoying
bad
horrible
miserable
terrible
uncomfortable

2
aching
hurting
like an ache
like a hurt
sore

3
beating
hitting
pounding
punching
throbbing

4
biting
cutting
like a pin
like a sharp knife
pin like
sharp
stabbing

5
blistering
burning
hot

6
cramping
crushing
like a pinch
pinching
pressure

7
itching
like a scratch
like a sting
scratching
stinging

8
shocking
shooting
splitting

9
numb
stiff
swollen
tight

10
awful
deadly
dying
killing

11
crying
frightening
screaming
terrifying

12
dizzy
sickening
suffocating

13
never goes away
uncontrollable

14
always
comes and goes
comes on all of a sudden
constant
continuous
forever

15
off and on
once in a while
sneaks up
sometimes
steady

If you like, you may add other words:

____

____

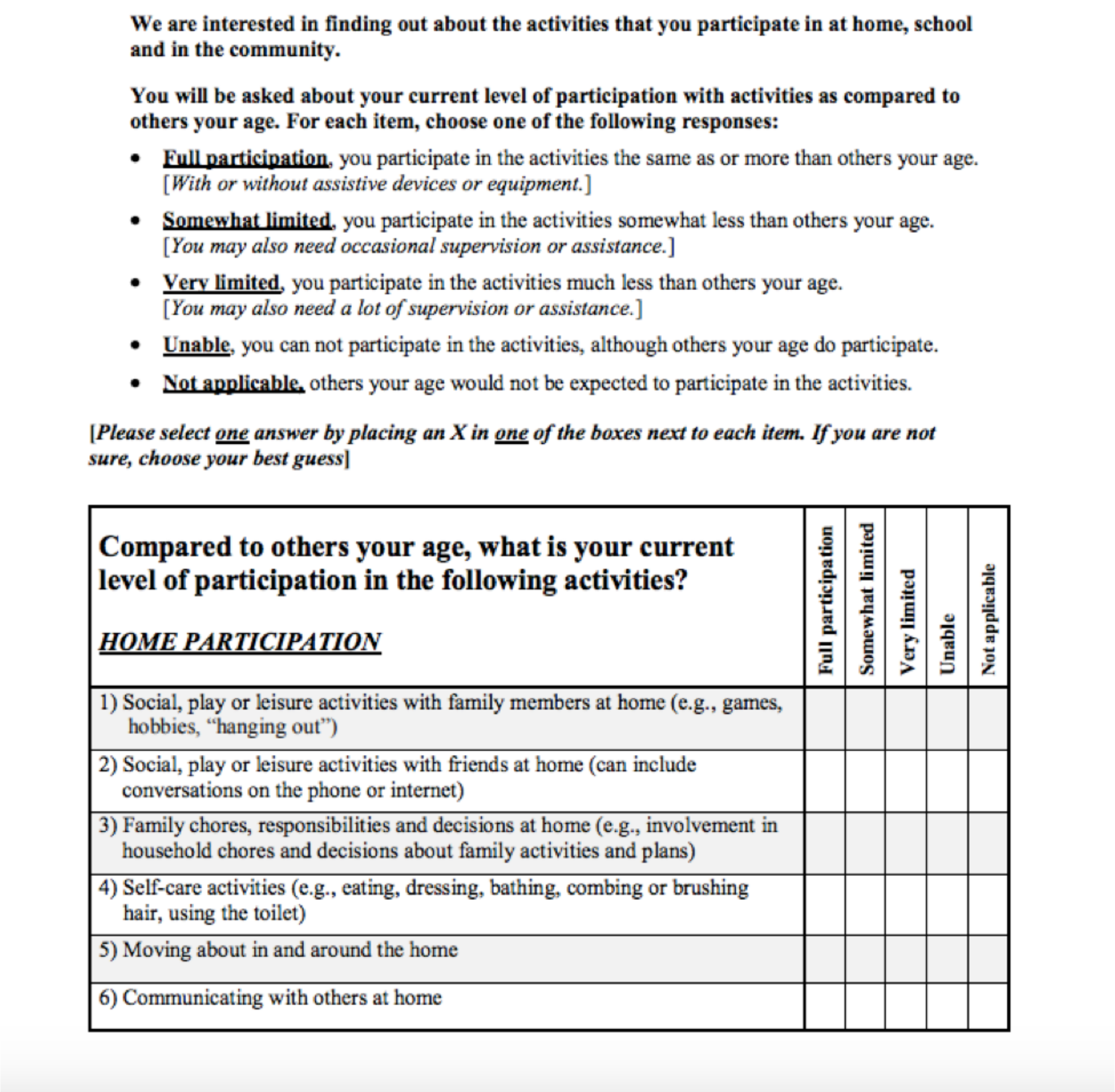
____

For office use only.

BSA: ______
IS: ______
#S(2-9) ______ /37= ______%
#A(10-12) ______ /11= ______%
#E(1,13) ______ /8 = ______%
#T(14,15) ______ /11= ______%
Total ______ /67= ______%

***Figure 25**. The Adolescent Pediatric Pain Tool (APPT) for multi-dimensional assessment of pediatric pain*

Appendix D: Children and Adolescent Scale of Participation (CASP) Form



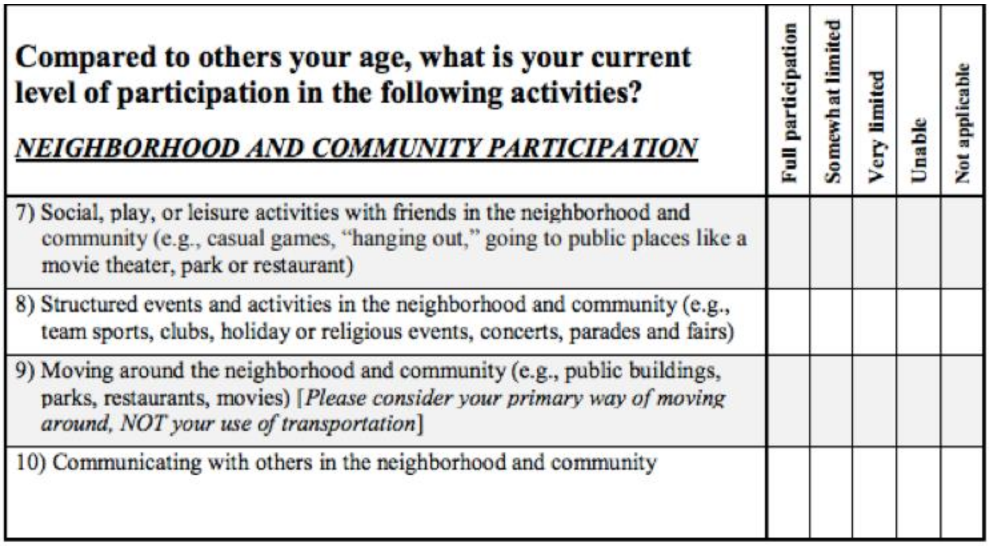
We are interested in finding out about the activities that you participate in at home, school and in the community.

You will be asked about your current level of participation with activities as compared to others your age. For each item, choose one of the following responses:

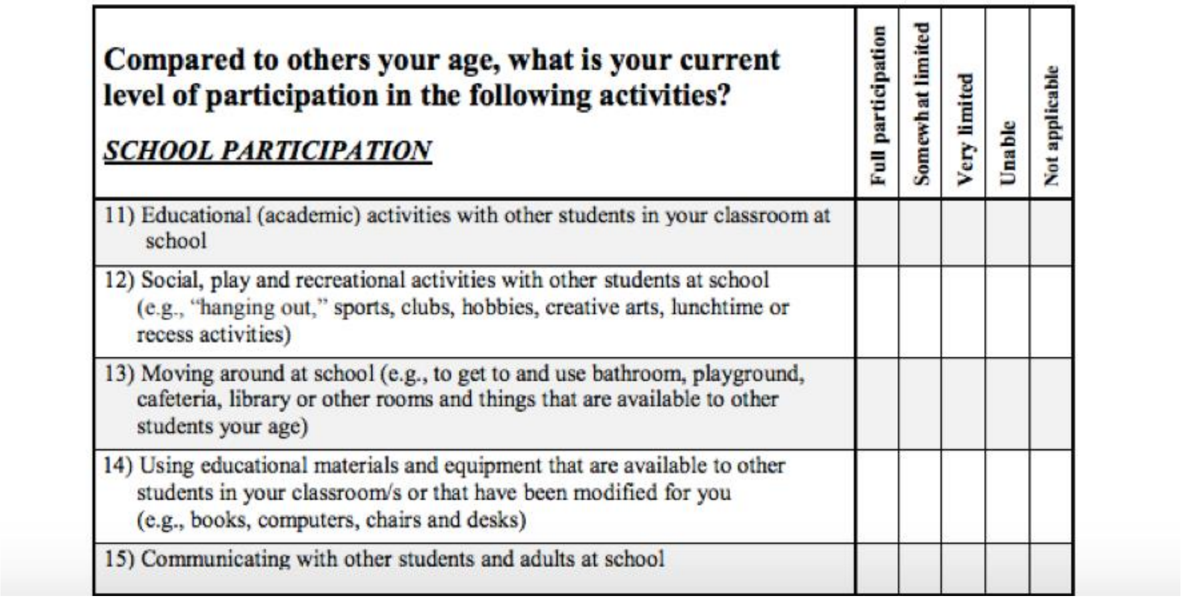
- **Full participation**, you participate in the activities the same as or more than others your age. [*With or without assistive devices or equipment.*]
- **Somewhat limited**, you participate in the activities somewhat less than others your age. [*You may also need occasional supervision or assistance.*]
- **Very limited**, you participate in the activities much less than others your age. [*You may also need a lot of supervision or assistance.*]
- **Unable**, you can not participate in the activities, although others your age do participate.
- **Not applicable,** others your age would not be expected to participate in the activities.

[Please select one answer by placing an X in one of the boxes next to each item. If you are not sure, choose your best guess]

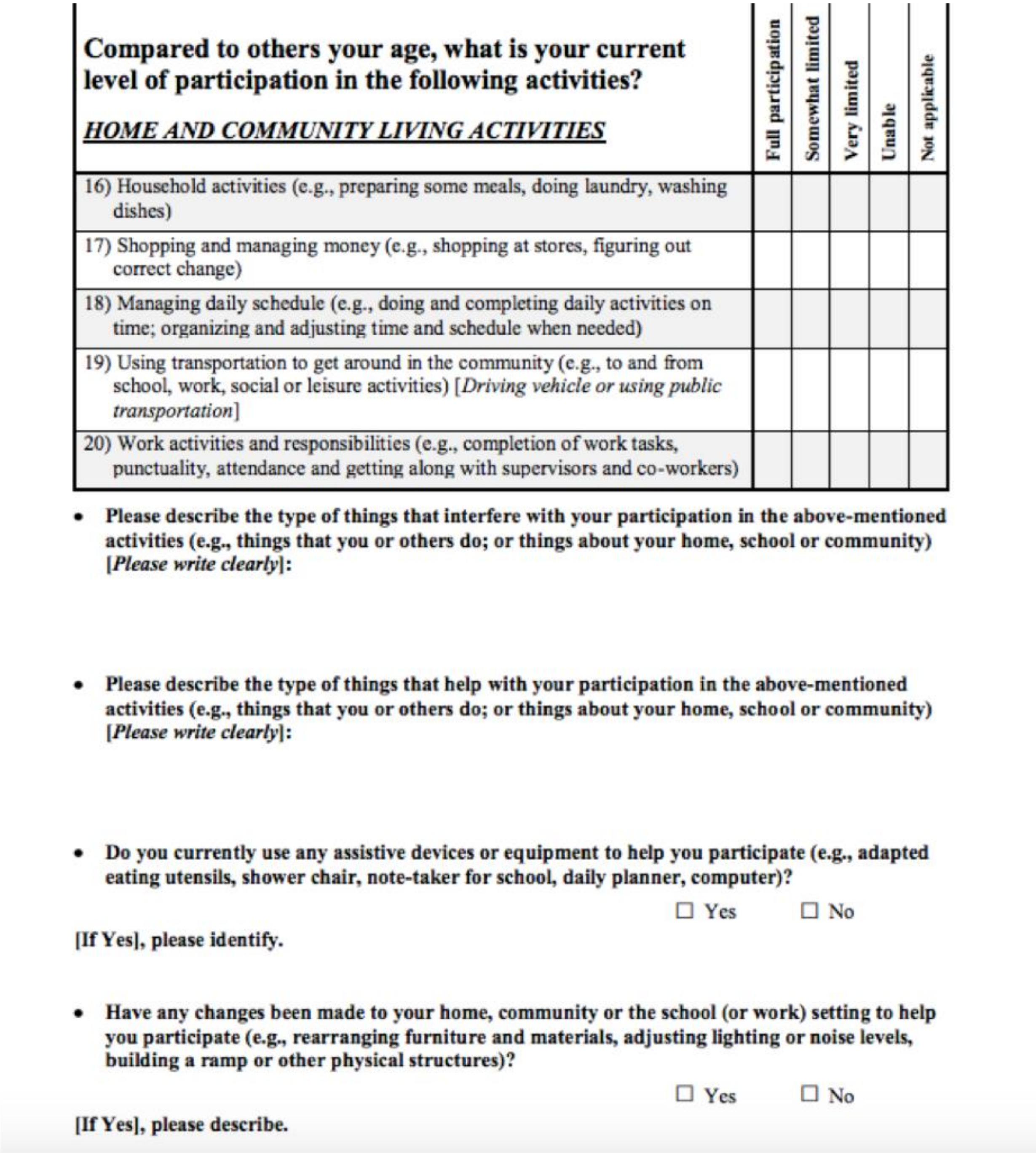
Compared to others your age, what is your current level of participation in the following activities? ***HOME PARTICIPATION***	**Full participation**	**Somewhat limited**	**Very limited**	**Unable**	**Not applicable**
1) Social, play or leisure activities with family members at home (e.g., games, hobbies, "hanging out")					
2) Social, play or leisure activities with friends at home (can include conversations on the phone or internet)					
3) Family chores, responsibilities and decisions at home (e.g., involvement in household chores and decisions about family activities and plans)					
4) Self-care activities (e.g., eating, dressing, bathing, combing or brushing hair, using the toilet)					
5) Moving about in and around the home					
6) Communicating with others at home					



Compared to others your age, what is your current level of participation in the following activities? ***NEIGHBORHOOD AND COMMUNITY PARTICIPATION***	**Full participation**	**Somewhat limited**	**Very limited**	**Unable**	**Not applicable**
7) Social, play, or leisure activities with friends in the neighborhood and community (e.g., casual games, "hanging out," going to public places like a movie theater, park or restaurant)					
8) Structured events and activities in the neighborhood and community (e.g., team sports, clubs, holiday or religious events, concerts, parades and fairs)					
9) Moving around the neighborhood and community (e.g., public buildings, parks, restaurants, movies) [*Please consider your primary way of moving around, NOT your use of transportation*]					
10) Communicating with others in the neighborhood and community					



Compared to others your age, what is your current level of participation in the following activities? ***SCHOOL PARTICIPATION***	**Full participation**	**Somewhat limited**	**Very limited**	**Unable**	**Not applicable**
11) Educational (academic) activities with other students in your classroom at school					
12) Social, play and recreational activities with other students at school (e.g., "hanging out," sports, clubs, hobbies, creative arts, lunchtime or recess activities)					
13) Moving around at school (e.g., to get to and use bathroom, playground, cafeteria, library or other rooms and things that are available to other students your age)					
14) Using educational materials and equipment that are available to other students in your classroom/s or that have been modified for you (e.g., books, computers, chairs and desks)					
15) Communicating with other students and adults at school					



Compared to others your age, what is your current level of participation in the following activities? ***HOME AND COMMUNITY LIVING ACTIVITIES***	**Full participation**	**Somewhat limited**	**Very limited**	**Unable**	**Not applicable**
16) Household activities (e.g., preparing some meals, doing laundry, washing dishes)					
17) Shopping and managing money (e.g., shopping at stores, figuring out correct change)					
18) Managing daily schedule (e.g., doing and completing daily activities on time; organizing and adjusting time and schedule when needed)					
19) Using transportation to get around in the community (e.g., to and from school, work, social or leisure activities) [*Driving vehicle or using public transportation*]					
20) Work activities and responsibilities (e.g., completion of work tasks, punctuality, attendance and getting along with supervisors and co-workers)					

- **Please describe the type of things that interfere with your participation in the above-mentioned activities (e.g., things that you or others do; or things about your home, school or community) [*Please write clearly*]:**

- **Please describe the type of things that help with your participation in the above-mentioned activities (e.g., things that you or others do; or things about your home, school or community) [*Please write clearly*]:**

- **Do you currently use any assistive devices or equipment to help you participate (e.g., adapted eating utensils, shower chair, note-taker for school, daily planner, computer)?**

☐ Yes ☐ No

[If Yes], please identify.

- **Have any changes been made to your home, community or the school (or work) setting to help you participate (e.g., rearranging furniture and materials, adjusting lighting or noise levels, building a ramp or other physical structures)?**

☐ Yes ☐ No

[If Yes], please describe.

Figure 26. *The Children and Adolescent Scale of Participation (CASP) for the assessment of pediatric health-related quality of life.*

Appendix E: OT Summit of Scholars Abstract

Stroke Pattern Use and Quality of Life of Pediatric Manual Wheelchair Users with Spinal Cord Injury

Paige Aschenbrener, OTS[1]; Alyssa J. Schnorenberg, MS[1,2], Dana H. Washburn, MS,OTR/L[1] ;
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Introduction: A stroke pattern is the path a manual wheelchair (MWC) user's hand follows with respect to the push rim during the recovery phase of propulsion. For the long-term preservation of upper extremity (UE) function, clinical guidelines for adults with spinal cord injury (SCI) recommend sole use of the semicircular (SC) pattern over the other three identified: arcing (ARC), double (DLOP) looping over propulsion and single (SLOP). However, there are no guidelines specific to pediatric MWC users. Adult-based recommendations may not be appropriate for children with extremities of different segmental lengths and have yet to reach musculoskeletal maturity. To support the development of pediatric clinical guidelines, we investigated stroke pattern use among children with SCI. The impact of varying stroke pattern use on self-perceived quality of life (QoL) was explored.

Methods: Twenty-two MWC users between 6 and 21 years of age with a paraplegic SCI performed steady-state propulsion at Shriners Hospitals for Children – Chicago. A 14-camera Vicon MX system captured three-dimensional motion of the 3rd metacarpophalangeal joint marker. Flexion/extension motion was used to visually assess and classify the stroke pattern as SC, ARC, SLOP, or DLOP. The Short-Form 12 (SF-12) for QoL was administered; physical (PCS) and mental health (MCS) composite scores (range: 0 – 100) were determined and group averages were calculated. MANOVA was used to compare PCS and MCS between groups stratified by use of one to four patterns.

Results: Children used one (n=4), two (n=15), three (n=2), or four (n=1) different stroke patterns, with 82% using 2 or more patterns. The average PCS (standard deviation) for children who used one stroke pattern was 28.6 (12.2), which significantly increased to 45.2 (7.7) for 2 patterns ($p = 0.01$) and increased to 45.0 (9.9) for 3. There were no significant differences amongst average MCS scores. The single subject who used all 4 patterns was not included in the statistical analysis.

Conclusion: Pediatric MWC users with SCI exhibited use of more than one stroke pattern. We found that children and youth prefer to use two stroke patterns, which may have implications for reducing overuse injuries associated with long-term MWC use. Further analyses investigating differences in stroke patterns and joint dynamics are underway. This work may ultimately lead to the development of clinical recommendations for best practice that would aid therapists in the prescription and training of pediatric MWC users with SCI.

Funding Source: Research reported in this publication was supported by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number R01HD098698 and the National Institute on Disability, Independent Living, and Rehabilitation Research Award Number 90AR5022-01-00.

Appendix D: ASIA 2021 Annual Scientific Meeting Abstract Submission

Stroke Pattern Classification in Pediatric Manual Wheelchair Users with Spinal Cord Injury

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Objective: A stroke pattern is the path the hand follows with respect to the push rim during the recovery phase of manual wheelchair (MWC) propulsion. MWC propulsion is considered a repetitive activity due to the cyclical motions and forces it places on the shoulder joint (NIOSH, 1997). For the long-term preservation of upper extremity (UE) function, clinical guidelines for adult MWC users with spinal cord injury (SCI) recommend use of the semicircular (SC) pattern over three other patterns: arcing (ARC), double (DLOP) and single looping over propulsion (SLOP) (Boninger et al., 2002; PVA, 2005). There are no current pediatric guidelines or recommendations for best practice for the pediatric population. Moreso, adult-based recommendations may not be appropriate for children because the extremities are of different segmental lengths and musculoskeletal maturity has not been reached (Schnorenberg et al., 2014). Because individuals with pediatric-onset SCI have shown greater resilience to the sequalae of shoulder dysfunction seen in adults secondary to long-term MWC use, it is expected that children and youth will use more than one type of stroke pattern during steady-state MWC propulsion (Vogel & Zebracki, 2015).

Design/Methods: Twenty-two (22) participants, 13 males and 9 females between the ages of 7 - 21 years old (13.85 ± 4.49) participated in the study at the Motion Analysis Laboratory at Shriners Hospitals for Children – Chicago. A 14-camera Vicon MX motion analysis system captured three-dimensional UE kinematics during steady-state MWC propulsion task. A visual representation of each stroke cycle pattern from the sagittal perspective was modeled via MATLAB. Three-hundred-eighty-three (383) stroke patterns were subjectively classified as SC, DLOP, SLOP, ARC, or one of two novel pediatric stroke patterns that consistently presented themselves during the classification process. A two-stage protocol was used to establish inter-rater agreement (IRA) for stroke pattern classification into six different categories (Tarima & Flournoy, 2019). The goal for the study was to establish good ($\kappa = 0.61 – 0.8$) or very good ($\kappa > 0.8$) inter-rater reliability (IRR).

Results: Most subjects used two (n = 5) or four (n = 5) different types of stroke patterns during MWC propulsion. Three subjects (14%) adhered solely to the SC stroke pattern. The IRA between both raters was determined to be good or very good (Cohen's $\kappa > 0.6$). The interim IRA following Stage I did not provide enough statistical power to make a conclusive decision ($\kappa = 0.793 < 0.832$). An additional 48 stroke cycles were included as part of Stage II. The resulting, combined IRA ($\kappa = 0.911 > 0.738$) was great enough to reject the null hypothesis ($H_0 = K \leq 0.6$). The accuracy on all data was calculated ($\kappa = 0.932$).

Conclusion: This study is the first to classify stroke patterns with good to very good IRA amongst pediatric MWC users with SCI. This research provides the first step towards an understanding of the variability in pediatric stroke patterns that will lead to the development of pediatric clinical guidelines for MWC users.

Support: Research reported in this publication was supported by the NICHD of the NIH, grant #R01HD098698 and the NIDILRR, grant #90RE5006-01-00.

Learning Objectives: To subjectively classify stroke patterns used by pediatric MWC users with SCI and establish good to very good interrater agreement (IRA).

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