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Effectiveness of Functional Electrical Stimulation Assisted Rowing to Improve Shoulder Pain and Aerobic Fitness in Manual Wheelchair Users with Spinal Cord Injury

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EFFECTIVENESS OF FUNCTIONAL ELECTRICAL STIMULATION ASSISTED ROWING TO IMPROVE SHOULDER PAIN AND AEROBIC FITNESS IN MANUAL WHEELCHAIR USERS WITH SPINAL CORD INJURY

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EFFECTIVENESS OF FUNCTIONAL ELECTRICAL STIMULATION ASSISTED ROWING TO IMPROVE SHOULDER PAIN AND AEROBIC FITNESS IN MANUAL WHEELCHAIR USERS WITH SPINAL CORD INJURY

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PHYSICAL THERAPY - REHABILITATION SCIENCES

ABSTRACT

Exercise is beneficial to adults with spinal cord injury (SCI) because of its ability to improve function and increase life expectancy. The goal of this dissertation was to determine an effective intervention for increasing aerobic fitness and decreasing shoulder pain in manual wheelchair users with SCI by identifying underlying mechanisms for shoulder pain, optimizing training and utilizing appropriate outcome measures. Three studies were conducted. The first study indicated that exercise interventions for adults with SCI are of low to moderate methodological quality, frequently using outcome measures associated with changes in body structures and functions, and not frequently examining effects on daily activities. The second study indicated that manual wheelchair users with SCI who have subacromial impingement present with similar patterns of scapular instability as able-bodied individuals with impingement, including weakness in the posterior shoulder musculature. The final study indicated that functional electrical stimulation (FES)-assisted rowing is effective to improve aerobic fitness and shoulder pain in manual wheelchair users with SCI. It was concluded that exercise interventions should address outcomes related to daily activities and participation, manual wheelchair users with SCI who have impingement can benefit from able-bodied therapeutic protocols, though emphasis should be placed on increasing posterior shoulder strength,

and that FES-assisted rowing is a promising mode of exercise for manual wheelchair users with SCI who have shoulder pain.

This thesis is dedicated to my family,

without whom this project would not have been possible.

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INTRODUCTION

Exercise is an important component of health and quality of life. Adults with spinal cord injury (SCI) report very low levels of physical activity, which may result from difficult, inaccessible modes of exercise and a high incidence of shoulder pain, especially for those who use a manual wheelchair for their primary means of mobility. Exercise intensity is limited by SCI due to loss of function below the lesion level. Decreased or inadequate exercise can lead to increased cardiovascular disease risk and mortality, decreased participation and decline in quality of life. Optimal modes of exercise that can increase exercise intensity to beneficial levels, while reducing stress on the shoulder are necessary for adults with SCI to maintain and improve health and function.

Although previous research has shown that aerobic exercise is effective to improve fitness and health in adults with SCI, the most frequent mode of aerobic exercise is upper body cycling, which has not been shown to improve shoulder pain.[1-3] Targeted resistance training exercises have been shown to improve shoulder pain, but they do not improve aerobic fitness.[4] Therefore, it would be beneficial to identify an activity that simultaneously improves aerobic fitness and relieves shoulder pain. One mode of exercise that has been shown to be effective for improving aerobic fitness in SCI is functional electrical stimulation (FES) assisted rowing.[5] FES-assisted rowing has the potential to be an optimal mode of exercise for adults with SCI because it engages the paralyzed muscles of the lower extremities to increase exercise intensity, while requiring repeated activation of the posterior shoulder muscles, which are not routinely activated. Increased activation of posterior shoulder musculature is important in SCI because of the high incidence of shoulder pain in this population, and the reported muscle imbalances that are known to occur in people with chronic shoulder pain.[6-8] Reduction in shoulder pain can increase participation and improve quality of life after SCI.[9] Therefore, the overarching goal of these investigations is to determine an effective intervention for increasing fitness and decreasing shoulder pain in manual wheelchair users with SCI by identifying underlying mechanisms for shoulder pain, optimizing training and utilizing appropriate outcome measures for the intervention.

In order to achieve the goals of this dissertation, three separate studies were conducted. First, we performed a systematic review of exercise interventions in adults with SCI to determine which variables are most frequently examined, and which variables should be included into future exercise interventions for manual wheelchair users with SCI (Chapter 2). Second, we examined the scapular stability and shoulder muscle balance of adults with and without SCI who had shoulder impingement in order to detail the specific muscle imbalances that occur in painful shoulders of manual wheelchair users with SCI. Finally, we conducted a six-week FES-assisted rowing intervention in order to determine the effectiveness of the intervention to improve aerobic fitness and shoulder pain.

The rationale for these studies is to help us to develop and test more effective exercise programming for manual wheelchair users with SCI. This population has low levels of physical activity, frequently identifies lack of time as a significant barrier to performing physical activity and often experience shoulder pain. **Figure 1** depicts my conceptual model of shoulder pain in adult manual wheelchair users with SCI. The conceptual model is based on supporting evidence that physical inactivity is a major contributor to decline in health and function in people with physical disability.[10] The model suggests that both physical inactivity and subsequent decline in fitness affect shoulder function, which in turn affects pain, quality of life and participation. Using this model as a framework, we see that an optimal point of intervention exists, whereby we can prevent physical inactivity with an intervention of sufficient intensity to improve fitness while targeting disused muscle groups in order to reduce strain and improve shoulder function. To date, no studies have attempted to improve aerobic fitness and shoulder pain using a single activity.

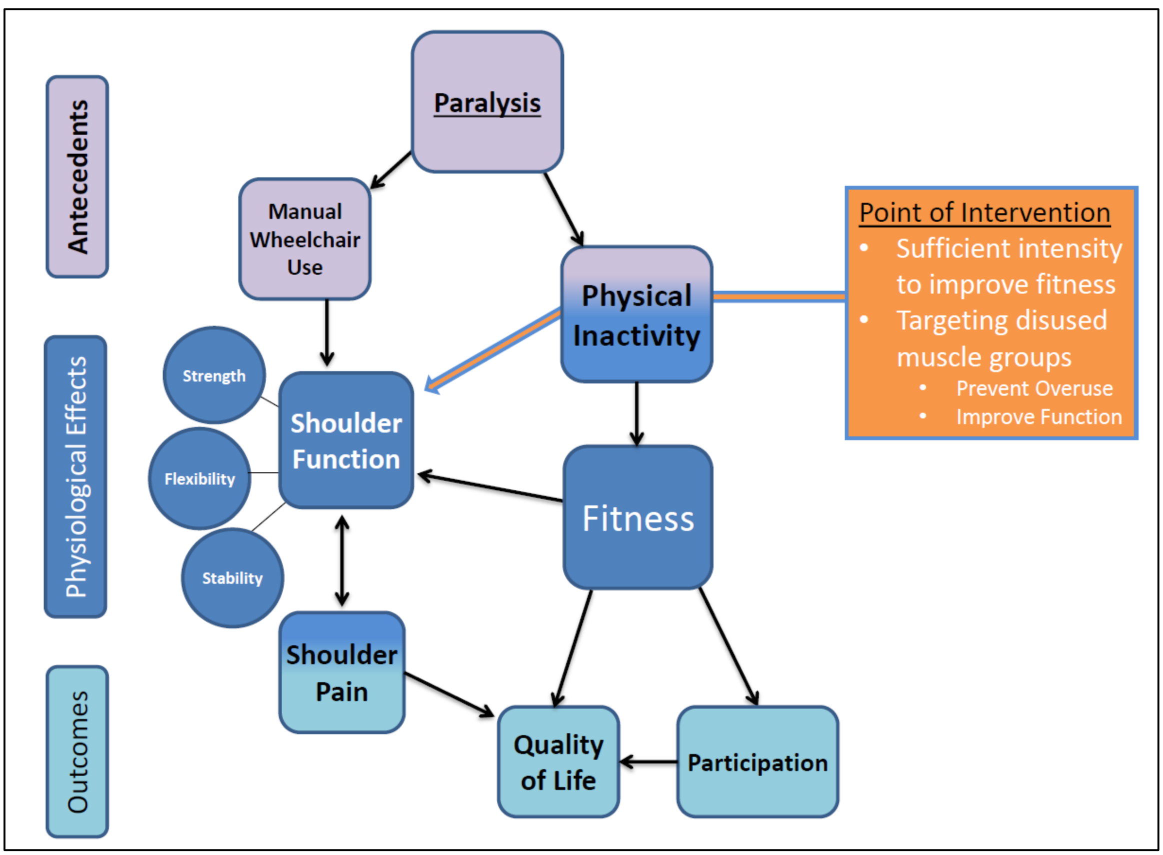

Figure 1: Conceptual model

Methodological quality and outcome measures in exercise interventions for adults with spinal cord injury

Aerobic capacity is one of, if not the most important, indicators of disease risk in the general population. Therefore, exercise interventions have frequently been studied for their effectiveness in improving the health status of people with chronic health conditions such as SCI. Cross-sectional evidence in adults with SCI shows that high fitness levels, lower levels of pain and higher levels of physical function are correlated with improved quality of life however, previous studies pertaining to exercise and SCI have focused primarily on improvements in physical capacity measures, without relating the outcome measures to the categories and components of the International Classification of Functioning, Disability and Health (ICF). Linking outcome measures from exercise intervention studies to the ICF is helpful, as it provides a knowledge base about which ICF categories, domains and components have been most frequently targeted, and which areas need to be addressed more adequately in future studies. Evaluating methodological quality is also important, as it provides a guide for clinicians and exercise professionals to make informed practice decisions and increases researchers' awareness of areas of methodological deficiency.

Aerobic capacity and shoulder pain in adults with spinal cord injury

Epidemiological studies reveal that in able-bodied adults, the risk for premature death is 4.5 times greater in adults with a peak VO_2 less than 21.1 ml/kg/min.[11] Adults with SCI report very low peak VO_2 levels. Even in active adults with SCI, VO_2 peak levels have been reported to be as low as 12.6 ml/kg/min.[12] Shoulder pain is also a significant problem associated with SCI that can lead to profound functional impairments such as rapid fatigue, decreased tolerance for work and leisure activities and a reduced quality of life.[6,13] Adults with SCI are highly prone to experiencing shoulder pain with a reported prevalence up to 73%.[14] Shoulder pain in adults with SCI is frequently attributed to overuse and subacromial impingement syndrome (SIS).[15,16] In adults with SCI, shoulder pain is easily assessed using the Wheelchair Users' Shoulder Pain Index (WUSPI).[17]

Impaired muscle balance and scapular stabilization in subacromial impingement syndrome

Subacromial impingement syndrome (SIS) is defined as *mechanical compression of subacromial structures under the coracoacromial arch during humeral elevation.* Neer first described subacromial impingement using the "painful arc of motion" or 60 – 120 degrees of humeral elevation.[18] Able-bodied adults with shoulder pain resulting from SIS demonstrate impaired scapular stabilization and muscle balance. For the purpose of this study impaired scapular stabilization was operationally defined as *increased electrical activity in the upper trapezius when compared to the lower trapezius during humeral elevation*, and muscle imbalance was operationally defined as *alteration in typically observed strength ratios of muscle groups at the shoulder joint.* These observed changes in muscle balance and scapular stabilization are important factors in SIS because of their impact on the height of the subacromial space during humeral elevation. During humeral elevation it is necessary to have sufficient scapular posterior tilt and upward rotation to maintain subacromial space.[19] This is accomplished by cooperative activity of the upper and lower trapezius along with serratus anterior and the rotator cuff.[20] Muscle imbalance in the rotator cuff can also lead to increased anterior and superior translation of the humeral head and poor centralization of the humeral head during arm elevation, leading to impingement in the subacromial space.[21] Previous observations of impaired muscle balance and scapular stabilization in adults with SIS have documented three important changes; (1) Increased ratio of upper to lower trapezius EMG activation during isokinetic abduction, (2) increased ratio of isokinetic internal rotation strength (IR) to external rotation strength (ER), and (3) increased ratio of isokinetic abduction strength (ABD) to adduction strength (ADD).

Functional electrical stimulation assisted rowing

As demonstrated in the conceptual model (**Fig. 1**), an optimal point of intervention for preventing and improving shoulder pain in adults with SCI is at the level of physical inactivity. The intervention needs to be considerate of two primary factors: it must be of sufficient intensity to improve aerobic fitness, and must target disused muscle groups to reduce strain and improve shoulder function. FES rowing is an ideal training intervention for adults with SCI who have shoulder pain due to SIS for three reasons; (1) FES-rowing allows participants to obtain a higher VO_2 during exercise than arms-only exercise or FES-cycling,[22] (2) FES-rowing is better tolerated than other forms of hybrid exercise,[23] and (3) the muscular demand of FES-rowing (closed-chain extension, open-chain flexion) is the exact opposite of the demand for wheelchair propulsion (closed-chain flexion, open-chain extension) which can reduce strain while improving shoulder function by simultaneously activating the disused posterior shoulder musculature implicated in SIS in able-bodied adults.

The FES-rower that was developed for this dissertation improves upon three design elements from FES-rowers designed by other groups. First, the Concept II dynamic rowing ergometer was utilized. Unlike previous models, the seat on the dynamic ergometer can be fixed in place with the feet moving away from the body, instead of the feet being fixed and the body moving away from the feet. Using this model, the seating system has greater stability and adjustable seat tilt and recline. Second, the action of the feet moving away from a stationary seat decreases the necessary amount of force needed to extend the legs. This may allow participants to begin FES row training sooner than on previous models where remedial FES strength training was conducted until the participant could produce enough force to extend the legs against the weight of the body and seating system. Finally, FES switch system was incorporated into the motion of the legs. Previous models have had a handle-mounted switch that the participant had to voluntarily activate in order to switch the stimulation between quadriceps and hamstrings. This created a problem with performing a proper rowing stroke. By incorporating the switches into the motion of the legs, stimulation will continue in the proper direction until the legs reach their full point of extension or flexion, while the participant synchronizes their arms to the legs without needing to depress or release a handle-mounted switch.

Specific Aim 1—Determine the methodological quality and frequency of outcome measures utilized in exercise interventions for adults with spinal cord injury.

Researchers and practitioners in the field of physical medicine and rehabilitation generally agree that exercise is beneficial for people with SCI because it can improve functional capacity and increase life expectancy.[1,24] In 2001 The World Health Organization release the International Classification of Functioning, Disability and Health (ICF), a classification system that allows for clinicians and researchers to categorize disease effects and outcome measures into body functions, body structures, activities and participation or environmental factors.[25] It is beneficial to understand the impact of interventions on all four ICF categories so that treatments can be tailored to improve general wellness. We sought to examine which categories of the ICF are most frequently addressed as outcome measures in exercise interventions for adults with SCI. In this investigation, we also examined the methodological quality of the interventions.

We found that the majority of outcome measures utilized in exercise interventions for adults with spinal cord injury are related to body functions and body structures and demonstrate low to moderate levels of methodological quality. These results indicate that researchers should attempt to include measures of activities and participation in their outcome measures in order to examine the effects of an intervention on daily living. Methodological quality issues were often related to small sample sizes and inability to blind participants. Items that could be addressed to improve methodological quality include description of and adjustment for confounding variables, clear description of participant characteristics, selecting participants who are representative of the population and using appropriate statistical analyses.

Specific Aim 2 – Determine if the presence of muscle imbalance and impaired scapular stabilization contribute to shoulder pain in adults with SCI.

Previous research has shown that able-bodied adults whose shoulder pain is due to subacromial impingement syndrome (SIS) demonstrate increased activity in the upper trapezius muscle and decreased adduction and external rotation strength.[7,8,26-28] These alterations may be worsened by prolonged wheelchair propulsion for mobility. Based on these findings it was hypothesized that adults with SCI and shoulder pain who use manual wheelchairs would demonstrate this pattern of muscle imbalance and impaired scapular stabilization to a greater extent than able-bodied adults with shoulder pain.

We found that manual wheelchair users with SCI who have impingement demonstrate a similar pattern of scapular instability as able-bodied adults with impingement, and that manual wheelchair users with SCI, regardless of impingement status, demonstrate weak posterior shoulder muscle strength compared to able-bodied adults. Thus we concluded that therapeutic exercises utilized in able-bodied adults with impingement are appropriate for adults with SCI and impingement, and that a special emphasis should be placed on posterior shoulder strengthening in the population of manual wheelchair users with SCI.

Specific Aim 3 – Determine the effectiveness of an FES rowing intervention to decrease shoulder pain, and increase fitness and participation in adults with SCI.

Previous research has shown that a kayak ergometer training intervention improves shoulder strength and aerobic fitness, and targeted posterior shoulder muscle training improves shoulder pain in adults with SCI.[29,30] Based on these findings it was hypothesized that a 6-week FES-assisted rowing intervention will decrease shoulder pain, and increase fitness and participation in adults with SCI.

We found that after a 6-week FES-assisted rowing intervention, participants were able to increase their VO2 peak by 7 to 9% and significantly reduce their shoulder pain, although we found no significant changes in shoulder muscle strength or scapular stability. Thus, we concluded that FES-assisted rowing is effective to improve aerobic fitness and shoulder pain in manual wheelchair users with SCI.

SYSTEMATIC REVIEW OF THE METHODOLOGICAL QUALITY AND OUTCOME MEASURES UTILIZED IN EXERCISE INTERVENTIONS FOR ADULTS WITH SPINAL CORD INJURY.

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Format adapted for dissertation

ABSTRACT

Objectives: The primary aims of this study were to evaluate the methodological quality of exercise intervention studies in adults with spinal cord injuries (SCI); and to classify the reported outcome measures according to the International Classification of Functioning, Disability and Health (ICF). **Study Design**: Systematic literature review **Methods**: Electronic searches of PubMed, CINAHL, SPORTDiscus, PsychINFO, Scopus and the Cochrane Center Register of Controlled Trials from 2001-2011 were performed. Selected studies were evaluated for methodological quality using the Downs and Black checklist. Outcome measures were extracted and linked to categories of the ICF using standardized linking rules. **Results**: 240 abstracts were retrieved, 57 studies met eligibility criteria. The mean methodological quality score was 14.7 ± 3.2 out of 28 on the Downs and Black checklist. 371 outcome measures were extracted with 325 concepts linked to 32 second-level ICF categories across the four components. **Conclusion**: Studies of exercise interventions for adults with SCI included in this review are generally low in methodological quality, primarily reporting outcomes related to the Body Functions and Body Structures components of the ICF. It is recommended that studies employ more vigorous methodological designs to reduce bias and confounding and include outcome measures targeting more categories in the Activities and Participation component so as to reflect the potential benefits of exercise on health and functioning in this population.

Keywords: spinal cord injury, exercise, physical activity, outcome measures, ICF, methodological quality.

Introduction

Spinal cord injuries (SCI) lead to impairment or loss of function below the level of injury. Impairment or loss of function may ultimately lead to activity limitations, restricted participation in a variety of activities, and limitations in community involvement due to restricted mobility.[1-3] Lack of physical activity in adults with SCI has been shown to increase adiposity, alter lipid metabolism and affect cardiovascular function.[4-6] These changes may increase a person with SCI's risk for mortality as observed in able-bodied adults.[7] Therefore, increasing levels of physical activity for individuals with SCI is advocated.[8]

Studies have shown increasing physical activity may be beneficial for individuals with SCI.[4,9] Previous reviews pertaining to exercise and SCI have focused primarily on improvements in physical capacity measures,[9-11] without relating the outcome measures to the categories and components of the International Classification of Functioning, Disability and Health (ICF).[12] A recent review that linked outcome measures to the ICF in people with SCI reported a large number of outcomes were related to 'Body Structures' and 'Body Functions' components.[13] This particular review evaluated a random sample of any study involving individuals with SCI without specifically addressing exercise interventions. Linking outcome measures from exercise intervention studies to the ICF is helpful as it provides a knowledge base about which ICF categories, domains, and components have been most frequently targeted, and which areas need to be addressed further in future studies.

Another issue related to studies on exercise interventions in adults with SCI is methodological quality. Evaluating methodological quality of studies on exercise interventions not only provides a guide for clinicians and exercise professionals to make informed decisions on adopting the best available evidence in their practice, but also increases researchers' awareness of areas of methodological deficiency. This information is beneficial when designing studies to avoid those pitfalls and improve scientific quality. Although randomized controlled trials (RCTs) are typically viewed as the highest quality of study,[14] poorly designed RCTs will not provide evidence that is superior to other study designs.

The purpose of this systematic review was to 1) assess the methodological quality of prospective studies of exercise interventions in adults with SCI and 2) classify the reported study outcome measures according to the ICF.

Materials and Methods

This systematic review was conducted in four major steps. First, we performed an extensive search of several commonly used literature databases to locate studies on exercise and SCI, and selected studies that met eligibility criteria. Second, studies were scored for methodological quality using the Downs and Black checklist.[15] Third, outcome measures were extracted from each eligibile study. Finally, the concepts within the outcome measures were linked to the categories of the ICF.

Methodological quality and level of evidence

The Downs and Black checklist was designed to evaluate the methodological quality of both randomized and non-randomized comparative studies.[15] The checklist consists of 27 items that address the following methodological components: reporting, external validity, internal validity (bias and confounding), and power. Twenty-six items were rated either as yes (=1) or no / unable to determine (=0), and one item was rated on a 3-point scale (yes=2, partial=1, and no=0). Scores range from 0 to 28 with higher scores indicating a better methodological quality of the study. The following cut-points have been suggested to categorize studies by quality: excellent (26 to 28), good (20 to 25), fair (15 to 19) and poor (≤ 14).[16] Adequate psychometric properties of the Downs and Black checklist such as internal consistency, test-retest reliability, inter-rater reliability and criterion validity have been reported elsewhere.[15] The checklist has been ranked in the top six quality assessment tools suitable for use in systematic reviews.[17]

In addition, for studies utilizing the RCT design, ratings were extracted from the Physiotherapy Evidence Database (PEDro) at www.pedro.org.au.[18] The PEDro scale consists of 11 items with each item awarding one point when the criterion specified in the item is satisfied. The first item is not included to calculate the PEDro score. Scores range from 0 to 10 with higher scores indicating a better methodological quality of the RCT. The following cut-points were suggested to categorize studies by quality: excellent (9 to 10), good (6 to 8), fair (4 to 5) and poor (≤ 3).[19] The PEDro scale has demonstrated adequate reliability for use in systematic reviews of exercise intervention RCTs.[20] Finally, the strength of evidence of the exercise intervention studies was determined using a modified Sackett's levels of evidence (Table 1).[21] The levels are ranked 1 through 5 and represent the amount of scientific evidence from clinical studies providing results that consistently support the recommendation made by Sackett, with 1 being the highest and 5 the lowest level of evidence.

Level	*Study Design*
1	RCT (PEDro score ≥ 6)
2	RCT (PEDro score < 6), Prospective controlled trial, Cohort
3	Case control
4	One-group pretest-posttest, case series
5	Case report

Table 1: Modified Sackett's levels of evidence

The International Classification of Functioning, Disability and Health

The outcome measures of the exercise intervention studies were classified using the ICF taxonomy. The ICF is organized into four main components: 1. Body Functions, 2. Body Structures, 3. Activities and Participation, and 4. Environmental Factors.[12] Each of the four components consists of various domains (i.e., chapters). Within each domain/chapter, categories and sub-categories are denoted by additional digits.[22] The ICF uses an alphanumeric system to classify each outcome measure. Letters (b-body functions, s-body structures, d-activities and participation and e-environmental factors) represent the four components, followed by a numeric code starting with the chapter number (one digit) indicating the first level, followed by the second level (two digits) and the third and fourth levels (one digit each), which represent an increase in the level of precision in describing the outcome measures.[22] For example, 'power of the quadriceps' would follow the code for chapter 7 'Neuromusculoskeletal and movement-related functions' of the component 'Body Functions' which is b7 (first level), then 'muscle power functions' is b730 (second level), and finally 'power of muscles in lower half of the body' is b7303 (third level). Outcome measures extracted from the selected studies were linked to categories in the ICF using linking rules established by Cieza et al.[23,24] Linking rules include the following: all meaningful concepts within each outcome measure are identified, the aim with which the measure used is considered, outcome measure should be linked to the most precise ICF category, and if information is insufficient for making a decision or the concept is not contained within the ICF, the domains are coded *nd* (not definable) or *nc* (not coded).[23,24]

Eligibility criteria

We aimed to include studies that provided original data on the effects of exercise training in adults with SCI. Studies were eligible for inclusion if the independent variable was an exercise intervention lasting at least 4 weeks in duration with a focus other than task-specific training that is typically conducted in clinical rehabilitation settings (i.e. outpatient physical therapy). To be included, the exercise intervention had to be described with a specific frequency, duration, and mode, including both aerobic and/or strength training. Studies were excluded if the outcome measures of the prescribed intervention were only task-specific, such as studies utilizing body-weight supported treadmill training (BWSTT) with outcomes only focused on that task (e.g. improvements in gait). Additional exclusion criteria were: not employing a prescribed exercise intervention that had a known frequency, duration, and mode (e.g. physical activity promotion interventions), respiratory muscle training interventions and studies that included participants with common comorbidities of SCI (e.g. traumatic brain injury).

Search Strategy

All types and etiologies of SCI were included to provide a comprehensive, unbiased review of the literature. Electronic databases in PubMed, CINAHL, SPORTDiscus, PsychINFO, Scopus, and the Cochrane Center Register of Controlled Trials were last searched on October 11, 2011. Searches were limited to studies published after 2001 (year of publication of the ICF), English language, adult ($\geq$18 years), and human studies. Search terms included: exercise, physical activity, resistance training, spinal cord injur*, parapleg*, quadripleg* and tetrapleg*.

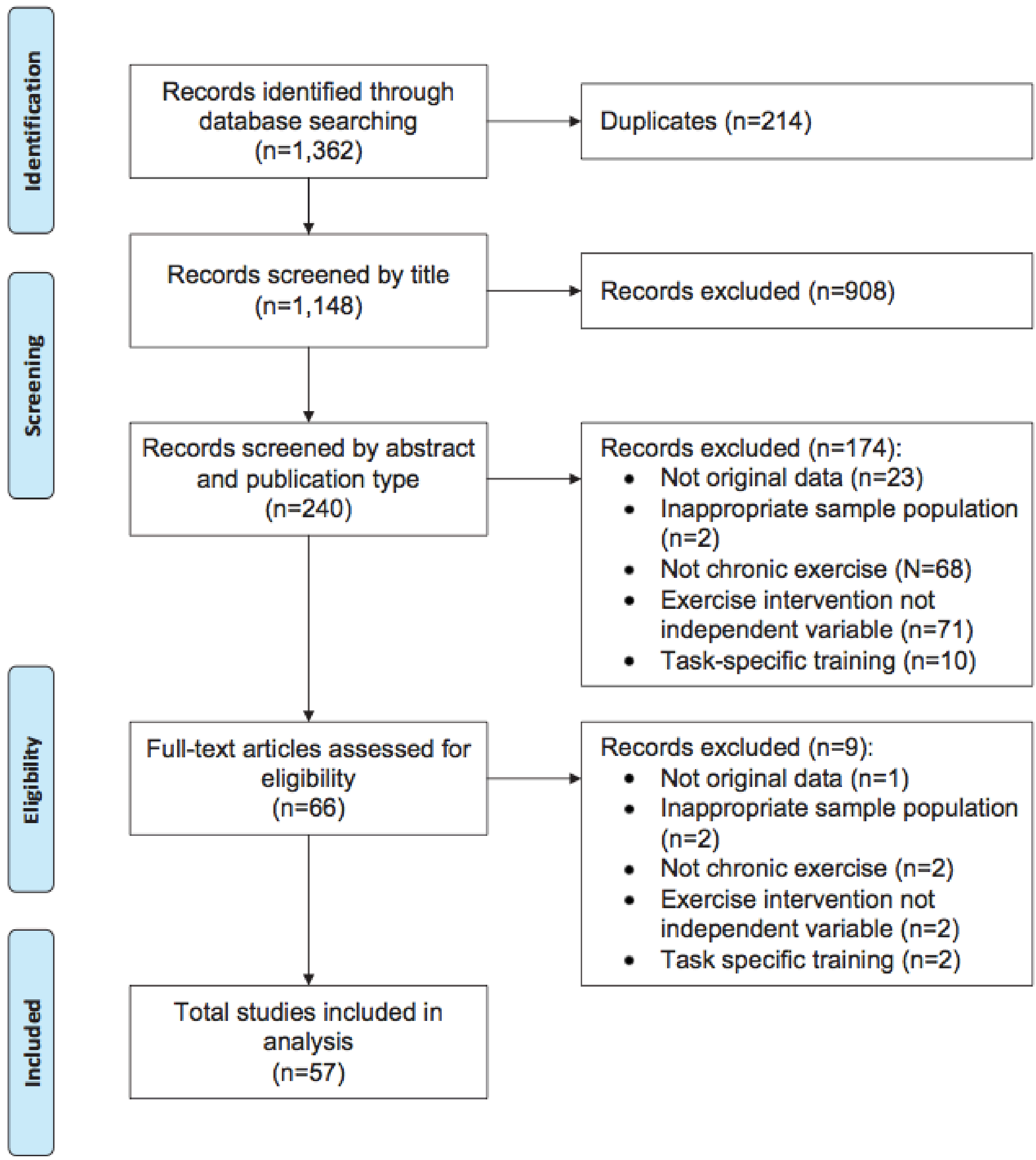

Figure 1: Description of the search strategy

Data Extraction

Articles were reviewed independently by two authors (SS and LS). First, articles were evaluated for methodological quality using the Downs and Black checklist.[15] Quality scores for RCTs were extracted from the PEDro. Study designs were determined by the primary reviewer (SS) with agreement from the second reviewer (LS). The intraclass correlation coefficient (ICC) for Downs and Black methodological quality scores between the two reviewers was 0.90. When discrepancies in ratings between reviewers were more than one scoring point, discussion between reviewers with consultation from a third party (SB) was sought to resolve the difference.

Second, outcome measures within each article were extracted by the primary reviewer (SS). Outcome measures were linked to the ICF independently by two reviewers (SS and LS) using standard linking rules.[23,24] We aimed to use the most precise ICF category (i.e., the highest level) possible. For example, quadriceps strength would be linked to the ICF category b7303 'power of muscles in lower half of the body' instead of the broader (i.e., lower level) category b730 'muscle power functions.' The Kappa coefficient for the agreement between the two reviewers on classifying the ICF codes of the components was 0.79. Discrepancies in linking outcomes were discussed between reviewers with consultation from a third party (JL) when necessary.

Results

Study Design

A total of 240 abstracts were retrieved, 57 studies met the eligibility criteria (Figure 1). Study design, intervention type, methodological quality scores and outcome measures of these 57 studies are presented in Table 2.[25-81] Of the 57 studies, study designs included RCTs (n = 7), prospective controlled trials (n = 9), one-group pretest-posttest design (n = 33), case series (n = 4), and case reports (n = 4). The number of subjects in each study ranged from 1 to 34 (median = 10). The most common mode of intervention was functional electrical stimulation (FES) cycling (n = 13), followed by

BWSTT (n = 10) and FES resistance training (n = 9). Interventions were performed 3-4 days per week with a range of 10-120 minutes of exercise per session for a mean duration of 18 weeks (SD = 18.5 weeks, three studies were ≥ 1 year duration).

Methodological Quality

The distribution of methodological quality scores based on the Downs and Black checklist are presented in Figure 2. The distribution of scores followed a normal distribution (mean = 14.7, median = 15).[15] For the seven RCTs, the PEDro scores ranged from 1-8, with a median of 5. Three studies were qualified as level 1 evidence using the modified Sackett's criteria.[10]

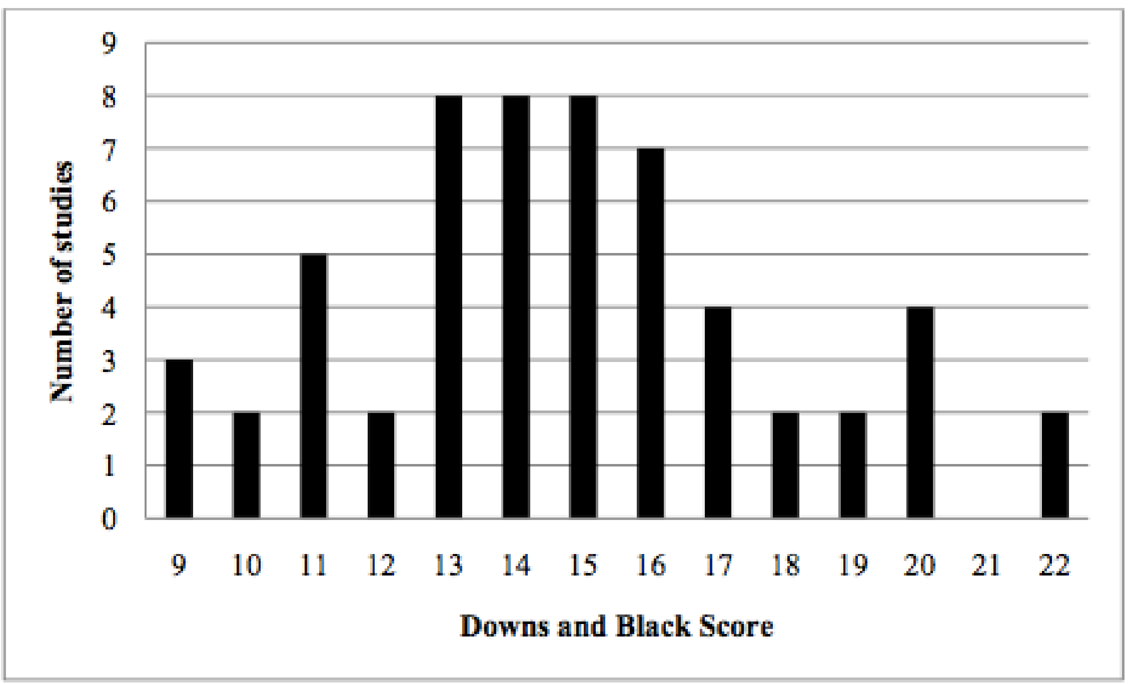

Figure 2: Methodological quality score distribution based on the Downs and Black checklist. Possible range of scores 0 - 28

		Quality Scores				Outcome Measures		
References	**Intervention Type**	**D&B**	**PEDro**	**Level**	**Study Type**	**Improvement****	**Decline**	**No Change**
Ashe, M.C (2010)[25]	FES cycling	9	-	4	C. series	BMD, % lean, % fat	-	-
Bizzarini, E. (2005)[26]	UE erg and resistance training	12	-	4	Pre/Post	FES cycle workload	-	Weight, Body Composition*, Testosterone/Cortisol Ratio, CPK level
Bjerkefors, A. (2005)[27]	Kayak ergometer	17	-	4	Pre/Post	Transfer Height, WC propulsion, Platform mount height	-	WC agility
Bjerkefors, A. (2006 a.)[28]	Kayak ergometer	20	-	4	Pre/Post	Multidirectional shoulder strength*	-	-
Bjerkefors, A. (2006 b.)[29]	Kayak ergometer	19	-	4	Pre/Post	Trunk displacement during perturbation	-	-
Bogie, K.M. (2003)[30]	Implanted NMES	15	-	4	Pre/Post	Ischial pressure	-	Total interface pressure
Bougenot, M.P. (2003)[31]	Wheelchair ergometry	14	-	4	Pre/Post	VO_2, VCO_2, Tolerated Power, SpO_2	-	HR, Peak ventillation, Tidal volume
Carvalho, D.C.L. (2006)[32]	FES+BWSTT	11	-	2	PCT	Muscle CSA (quad)	-	-
Carvalho, D.C.L. (2009)[33]	FES+BWSTT	14	-	2	PCT	Bone biochemical markers	-	BMD (lumbar, femur)
Chen, S.C. (2005)[34]	FES cycling	13	-	2	PCT	BMD (femur, tibia)	-	BMD (calcaneus)
Clark, J.M. (2007)[35]	FES knee extension, ankle dorsiflexion	20	-	2	PCT	Body Composition	BMD (total)	BMD (hip, spine)
Coupaud, S. (2009)[36]	BWSTT	13	-	5	C. study	Bone mineral content, BMD (total, trabecular), Muscle CSA (quad)	Fat CSA (quadriceps)	Bone CSA (femur)
Crameri, R.M. (2002)[37]	FES cycling	12	-	4	Pre/Post	FES cycle workload, muscle fiber type*, Muscle CSA (quadriceps), Muscle capillarization (quadriceps), Citrate synthase level, Hexokinase level	-	-
de Groot, P.C.E. (2003)[38]	UE erg	14	5	2	RCT	VO_2, Power output, Blood lipids*	-	Insulin sensitivity
De Mello, M.T. (2002)[39]	Aerobic exercise	11	-	4	Pre/Post	Leg movements during sleep	-	-
Dolbow, D.R. (2010)[40]	UE erg	9	-	5	C. study	VO_2, % body fat	-	BMD (total)
Dyson-Hudson, T.A. (2007)[41]	UE erg	22	-	2	PCT	WUSPI score*	-	-
Effing, T.W. (2006)[42]	BWSTT	15	-	4	Pre/Post	Case series- varied by subject		
El-Sayed, M.S. (2005)[43]	UE erg	16	-	2	PCT	VO_2, Ventilation max, Workload	-	Blood lipids*
Gerrits, H.L. (2001)[44]	FES knee extension	11	-	4	C. series	Mean blood velocity, systolic inflow volume	-	Peak blood velocity, Min blood velocity, End-diastolic velocity
Gerrits, H.L. (2002)[45]	FES cycling	15	-	4	Pre/Post	FES force, Fatigue resistance	-	Contraction/Relaxation speed (quadriceps)
Gerrits, H.L. (2003)[46]	FES knee extension, ankle dorsiflexion	14	-	4	Pre/Post	Knee extension. strength, Fatigue resistance (quadriceps), Succinate dehydrogenase (quadriceps)	-	Myosin type I, Muscle fiber diameter (quadriceps), Alpha-glycerophosphate dehydrogenase (quadriceps)
Giangregorio, L.M. (2005)[47]	BWSTT	13	-	4	C. series	Walking duration, Walking speed, BWS, % lean mass, Muscle CSA (quadriceps)	BMD (femur, tibial, lumbar)	Bone biochemical markers
Giangregorio, L.M. (2006)[48]	BWSTT	17	-	4	Pre/Post	Walking duration, Walking speed, BWS, Body composition, Muscle CSA (quadriceps)	BMD (total)	BMD (spine, femur, tibia), bone biochemical markers
Gorgey, A.S. (2010)[49]	NMES+ resistance knee flex/extension	9	-	5	C. study	Muscle CSA*, IM fat, Subcutaneous fat, NMES resistance	-	-
Gregory, C.M. (2007)[50]	LE resistance and plyometric training	10	-	4	C. series	Torque (knee extension, plantarflexion), Rate of torque development (knee extension, plantarflexion), Activation deficit (knee extension, plantarflexion)	-	-
Griffin, L. (2009)[51]	FES cycling	16	-	4	Pre/Post	Ride time, Power, Body composition, OGTT, AIS*	-	Cholesterol
Grigorenko, A. (2004)[52]	Sea kayaking	15	-	2	PCT	Acceleration of change (sagittal)	-	COP change*, Velocity of change*, Acceleration of change (frontal)
Harvey, L.A. (2010)[53]	FES+ PRT on single quadriceps	20	8	1	RCT	Quadriceps strength (voluntary), Perception of exercise effectiveness	-	Quadriceps strength (stim), Quadriceps endurance (voluntary, stim), perceived ability, Satisfaction w/ program
Heesterbeek, P.J.C. (2005)[54]	Hybrid FES cycling + UE erg	16	-	4	Pre/Post	Leg volume, VO_2	-	Peak ventilation, Peak HR, Power output

***Multiple items included within measure**

****Improvement indicates physiologically desirable change**

AIS- ASIA impairment score, **BMD-** Bone Mineral Density, **BMI-** Body Mass Index, **BP-** Blood Pressure, **BWS-** Body Weight Support, **BWSTT-** Body Weight Supported Treadmill Training, **COP-** Center of Pressure, **CPK-** Creatine Phosphokinase, **CSA-** Cross Sectional Area, **FES-** Functional Electrical Stimulation, **FVC-** Forced Vital Capacity, **HR-** Heart Rate, **OGTT-** Oral Glucose Tolerance Test, **PCT-** Prospective Controlled Trial, **PQOL-** Perceived Quality of Life, **PRT-** Progressive Resistance Training, **RCT-** Randomzied Controlled Trial, **RER-** Respiratory Exchange Ratio, **RPE-** Rating of Perceived Exertion, **SpO2-** Oxygen Pulse, **UE erg-** Upper Extremity Ergometry, **VL-** Vastus Lateralis, **WC-** Wheelchair, **WUSPI-** Wheelchair User's Shoulder Pain Index

Table 2: Study design and description of relevant studies that met inclusion criteria

References	Intervention Type	Quality Scores D&B	PEDro	Level	Study Type	Outcome Measures Improvement**	Decline	No Change
Hicks, A.L. (2003)[55]	PRE upper extremity, UE erg	20	5	1	RCT	Walking score, BWS, Speed, Distance, Life satisfaction, Satisfaction w/ physical function	-	Depression, Perceived health, Perceived ability for IADL
Hicks, A.L. (2005)[56]	BWSTT	16	-	4	Pre/Post	Peak HR, BP, UE strength*, Power output, Satisfaction w/ physical function, Satisfaction w/ appearance, Pain, Stress, Depression, PQOL, Perceived health	-	-
Jacobs, P.L. (2001)[57]	circuit resistance training	13	-	4	Pre/Post	Fatigue resistance, VO_2, UE strength*	-	Elbow flexion/extension strength
Jacobs, P.L. (2009)[58]	Endurance or resistance	17	-	4	Pre/Post	VO_2, Power, UE strength*	-	Peak ventillation, Peak HR, Peak RPE
Jeon, J.Y. (2002)[59]	FES cycling	15	-	4	Pre/Post	OGTT	-	Insulin secretion, Insulin sensitivity
Jeon, J.Y. (2010)[60]	FES rowing	15	-	4	Pre/Post	Fasting glucose, fasting leptin	-	Body composition, Fasting insulin, Insulin resistance
Kakebeeke, T.H. (2008)[61]	FES cycling	10	-	5	C. study	BMD (femur), Thigh CSA, Fat CSA (thigh, lower leg), Peak HR, VO_2, Blood lactate	-	Muscle CSA (lower leg)
Kern, H. (2010)[62]	FES knee extension/flexion	18	-	4	Pre/Post	Knee extension torque, Muscle composition (quadriceps)*	-	-
Kjaer, M. (2001)[63]	FES cycling	11	-	4	Pre/Post	quadriceps: hexokinase, lactate dehydrogenase, citrate synthase, hydroxyacyl-3-dehydrogenase	-	-
Latimer, A. (2004)[64]	PRE UE erg and resistance training	14	2	2	RCT	Exercise influences depression through stress, independent of pain.		
Latimer, A. (2005)[65]	PRE UE erg and resistance training	18	1	2	RCT	Stress, Depression, PQOL	-	-
Liu, C.W. (2007)[66]	FES cycling	15	-	4	Pre/Post	Thigh girth, Body composition, Knee flex/extension torque	-	-
Mahoney, E.T. (2005)[67]	FES knee extension	14	-	4	Pre/Post	CSA (quadriceps)	-	OGTT, Fasting insulin
Martin Ginis, K.A. (2003)[68]	UE erg and resistance training	22	6	1	RCT	Pain, Stress, Self-efficacy, Perceived control, PQOL, Depression, Satisfaction w/ physical function, Satisfaction w/ appearance	-	-
Mohr, T. (2001)[69]	FES cycling	11	-	4	Pre/Post	GLUT-4 transport level, Insulin-stimulated glucose uptake	-	OGTT
Nash, M.S. (2007)[70]	circuit resistance training	15	-	4	Pre/Post	UE force, VO_2 peak, Anaerobic power, WUSPI score*	-	-
Phillips, S.M. (2004)[71]	BWSTT	13	-	4	Pre/Post	BWS, Gait Velocity, Glucose tolerance, Insulin response, Substrate oxidation, GLUT-4 level, Muscle hexokinase, Muscle metabolites	-	Body composition
Sk□ld, C. (2002)[72]	FES cycling	13	2	2	RCT	LE muscle volume	-	Spasticity*, Body composition, Body weight
Soyupek, F. (2009)[73]	BWSTT	14	-	4	Pre/Post	Resting HR, FVC, Inspiratory capacity, Depression	-	BP, Max inspiratory pressure, FEV1, FEV1/FVC, Expiratory reserve volume, Forced expiratory flow, Slow vital capacity
Stewart, B. (2004)[74]	BWSTT	14	-	4	Pre/Post	Ambulatory capacity, Cholesterol, Muscle fiber CSA (VL), Muscle fiber composition (VL)*, Citrate synthase (VL)	-	-
Stoner, L. (2007)[75]	FES knee extension	16	-	4	Pre/Post	Flow mediated dilation (posterior tibial artery)	-	Artery vessel diameter (posterior tibial artery)
Sutbeyaz, S.T. (2005)[76]	Breathing exercises and UE erg	13	-	4	Pre/Post	VO_2, Peak HR, HR reserve, Minute ventilation, SpO_2, Power output (UE), Exercise time	-	BP
Thijssen, D.H. (2005)[77]	FES cycling & UE erg	13	-	4	Pre/Post	VO2, Thigh bloodflow, Vessel diameter, Vascular resistance, Thigh volume, Fatigue resistance	-	Forearm bloodflow, Calf bloodflow, Mean wall shear weight, Forearm circumference, Lower leg volume
Valent, L.J. (2009)[78]	Hand cycling	19	-	4	Pre/Post	Power output (UE), VO_2, Shoulder abduction strength	-	RER, Peak HR, SpO_2, Elbow flexion/extension strength, Shoulder IR strength, FVC, Peak expiratory flow
Valent, L.J. (2010)[79]	Hand cycling	17	-	2	PCT	Power output (UE), Shoulder strength*, Elbow flexion strength	-	Peak HR, Resting HR, VO_2, FVC, Shoulder flexion/extension strength, Elbow extension strength, wheelchair capacity
Van Duijnhoven, N. (2010)[80]	FES cycling	16	-	2	PCT	-	-	Malondialdehyde level, Superoxide dismutase level, Glutathione peroxidase level
Wheeler, G.D. (2002)[81]	FES rowing	16	-	4	Pre/Post	VO_2, $Sp0_2$	-	Ventillation volume, RER, Peak HR

***Multiple items included within measure**

****Improvement indicates physiologically desirable change**

AIS- ASIA impairment score, **BMD-** Bone Mineral Density, **BMI-** Body Mass Index, **BP-** Blood Pressure, **BWS-** Body Weight Support, **BWSTT-** Body Weight Supported Treadmill Training, **COP-** Center of Pressure, **CPK-** Creatine Phosphokinase, **CSA-** Cross Sectional Area, **FES-** Functional Electrical Stimulation, **FVC-** Forced Vital Capacity, **HR-** Heart Rate, **OGTT-** Oral Glucose Tolerance Test, **PCT-** Prospective Controlled Trial, **PQOL-** Perceived Quality of Life, **PRE-** Progressive Resistance Exercise**RCT-** Randomzied Controlled Trial, **RER-** Respiratory Exchange Ratio, **RPE-** Rating of Perceived Exertion, **SpO_2**-Oxygen Pulse, **UE erg-** Upper Extremity Ergometry, **VL-** Vastus Lateralis, **WC-** Wheelchair, **WUSPI-** Wheelchair User's Shoulder Pain Index

Outcome Measures Linked to the ICF

A total of 371 outcomes were extracted from the selected studies. For those outcome measures that belong to multi-item surveys, we attempted to retrieve survey documents to include as many ICF codes as possible. Tables 3-5 represent the first and second-level ICF categories with frequency of occurrences in the coded outcome measures. Frequency of occurrence refers to the total number of outcome measures (including survey items) that were linked to a unique ICF code. In 'Body Functions,' 5 of 8 first-level categories were addressed, 1 of 7 'Body Structures' categories was addressed, 1 of 9 'Activities and Participation' categories were addressed, and 1 of 5 'Environmental Factors' categories was addressed. Measures that could not be linked to a specific ICF category included quality of life and some anthropometric measures such as waist to hip ratio. Figure 3 represents the percentages of the ICF categories referred to by the outcome measures. A total of 325 concepts could be linked to 32 unique second-level ICF categories.

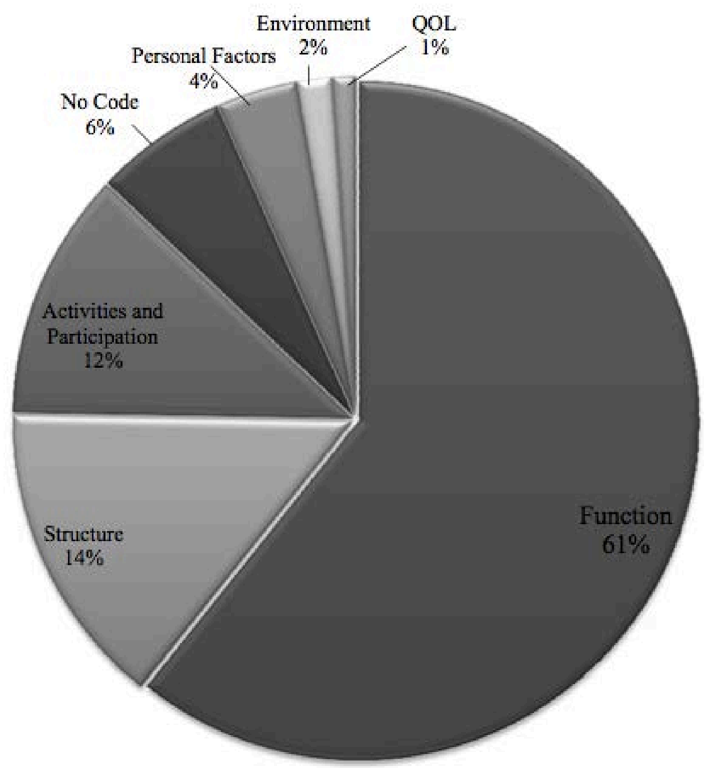

Figure 3:Percentage of outcome measures linked to specific ICF categories. A total of 374 outcomes were extracted.

ICF code	*Description*	*frequency*
Chapter 1: mental functions (8)		
b152	Emotional functions	8
Chapter 2: sensory functions and pain (2)		
b280	Pain	2
Chapter 4: functions of the cardiovascular, hematological, immunological and respiratory systems (81)		
b410	Heart functions	13
b415	Blood vessel functions	14
b420	Blood pressure functions	4
b430	Haematological functions	4
b440	Respiration functions	19
b455	Exercise tolerance functions	27
Chapter 5: functions of the digestive, metabolic and endocrine systems (50)		
b530	Weight maintenance functions	15
b540	General metabolic functions	25
b555	Endocrine gland functions	10
Chapter 7: neuromusculoskeletal and movement related functions (81)		
b730	Muscle power functions	66
b735	Muscle tone functions	4
b740	Muscle endurance functions	1
b750	Motor reflex functions	1
b755	Involuntary movement reaction functions	7
b760	Control of voluntary movement functions	2

Table 3: Frequency of second-level categories of the ICF relative to body functions

ICF code	*Description*	*frequency*
Chapter 7: structures related to movement (54)		
s730	Structure of the upper extremity	1
s740	Structure of the pelvic region	1
s750	Structure of the lower extremity	45
s760	Structure of the trunk	4
s770	Additional musculoskeletal structures related to movement	3

Table 4: Frequency of second-level categories of the ICF relative to body functions

ICF code	*Description*	*frequency*
Chapter 4: mobility (33)		
d410	Changing basic body position	1
d420	Transferring oneself	7
d430	Lifting and carrying objects	4
d450	Walking	11
d465	Moving around using equipment	8
d475	Driving	2
Chapter 5: self-care (8)		
d510	Washing oneself	2
d540	Dressing	6
Chapter 6: domestic life (2)		
d640	Doing housework	2
Environment		
Chapter 1: products and technology (6)		
e120	Products and technology for personal indoor and outdoor mobility and transportation	6

Table 5: Frequency of second-level categories of the ICF relative to activities and participation and environmental factors

Discussion

Of the exercise interventions for people with SCI studies evaluated in this report, the overall methodological quality of the studies was fair according to the suggested categorization scheme for the Downs and Black score. There were very few trials with good methodological quality, or that qualified as level 1 evidence according to the modified Sackett's criteria. Even though exercise is considered to be beneficial for health and is often recommended for people with SCI, this systematic review revealed that there are insufficient numbers of high quality studies of exercise interventions in people with SCI to support the health and function benefits of exercise for this population. In addition, the outcome measures that are typically included in these exercise intervention studies mainly targeted 'Body Functions' without adequately addressing the ICF component of 'Activities and Participation.' It is recommended that the impact of any improvements in body functions and structures from exercise interventions should also be evaluated for their effects on activities and participation.

Study Design and Methodological Quality

Results of this systematic review give an overview of the current research design and methodological quality issues for studies examining exercise interventions for individuals with SCI. The majority of studies utilized either a one-group pretest-posttest or a non-randomized controlled design. These findings are in agreement with other reviews of exercise interventions in people with chronic conditions. Two recent reviews of exercise interventions for individuals with traumatic brain injury (TBI) and muscle disease, yielded only 6 and 3 RCTs respectively.[82,83] Both reviews concluded that insufficient high quality evidence exists for exercise interventions in these two populations.

Inability to recruit a sufficiently large sample and group heterogeneity in the SCI population may partly explain the frequent use of lower quality study designs. Given the characteristics of the SCI population, RCTs for this population tend to be small with a high drop-out rate.[14] This is in agreement with the review by Martin-Ginis and Hicks addressing exercise research issues in this population.[14] Due to lack of higher levels of evidence in exercise interventions for people with SCI, current consensus on its efficacy is largely based on well-conducted non-randomized or single group studies.

In regard to the scoring of the review studies using the Downs and Black checklist, some studies did not satisfy the criteria because information was not included within the publication. However, according to the Downs and Black scoring criterion, if the study did not explicitly state certain requested methodology for a particular item, that item must be scored as not satisfying the criterion. The methodological rating criteria that were most frequently not satisfied in the papers we reviewed were related to blinding, randomization, representativeness of the sample group, and adjustment for confounding factors in data analysis. Adequate adjustment for confounding in analysis was a fairly subjective criterion and depended on the rater's opinion of whether or not confounding factors exist. As the SCI population is a heterogeneous group, variables such as lesion level, completeness, and age should be controlled for statistically, particularly if the study design did not employ randomization or group matching.

The Downs and Black checklist includes a criterion concerning appropriate statistical tests,[15] however it is unclear if there was adequate control for the risk of type I errors among the reviewed studies. Some studies included a large number of outcome measures, particularly those measuring multidirectional upper extremity strength, however, the statistical analyses did not always indicate if appropriate statistical adjustments were utilized. Due to the inherent risk of type I error, researchers should be cautious when considering the inclusion of a high number of outcome measures that address the same research question.

Outcome Measures Linked to the ICF

The most commonly addressed outcomes were related to 'muscle power functions' (b730). Within this second-level category, however, muscular strength and power are considered together. This was problematic for outcome measures in exercise intervention studies because power and strength are often considered as different concepts, whereas in the ICF, they share the same code. In addition, 'power of muscles in lower half of the body' is a third-level code, however there is no corresponding code for power of muscles in upper half of the body. As a result, only the second-level code was used to address upper-extremity strength.

We occasionally had difficulty determining the usefulness of the code ‘fatiguability’ (b4554) due to the overlapped concept of muscle function when the outcome measure was specific to skeletal muscle fatigue. To overcome this difficulty we chose to code muscle fatigue to ‘muscle endurance functions’(b740) and general fatigue to ‘fatiguability’ (b4554). Another example was ‘respiration functions’ (b440) which is closely related to exercise tolerance but was utilized for multiple outcomes concerning items such as tidal volume and forced vital capacity.

‘General metabolic functions’ (b540) was also frequently addressed in the published reports. For the studies examined, this code typically included the outcomes of glucose tolerance as measured by oral glucose tolerance test and blood lipids. We also coded cholesterol and triglyceride levels within this category since they are a component of fat metabolism. When considering components of metabolic syndrome, the b540 category is a useful descriptor because it covers both glucose tolerance and blood lipid levels.

‘Body Structures’ component was commonly coded within the extracted outcome measures. The most frequent occurrence was ‘structure of the lower extremity’ (s750). Within the s750 code we included muscle size, muscle fiber size, and muscle cross-sectional area. We chose to use this category (s750) for bone mineral density (BMD) when a specific lower extremity site was stated as an outcome measure. When considering total BMD, following standard linking rules by Cieza et al.[23,24] the lower-level code s7 was used. However, total BMD may also refer to the ICF ‘Body Functions’ component of ‘maintaining mineral balance’ (b5451).

The most frequent code within the ‘Activities and Participation’ component was d450 ‘walking.’ This outcome measure may be over-represented due to the high number of studies using BWSTT. In studies where the exercise intervention was BWSTT, the outcome measure walking time was frequently used. Examining walking in light of tolerated walking time during BWSTT is coded under the ‘Activities and Participation,’ however, as an outcome measure during BWSTT, walking could be better suited to the ‘gait pattern functions’ (b770) category of the ‘Body Functions.’ Within the ‘Activities and Participation’ there is also a code for ‘mobility’(d4). This includes using assistive devices such as a wheelchair or scooter. Under the category of ‘mobility’ is d465 ‘moving around using equipment.’ This second-level code might be a better representation of mobility from an activities and participation standpoint than ‘walking’ (d450) among people with chronic conditions such as SCI , because the important concept is the ability to move around in one’s environment, not necessarily the ability to walk.

The ICF component ‘Activities and Participation’ replaces the International Classification of Impairments, Disabilities and Handicaps (ICIDH) concept of handicap.[84] The important difference between the two models is that ‘Activities and Participation’ refers to an individual’s ability to fulfill a role within their specific life situation.[84] Handicap is referred more specifically to fulfillment of roles as defined by society.[84] Specific instruments for measuring participation in wheelchair users have been developed within the past 10 years.[85,86] Previous reviews have found multiple validated and reliable instruments that can be used to assess participation by wheelchair users.[1,85,86] The results of the current review indicate that the concept of participation is still not being well addressed as an outcome of exercise interventions for individuals with SCI, despite the availability of these instruments.

The 'Environment Factors' component includes social support, assistive technology and aspects of the natural environment. Within the 57 studies evaluated for this review, we extracted only one second-level category within the 'Environment Factors' 'products and technology for personal indoor and outdoor mobility and transportation' (e120). When considering the effects of an exercise intervention, some aspects of the 'Activities and Participation' will be affected by one's environment such as climate and the accessibility and availability of appropriate equipment; however, these were not addressed as an outcome measure by the studies evaluated in this review.

Outcome measures that fell into the categories of 'not defined,' 'not coded' or 'Personal Factors,' component such as quality of life and self-efficacy are currently recognized as weaknesses within the ICF. Some outcome measures that fell into the category of 'not coded' could potentially be incorporated in the existing taxonomy but currently there is not an adequate fit. For example, muscle biochemistry, which involves both body structures and functions, but there are no specific codes for muscle biochemistry within either component.

Limitations

The studies included in the current review were selected from papers published over a ten year period from 2001 to 2011. The ICF was introduced in 2001, bringing increased awareness and attention to researchers and scientists that encouraged inclusion of outcome measures that assessed domains other than body structures and functions.[87,88] Noreau and Shephard[89] also indicated in their review of studies on exercise after SCI that studies were heavily weighted towards body structures and functions, although they did not use current ICF language. We acknowledge that there were significant contributions to the literature on exercise and SCI prior to 2001, but including exercise papers prior to this time would certainly have biased our findings even more as there were few studies with outcome measures that targeted domains other than body structures and functions[89].

Implications

The results of this review indicate that studies focusing on exercise interventions for individuals with SCI face both methodological and measurement deficiency. The methodological quality of the studies for this review was generally low. Previous research has suggested that non-randomized study designs are more frequently conducted due to inherent difficulties in studying chronic condition populations, such as SCI.[14] Although some evidence for efficacy of exercise interventions for people with SCI has been gleaned from this review, it is necessary for researchers to improve the methodological quality of studies to definitively determine efficacy of the interventions.

Methodological quality can be improved in future studies that utilize non-randomized controlled designs by improving statistical control for confounding factors such as lesion level and level of completeness. Given that small sample size and heterogeneous characteristics of the participants are always an issue to conducting exercise intervention research in this population, higher methodological quality studies could be achieved by using multi-site RCTs that would allow for a greater number of participants to be recruited. High drop-out rates were another main issue that reduced the methodological quality of the reviewed studies. Future exercise intervention studies for this population may benefit from improving the research design and developing sophisticated incentive strategies to improve participant retention.

Using the ICF as a reference, the results of this review indicate that the majority of outcome measures are classified under the components of ‘Body Functions’ and ‘Body Structures,’ with ‘Environment Factors’ being the least frequently addressed. We believe that future research may benefit from evaluating the influence of environmental factors related to exercise interventions for individuals with SCI. The most frequently addressed category in the ‘Activities and Participation’ was walking, however this may have been over-represented due to a relatively high proportion of reviewed studies (n = 10, 17.5%) using BWSTT. Within the ICF, walking is coded under the ‘Activities and Participation’ component; however for individuals with SCI, walking as an outcome measure may be more accurately coded under the ‘Body Functions’ component if walking was conducted in a controlled setting such as on a treadmill . Whereas, walking in a natural environment such as in one’s home or the community may more accurately reflect participation.

Measurement instruments are available to assess participation for people with SCI, however, to our knowledge, they have not been widely implemented as an outcome measure for exercise interventions for people with SCI. Currently available evidence indicates that outcome measures of exercise intervention for individuals with SCI are primarily targeted at body functions and body structures. Future research on the efficacy of exercise interventions on individuals with SCI should place increased emphasis on the outcome measures related to activities and participation, and attempt to include the influence of environment.

Conflict of interest

The authors declare no conflict of interest.

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SCAPULAR STABILIZATION AND MUSCLE STRENGTH IN MANUAL WHEELCHAIR USERS WITH SPINAL CORD INJURY AND SUBACROMIAL IMPINGEMENT

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ABSTRACT

Study Design: Cross-sectional cohort design **Objective:** Determine if the pattern of muscle imbalance and impaired scapular stabilization observed in shoulders of manual wheelchair users with spinal cord injury (SCI) and impingement is different from the shoulders of able-bodied (AB) adults with impingement. **Setting:** Birmingham, AL USA **Methods:** 22 adults (11 SCI, 11 AB) had their strength and muscle electrical activity measured during a single testing session. Each shoulder was identified as belonging to one of four groups: non-impingement SCI (n=8), impingement SCI (n=9), non-impingement able-bodied (n=10) and impingement able-bodied (n=10). Comparison between AB/SCI and Impingement/Non-impingement were made for the ratio of normalized muscle electrical activity of upper and lower trapezius (UT:LT) during arm abduction; force during abduction, adduction, internal rotation, external rotation, push and pull; and the ratio of force for abduction to adduction (ABD:ADD), internal to external rotation (IR:ER) and push to pull (PUSH:PULL).

Results: Shoulders with impingement (n=19) had a significantly higher UT:LT activation (1.46 ± 0.52) compared to shoulders without impingement (n=18) (0.93 ± 0.45) (p=0.006), regardless of wheelchair user status. A significant difference between AB (n=20) and SCI (n=17) was also shown for ABD:ADD (p=0.005), PUSH:PULL (p=0.012), and PULL strength (p=0.043) but not for other absolute differences in strength. Shoulders of participants with SCI had a significantly greater ABD:ADD ratio (1.37 ± 0.36) than able-bodied participants (1.04 ± 0.22) (p=0.002) and a significantly greater PUSH:PULL ratio (1.53 ± 0.36) than able-bodied participants (1.26 ± 0.18) (p=0.005) which were due to decreased strength in adduction (p = 0.021) and pull (p=0.013) in the SCI group. **Conclusions:** Rehabilitation strategies targeting the posterior shoulder girdle that are prescribed for able-bodied adults are appropriate for manual wheelchair users with SCI who have impingement. Strengthening exercises should focus on scapular retractors and arm adductors with an emphasis on scapular depression and posterior tilting to target lower trapezius strength and scapular stability.

Introduction

Shoulder pain is reported to occur in up to 83% of adults with spinal cord injury (SCI).[1] In this population, shoulder pain has been correlated with decreased quality of life, limited participation in daily activities, and decreased physical activity.[1,2] Wheelchair propulsion, transfers and other daily activities are performed exclusively with the upper body, predisposing individuals to overuse and muscle imbalance. Subacromial impingement is frequently cited as the etiology for shoulder pain after SCI.[3,4] Able-bodied (AB) adults with shoulder pain resulting from impingement demonstrate compromised scapular stabilization and altered muscle balance.[5,6] Impaired scapular stabilization is defined as increased electrical activity in the upper trapezius compared to lower trapezius during humeral elevation. Muscle imbalance is an alteration in typically observed strength ratios of muscle groups at the shoulder joint.

Alterations in muscle balance and scapular stabilization are contributing factors to impingement because of their impact on the subacromial space during humeral elevation. During humeral elevation it is necessary to have sufficient scapular posterior tilt and upward rotation to maintain sufficient subacromial space.[7] This is accomplished by coordinated activity of the upper and lower trapezius along with serratus anterior and the rotator cuff.[8] Muscle imbalance in the rotator cuff can contribute to poor centralization and increased anterior and superior translation of the humeral head during arm elevation, leading to impingement of structures in the subacromial space.[9] Observations of muscle strength and scapular stabilization in AB adults with impingement have noted three important changes: (1) Increased ratio of upper to lower trapezius EMG activation during abduction (UT:LT);[5,10] (2) increased ratio of internal rotation (IR) to external rotation

(ER) strength;[11] and (3) increased ratio of abduction (ABD) to adduction (ADD) strength.[12]

The pattern of increased UT:LT, IR:ER, and ABD:ADD has not been well examined in manual wheelchair users with SCI and impingement. Current rehabilitation practice for this population is largely based on findings from able-bodied adults with impingement, typically overhand athletes or overhead workers. Several previous studies have demonstrated improvement in shoulder pain after a strength-training program for both able-bodied adults and manual wheelchair users, however these studies lack evaluation of changes in dynamic muscle force and measures of scapular stabilization.[13-15] It is very possible that manual wheelchair users who have impingement may present with a different or exacerbated pattern of muscle imbalance and scapular stabilization, due to the demands placed on the upper extremities by daily manual wheelchair use.

Manual wheelchair users with SCI demonstrate changes in scapular position during static activities such as sitting in their wheelchair or standing in a standing frame.[16] During a transfer task, manual wheelchair users with impingement have demonstrated increased scapular anterior tilt[17] and lower trapezius activity.[18] Increased anterior tilt of the scapula has also been observed in AB adults with impingement,[6] while lower trapezius activity is often decreased in AB adults with impingement. Decreased lower trapezius activation allows for increased scapular anterior tilt, leading to a decrease in subacromial space and potential for impingement. These previous studies[6,17,18] indicate that the pattern of muscle imbalance and scapular stabilization and current treatment protocols based on findings from AB adults with impingement may not be appropriate for people with SCI because of the daily demands placed on the shoulder and observed differences in muscle activation. Due to the potential for poor surgical outcomes in SCI, it is imperative that conservative treatment protocols are optimized in this population.[19] Previous studies have focused on isolated single-joint movements and static strength measures that are not representative of the muscular demands during wheelchair propulsion; therefore, we included a novel test of closed-chain flexion and extension. This multi-joint activity may be a better indicator of complete shoulder function and be more specific to manual wheelchair use, a push-dominant activity that appears to favor increased push versus pull strength.[6,7]

The purpose of this study was to determine if the pattern of muscle imbalance and impaired scapular stabilization observed in able-bodied adults with impingement is different from manual wheelchair users with SCI who have impingement. We hypothesized that manual wheelchair users with SCI and impingement would demonstrate a pattern of muscle imbalance (increased ABD:ADD, increased IR:ER) and impaired scapular stabilization (increased UT:LT) to a greater extent than AB adults with impingement.

Materials and Methods

Design

This cohort study design tested shoulder strength and scapular stabilization during a single testing session. If a participant had one shoulder with impingement and one shoulder without impingement, both shoulders were tested. In the case of bilateral impingement, only the more painful shoulder was included in the analysis. We also included one shoulder from each of two manual wheelchair users who did not have impingement in either shoulder. Each shoulder tested was identified as belonging to one of four groups: non-impingement SCI (NI-SCI, n=8), impingement SCI (I-SCI, n=9), non-impingement able-bodied (NI-AB, n=10) and impingement able-bodied (I-AB, n=10).

Participants

Participants with (n=11) and without (n=11) SCI were recruited from our local area (Tables 1 and 2). Sample size was based on a preliminary power analysis to detect differences in UT:LT ratio with 80% power and a moderate effect size (0.5).[5,10] Inclusion criteria were: 19–65 years of age; able to raise both arms overhead; no shoulder surgery, fracture, subluxation or dislocation in the past 5 years and no known cardiovascular or pulmonary disease. Shoulders in the impingement group had at least two positive clinical tests for impingement (Neer, Hawkins-Kennedy, Empty Can); and a negative test for both labral tear (O'Brien's) and instability (Sulcus Sign).[20] Additional inclusion criteria for the SCI group were: ≥2 years post-SCI (complete or incomplete, C7 or lower); use of manual wheelchair as primary means of mobility; no current pressure ulcer greater than

Table 1: Participant characteristics

Variable	AB Group (n = 11)	SCI Group (n = 11)	*p*
Age (y)	41 ± 13 (25 - 62)	41 ± 12 (24 - 58)	0.987
Men/Women	7/4	8/3	
Height (cm)	175.7 ± 6.75 (160 - 188)	178.4 ± 10.26 (157 - 196)	0.601
Weight (kg)	83.18 ± 16.9 (54 - 116)	88.05 ± 24.51 (43 - 117)	0.663
Activity level (MET hrs/wk)	59.06 ± 27.8 (17 - 114)	42.63 ± 25.05 (4 - 84)	0.053
SPADI Score	22.13 ± 10.8 (5 - 46)	36.75 ± 21 (6 - 65)	0.069
WUSPI Score	- -	50.08 ± 31.7 (12 - 93)	
Pain Severity (out of 10)	5.8 ± 1.4 (3 - 7)	6.44 ± 2.8 (2 - 9)	0.527
Pain Duration (y)	6 ± 6 (0.5 - 20)	4.8 ± 2.6 (1.5 - 20)	0.607

NOTE. Values are mean ± SD (range) or as otherwise indicated.
Abbreviations: AB - able bodied, SCI - spinal cord injury, SPADI - shoulder pain and disability index, WUSPI - wheelchair user's shoulder pain index

grade 2. All participants completed the Shoulder Pain and Disability Index (SPADI)[21] and a 10-point visual analog scale (VAS) for pain. Participants with SCI also completed the Wheelchair Users Shoulder Pain Index (WUSPI).[22] SPADI scores range from 0 – 100, WUSPI scores range from 0 – 150. For both scales, lower scores indicate less pain and higher function. Participants also completed questionnaires regarding physical activity level, specific to able-bodied (International Physical Activity Questionnaire)[23] or SCI (Physical Activity Scale for Individuals with Physical Disabilities).[24] Both scales provide estimated MET-hr/week of activity.

Table 2: SCI Group Description

ID	Injury Level	AIS	Years Since Injury
SCI01	T6	A	31
SCI02	T8	B	36
SCI03	T12	C	25
SCI04	T7	B	7
SCI05	T7	C	3
SCI06	C7	A	11
SCI07	T10	B	23
SCI08	C7	A	5
SCI09	T4	B	13
SCI10	T7	A	20
SCI11	T3	A	24

AIS: ASIA Impairment Scale

Instrumentation

Isokinetic strength and muscle activity of upper and lower trapezius were collected using an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) integrated with surface EMG (ADinstruments, Inc., Colorado Springs, CO). Bipolar surface electrodes were placed over the muscle belly, in line with the fibers of the upper and lower trapezius (Figure 1). A reference electrode was placed over the clavicle. Signals were amplified with a differential amplifier (ADinstruments, Inc., Colorado Springs, CO) with a high input impedance (>15Ω at 100 Hz), a common mode rejection ratio of 85 dB at 60 Hz, and a bandwidth (-3 dB) of 20 to 2,000 Hz. Root mean square

(RMS)-processed signals were collected in real time with a sampling rate of 2000 Hz using a 16-bit A/D board (ADinstruments, Inc., Colorado Springs, CO). In pilot testing our test/retest reliability was consistently greater than 0.9.

Figure 1: a) determination of upper trapezius electrode placement; b) determination of lower trapezius electrode placement; c) upper and lower trapezius electrode set-up (ground electrode over clavicle not pictured)

Testing Procedure

All testing was performed in the laboratory and took approximately 90 minutes to complete. Prior to testing, participants performed a short warm-up, consisting of wall push-ups, arms-only jumping jacks, and repetitions of maximal horizontal flexion and extension. Participants were then positioned on the dynamometer and resting level of electrical activity of the upper and lower trapezius was recorded. EMG signal quality was then verified and maximal electrical activity was determined by having the participant perform maximal voluntary isometric contractions (MVIC) against a stationary lever arm for each muscle group.

For the LT muscle, the attachment was positioned diagonally overhead in 160 degrees of forward flexion and 145 degrees of abduction. Participants were instructed to keep their elbow straight while applying a backward force on the attachment as if they were winding up to throw a ball. For the UT muscle, the attachment was positioned at 90 degrees of arm abduction and 5 degrees of horizontal flexion. Participants were instructed to keep their elbow straight while applying an upward force as if they were going to perform a jumping jack. Participants performed three 5-s maximum voluntary isometric muscle contractions against the attachment while receiving encouragement from the principle investigator. A 15 – s pause occurred between each contraction. EMG data collected during the MVICs were used to create a normalization reference for each participant. After signal filtering, the average RMS value for the middle 3 seconds of each contraction were averaged to determine the normalization value for each muscle group.

Figure 2: a) Abduction/adduction test set-up; b) internal/external rotation set-up; c) push/pull set-up

Isokinetic testing consisted of three protocols (Table 3): abduction (ABD) and adduction (ADD) in the frontal plane (Figure 2a), internal (IR) and external rotation (ER) in the scapular plane (Figure 2b) and closed chain flexion (push) and closed chain extension (pull) in the sagittal plane at waist level (Figure 2c). We included the novel test of closed-chain flexion and extension for two reasons; 1) a multi-joint activity may better indicate function of the entire shoulder girdle than isolated single-joint movements, and 2) manual wheelchair use is a chest-dominant activity that would logically favor increased push versus pull strength, however this hypothesis has not been tested previously.

After setting the range of motion limits for each test, participants were familiarized with the motion and speed, and were instructed to stop testing if the motion was too painful. For all tests, participants were stabilized with a lap belt, footrest and belt across the contralateral shoulder. After familiarization repetitions, gravity correction was performed with the arm in a relaxed position. Participants then performed 5 maximal repetitions at 60 degrees/s with verbal encouragement from the PI and study staff. During the maximal isokinetic movements, EMG data from the two trapezius parts were collected synchronously with the arm movement.

Isokinetic dynamometry signal processing

Raw isokinetic dynamometer signals were analog/digital converted (16-bit resolution) at 2000 Hz. Signals were converted to force, position and velocity following standardized calibrations. Range of motion markers were automatically generated to define 60–120 degrees of ABD/ADD, 0–20 degrees of IR/ER, and 5–15 cm of push/pull.

Table 3: Test Position Descriptions

Test	**Seat Back**	**Arm Position**	**Dynamometer Position**	**Movement**
Abduction/Adduction	75°	Scapular Plane 0° elbow flexion	10° tilt Aligned with posterior acromion	30° - 150° abduction
Internal/External Rotation	85°	45° abduction 30° forward flexion 90° elbow flexion	50° tilt Aligned with olecranon process	10° IR to 75° ER
Push/Pull	85°	90° supination (thumb up) Hand below shoulder 0° abduction	0° tilt Aligned with elbow when hand is in the lap	0 - 30 cm push

EMG signal processing

Raw EMG signals were analog/digital converted (16-bit resolution) at 2000 Hz, and were low and high-pass filtered. A 35ms moving average was used to smooth the signal. The average RMS values over 60–120 degrees of arm abduction were averaged across the five repetitions. The mean amplitude EMG signal, expressed as a percentage of MVIC was used to assess the activity of the two trapezius parts during arm abduction.

Statistical analysis

Means, standard deviations, and ranges were calculated for the dependent variables: ratio of normalized muscle activity of UT and LT (UT:LT) during arm abduction; average force during specified periods of abduction, adduction, internal rotation, external rotation, push and pull; ratio of force for abduction to adduction (ABD:ADD), internal to external rotation (IR:ER) and push to pull (PUSH:PULL).

Each shoulder tested was assigned to one of four groups; non-impingement SCI (NI-SCI, n=8), impingement SCI (I-SCI, n=9), non-impingement able-bodied (NI-AB, n=10) and impingement able-bodied (I-AB, n=10). If a participant had bilateral shoulder impingement, only their more painful shoulder was included in the analysis. Three participants in the SCI group had signs of bilateral impingement so we added two additional people with SCI who did not have impingement in an effort to have sufficient sample for analyses in the NI-SCI group. One AB participant had bilateral impingement and one I-AB shoulder was unable to produce sufficient force to register on the dynamometer and was not included in the analysis.

The primary interest was the interaction between impingement and SCI/AB. We first analyzed the data using 2-way MANOVA including independent variables:

Impingement x SCI/AB, and dependent variables: ratio of normalized muscle activity of UT and LT (UT:LT) during arm abduction; average force during specified periods of abduction, adduction, internal rotation, external rotation, push and pull; ratio of force for abduction to adduction (ABD:ADD), internal to external rotation (IR:ER) and push to pull (PUSH:PULL). The Impingement x SCI/AB interaction was not significant in the 2-way MANOVA model ($F(10,24) = 0.33$, $p=0.96$) therefore the model was re-fit using a multivariate general linear model (GLM) to determine the influence of the main effects (SCI/AB and Impingement/Non-impingement) on the dependent variables. There were no significant correlations between dominant and non-dominant sides for any of the dependent variables, therefore hand dominance was not included in the model.

Groups were similar for height, weight and age; no adjustments were made in the analyses for these variables. Using the single-item VAS and SPADI for level of pain, groups were similar ($p>0.05$), therefore pain level was not considered a confounding variable. The SCI group performed less physical activity than AB group, however the difference was not statistically significant ($p = 0.053$) and not adjusted for in the analysis. Statistical analyses were performed with SPSS, version 21.0.

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Results

Scapular stabilization during maximal isokinetic shoulder abduction

Descriptive results of EMG and isokinetic force data for all motions are summarized in Table 4. The The multivariate GLM model containing SCI/AB and

Impingement/Non-impingement showed a significant difference for UT:LT activity during maximal isokinetic shoulder abduction (p=0.019, Table 4). Post hoc analysis revealed

Table 4: Scapular stabilization and muscle torque by group

Variable	Group			
	I-SCI	I-AB	NI-SCI	NI-AB
UT:LT*	1.5 (0.58)	1.48 (0.44)	0.85 (0.32)	1.04 (0.51)
Abduction (Nm)	46.57 (12.86)	48.58 (16.62)	48.49 (15.52)	47.69 (17.75)
Adduction (Nm)	32.97 (8.88)	46.66 (19.93)	40.41 (16.31)	50.7 (21.25)
ABD:ADD*	1.43 (0.29)	1.11 (0.24)	1.29 (0.43)	0.96 (0.18)
Internal Rotation (Nm)	30.23 (13.22)	33.4 (14.99)	40.41 (16.31)	31.52 (15.41)
External Rotation (Nm)	27.72 (6.64)	28.34 (9.97)	27.91 (11.45)	27.3 (9.77)
IR:ER	1.06 (0.37)	1.17 (0.27)	1.25 (0.32)	1.13 (0.29)
Push (Kg)	36.61 (13.74)	47.34 (22.08)	39.76 (13.01)	45.45 (23.37)
Pull (Kg)*	24.34 (7.25)	39.01 (17.66)	26.17 (9.44)	36.78 (19.72)
PUSH:PULL*	1.49 (0.36)	1.21 (0.13)	1.57 (0.38)	1.3 (0.22)

NOTE. Values are mean (SD).
*Significant difference (p < 0.05)

Abbreviations: AB - Able bodied, ABD - abduction, ADD - adduction, ER - external rotation, I-impingement, IR - internal rotation, LT - lower trapezius, NI- Non-Impingement, SCI - spinal cord injury, UT - upper trapezius

that shoulders with impingement, regardless of SCI/AB status, had significantly higher UT:LT (1.46 ± 0.52) compared with non-impingement shoulders (0.93 ± 0.45) (p=0.006, Figure 3). There was no significant difference in the ratio between SCI and AB groups (p=0.62, Figure 3).

Muscle imbalance during maximal isokinetic movements

The multivariate GLM model containing SCI/AB and Impingement/Non-impingement showed a statistically significant difference for the ratio of ABD:ADD force (p = 0.005) PUSH:PULL force (p = 0.012), and absolute PULL force (p = 0.043) but not for rotation or any other absolute differences in strength (Table 4). Post hoc tests revealed that shoulders of participants with SCI had a significantly greater ABD:ADD ratio (1.37 ± 0.36) than AB participants (1.04 ± 0.22) (p = 0.002, Figure 3) and significantly greater PUSH:PULL ratio (1.53 ± 0.36) than AB participants (1.26 ± 0.18) (p = 0.005, Figure 3). Post-hoc analysis revealed that these differences were due to decreased strength in adduction (p = 0.021) and pull (p = 0.013) in the SCI group (Figure 4).

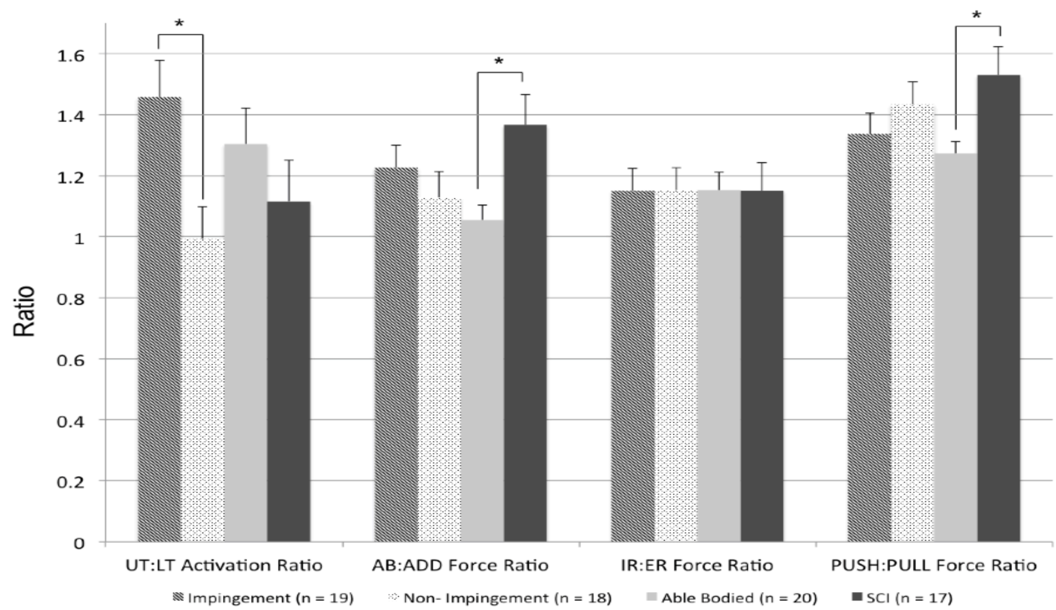

Figure 3: Main effects for impingement/non-impingement, able-bodied/spinal cord injury for all ratio variables (EMG and muscle torque) *Indicates significant group differences p< 0.05

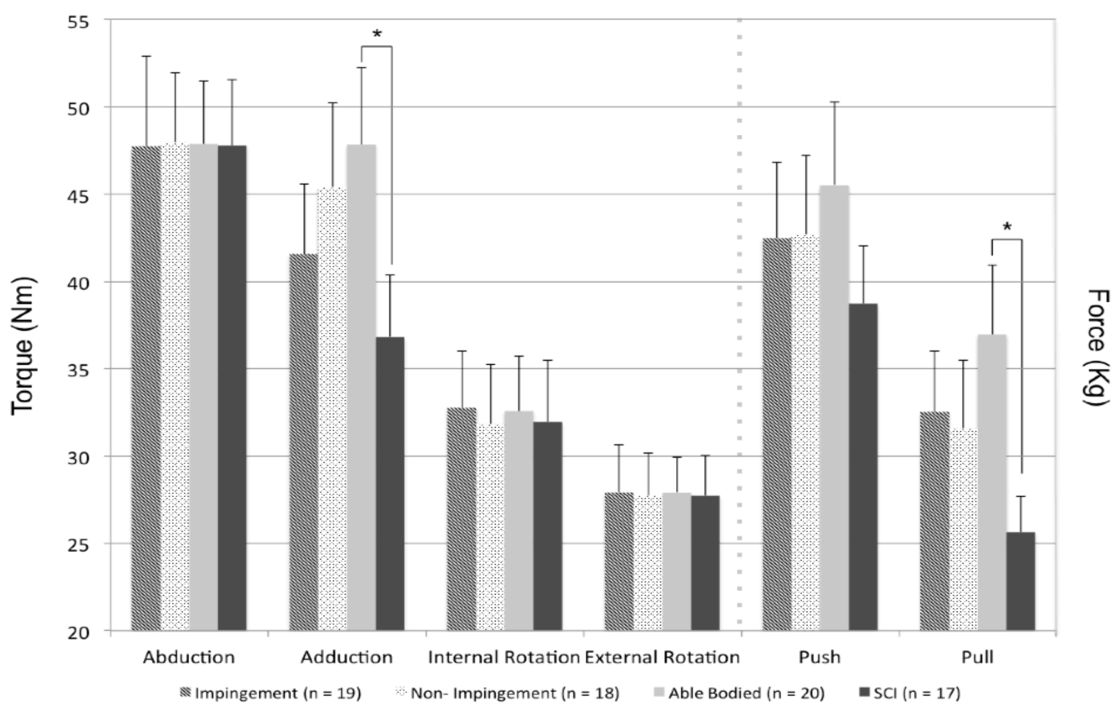

Figure 4: Main effects for impingement/non-impingement, able-bodied/spinal cord injury for all strength variables. *Indicates significant group differences p< 0.05

Discussion

Current physical therapy practice for impingement in manual wheelchair users with SCI is based on findings from AB adults, typically overhead athletes or workers. Understanding how muscle imbalance and scapular stabilization may differ in this population offers clinicians new insight into the treatment and prevention of shoulder pain in manual wheelchair users with SCI. Several important observations are made concerning scapular stabilization and muscle imbalance for manual wheelchair users with SCI and impingement. First; poor scapular stabilization (increased UT:LT) during arm abduction occurs in shoulders with impingement and is not greater in shoulders of manual wheelchair users with SCI who have impingement. Second, manual wheelchair users with SCI demonstrate an altered muscle balance (decreased strength in adduction and pulling) compared to able-bodied adults, and this difference is not amplified for those with impingement and SCI. Finally, no differences existed in rotational strength between SCI/AB or impingement/non-impingement.

Manual wheelchair users with SCI who have impingement have an increased UT:LT activity during maximal isokinetic arm abduction. These results are similar to AB adults in previous studies and our cohort.[5] The combined actions of upper and lower trapezius during arm abduction normally cause upward rotation and posterior tilting of the scapula in order to maintain subacromial height.[7] When there is an alteration in the function of these muscles, scapular stabilization is compromised, potentially leading to decreased subacromial space and impingement of the subacromial structures. We observed that muscle dysfunction in the trapezius occurs similarly for manual wheelchair users with SCI who have impingement and able-bodied adults with impingement. These results suggest that the altered muscle activity is related to the shoulder pathology, regardless of the type of repetitive activity being performed (overhead activities vs. wheelchair use).

In our evaluation of muscle balance (strength ratios of opposing motions) we found that manual wheelchair users with SCI have an increased ABD:ADD strength ratio. The increased strength ratio (ABD:ADD) is in agreement with previous groups who have observed decreased adduction strength in manual wheelchair users with shoulder pain.[25] Our results indicate that the increased ratios result primarily from decreased adduction strength in the SCI group. We did not observe any differences in the absolute force for rotational movements, or in the ratio of internal to external rotation strength (see Table 4). The rotator cuff is often cited as a causative factor for shoulder pain and impingement because of its role in humeral head centralization.[9] Our results showed greater differences in the larger surrounding muscles.

Wheelchair propulsion is a push-dominant activity, with forward flexion comprising the majority of the movement at the shoulder joint.[26] Previous EMG studies show that the pectoral muscles are a major contributor to the push phase of wheelchair propulsion, without subsequent contraction in the posterior shoulder girdle.[27] This is an important observation because other labs have noted that tightness in the pectoral muscles increases the likelihood for kinematic changes in the scapula, predisposing individuals to shoulder dysfunction.[7] Prolonged wheelchair propulsion, along with weight relief maneuvers and wheelchair transfers, may create an imbalance between push/pull strength in manual wheelchair users with SCI; which had not been evaluated previously. We found an increased ratio of push to pull force for the SCI group, indicating that they are more susceptible to shoulder dysfunction and may benefit from prophylactic strengthening of the posterior shoulder muscles.

Adduction strength was also significantly lower in the group with SCI. The combination of decreased pull strength, adduction strength, and lower trapezius activity, reveals that manual wheelchair users with SCI, specifically those with impingement, lack strength in the posterior shoulder girdle. Previous studies have shown that targeted strengthening activities for the posterior shoulder muscles are effective to improve both pain and scapular stabilization.[28] Based on our findings, rehabilitation prescriptions that focus on scapular stabilization and posterior shoulder strength are appropriate for the SCI population in the same manner as what is typically done with able-bodied adults.

We did not observe any differences in rotational strength for manual wheelchair users, indicating that it may be of lesser importance to target rotator cuff strengthening in this population. Manual wheelchair users are predisposed to weakness in the posterior shoulder girdle, potentially resulting from the push-dominant activities of wheelchair use.[26] This is important for rehabilitation professionals to note because preventative activities that strengthen the posterior shoulder girdle may help to avoid shoulder impingement.

Limitations and Implications for Future Study

Our study utilized a sample of convenience, although we did have a range of injury levels, we did not have a sufficient sample to stratify the group by functional level. Future work is warranted to evaluate the effects of injury level on scapular stabilization, in particular the contribution of trunk stability or seated posture. Future study is warranted into the contribution of rotator cuff strength on impingement as we did not observe any differences between shoulders with or without impingement. While protocols including rotator cuff strengthening have improved pain secondary to impingement, the mechanism for their effectiveness may not be uniquely dependent on increased strength of the cuff. Our work utilized a controlled dynamic evaluation of muscle strength and scapular stabilization. Going forward, it may be beneficial to evaluate these differences during other dynamic tasks such as pressure relief and transfers.

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EFFECTIVENESS OF FES-ASSISTED ROWING TO IMPROVE AEROBIC FITNESS AND SHOULDER PAIN IN MANUAL WHEELCHAIR USERS WITH SPINAL CORD INJURY.

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ABSTRACT

Objective: Test the effectiveness of a 6-week functional electrical stimulation (FES)-assisted rowing intervention to increase aerobic fitness and decrease shoulder pain in manual wheelchair users with spinal cord injury (SCI). **Design:** One group pre-test, post-test. **Setting:** Human performance laboratory. **Participants:** 10 adults with SCI (47±12 years, 86±19.7 kg, 175.5±13.2 cm) 18±14 years since injury, ASIA classification A-C who had pain in one or both shoulders for > 6 months. **Intervention:** 30 minutes of FES-assisted rowing, 3 days/week x 6 weeks. **Outcome Measures:** VO_2 peak (FES-row and arm bike), distance rowed, arm power output, Wheelchair User Shoulder Pain Index (WUSPI), Upper extremity isokinetic strength, scapular stabilization, Participation (LIFE-H), Quality of Life (QOL-SCI), qualitative exit interview. **Results:** Increased distance rowed by 257±266 m, increased arm power output by 6.7±7.9 W, 8% increase in VO^2 peak, 10.5±4.4 point decrease in shoulder pain ($p<0.05$). No change in upper extremity strength, scapular stabilization, participation or quality of life. Qualitative interviewing indicated overall enjoyment of the intervention. **Conclusions:** FES-assisted rowing is effective to improve aerobic fitness and shoulder pain in manual wheelchair users with SCI. Further research is necessary to determine the causative factor for improvement in shoulder pain, as we did not observe any changes in upper extremity strength or scapular stabilization.

Introduction

Physical activity is an important component of health and quality of life. Adults with spinal cord injury (SCI) typically report low levels of physical activity and subsequently have poor aerobic fitness.[1] In addition to poor aerobic fitness, shoulder pain is reported to occur in up to 83% of adults with SCI and may impact their ability to engage in routine physical activity.[2] Low aerobic fitness levels and increased shoulder pain are significantly correlated with early death from cardiovascular disease, decreased quality of life and declining participation in daily activities within this population. [2-4]

Currently, upper-body cycling and wheelchair pushing are frequently prescribed to improve aerobic fitness in adults with SCI,[5,6] and targeted shoulder strengthening exercises are used to improve shoulder pain.[7] Despite the effectiveness of these interventions, two problems persist. First, exercise intensity during upper-body cycling is relatively low and does not address the problem of shoulder pain and may aggravate the condition. Second, targeted shoulder strengthening exercises will not increase aerobic fitness. Therefore, it would be beneficial to identify a mode of exercise that could yield moderate to high exercise intensity while targeting less used upper extremity musculature in an effort to improve aerobic capacity and reduce strain on the shoulders.

Previous investigators have shown that hybrid exercise, exercise using voluntary upper extremity motion in combination with electrically-stimulated paralyzed muscles, can induce an increased exercise intensity and more favorable aerobic response than upper extremity exercise alone.[8,9] There is also evidence that resistance training programs that target posterior shoulder muscle strengthening and anterior shoulder muscle stretching is effective at reducing shoulder pain.[7,10-12] Improvement in shoulder pain from programs targeting posterior muscle strength may be effective in SCI because they strengthen the posterior shoulder muscles which have been shown to be significantly weaker in manual wheelchair users with SCI.[13,14] FES-assisted rowing is a promising mode of exercise in this population because it 1) utilizes both upper and lower extremities, 2) is better tolerated than other forms of hybrid exercise and 3) provides repeated activation of the posterior shoulder muscles that are not typically used during wheelchair propulsion.[15,16]

Previous investigations into the effectiveness of FES-assisted rowing have shown a significant improvement in upper extremity muscle strength, body composition and aerobic fitness.[17-19] Most FES-assisted rowing machines require the participant to have a significant baseline level of lower extremity muscle strength and endurance prior to the initiation of FES-row training. Low levels of strength and endurance in the lower extremities can limit the duration and intensity of FES-rowing because the force created by the pulling action of the arms must be counteracted by force through the lower extremities in current models.

The purpose of this study was to investigate the efficacy of a six-week FES-assisted rowing intervention using an innovative FES-assisted rowing device to improve aerobic fitness and shoulder pain in manual wheelchair users with SCI and its subsequent impact on quality of life and participation in daily activities.

Methods

Study Design and Participants

10 adults with SCI (2 female) with paraplegia (American Spinal Injury Association class A-C, T4 – T12) completed the pre-post test design study. Mean age was 47.2±18.3 years and mean time since injury was 18.2±14.3 years. All participants used a

manual wheelchair as their primary means of mobility and had pain in one or both shoulders. Eight of the ten participants had at least two positive clinical tests for subacromial impingement (Neer, Hawkins-Kennedy or empty can) in their painful shoulder. Participants had no clinical signs of joint instability (sulcus sign) and/or labral tear (O'Brien's),[20] and were able to raise both arms overhead. Participants were not included if they had shoulder surgery, fracture, subluxation or dislocation in the past year, and if they had a known cardiovascular or pulmonary disease or pressure ulcer greater than grade 2.

FES-Assisted Rowing Device

<u>Rower</u>

The Concept 2 Dynamic Indoor Rower was adapted to incorporate FES-assisted knee extension and flexion. Previous Concept 2 rower models that have been used in FES-assisted rowing applications have a static footplate and a dynamic seat moving in accordance with the rowing motion. This configuration requires the person rowing to have sufficient leg strength to push against the footplate and propel their body backwards along the seat track, and then maintain knee extension through the final pull of the arms. The Concept 2 Dynamic model rower has a static seat and a dynamic footplate. In its original design, the footplate and handle provide opposing forces to allow both arm and leg contribution to drive the flywheel of the rower. In our pilot testing, we found that this coupling provides too much resistance for the leg extension movement and hinders FES-assisted rowing intensity for most people with SCI who are not currently engaged in NMES exercise of the lower extremities. In order to accommodate the participants, we disengaged the ergometer's flywheel from the driveline allowing the legs to minimally move against the force of gravity. This removed the need for remedial strength training prior to the initiation of FES-row training, and allows for maximal upper-extremity force production during FES-assisted rowing.

Seating and support solutions

Additional items implemented for seated stability on Concept 2 Dynamic rower included addition of leg supports and an adapted rowing seat. Elastic bands of variable resistance were attached between the seat and the footplate in order to progressively increase the resistance being applied during leg extension and to assist in knee flexion. Additionally, high-tension springs were connected from the seat back to the leg support. These springs acted in the same manner as the hip flexors during able-bodied rowing and assisted with returning the footplate to the start position. (Figure 1A)

Electrical Stimulation

Electrical stimulation was delivered by two electrical stimulators (Medtronic, Respond II) through eight surface electrodes, two to each muscle group (quadriceps and hamstrings) and could be adjusted between 0 and 100 mA. In order to alternate the stimulation between the hamstrings and the quadriceps a circuit was created between two single-pole double-throw (SPDT) pushbutton switches and two 2.5 mm mono audio connectors for electrical stimulator control. The circuit allowed for the current to alternate between quadriceps and hamstrings as appropriate. A double-pole, double-throw (DPDT) toggle switch was located between the pushbutton switches, allowing for easier setup of the FES rower (Figure 1B). To control the circuit, two SPDT switches were placed along the footplate track of the ergometer. When the legs and the footplate are at maximum flexion or extension, the footplate contacts a switch and the current alternates from one muscle group to the other, reversing the direction of leg movement.

Two brackets were manufactured to position the pushbutton switches onto the Concept 2 Dynamic rower and were required to remain adjustable in order to accommodate individuals of different heights. An upper steel L-bracket mounted the switches and a lower aluminum bar, in combination with two eye bolts for each bracket which locked the switches in place along the footplate track. Non-identical brackets were created due to different sizing constraints on the front and rear of the rower (Figure 1C).

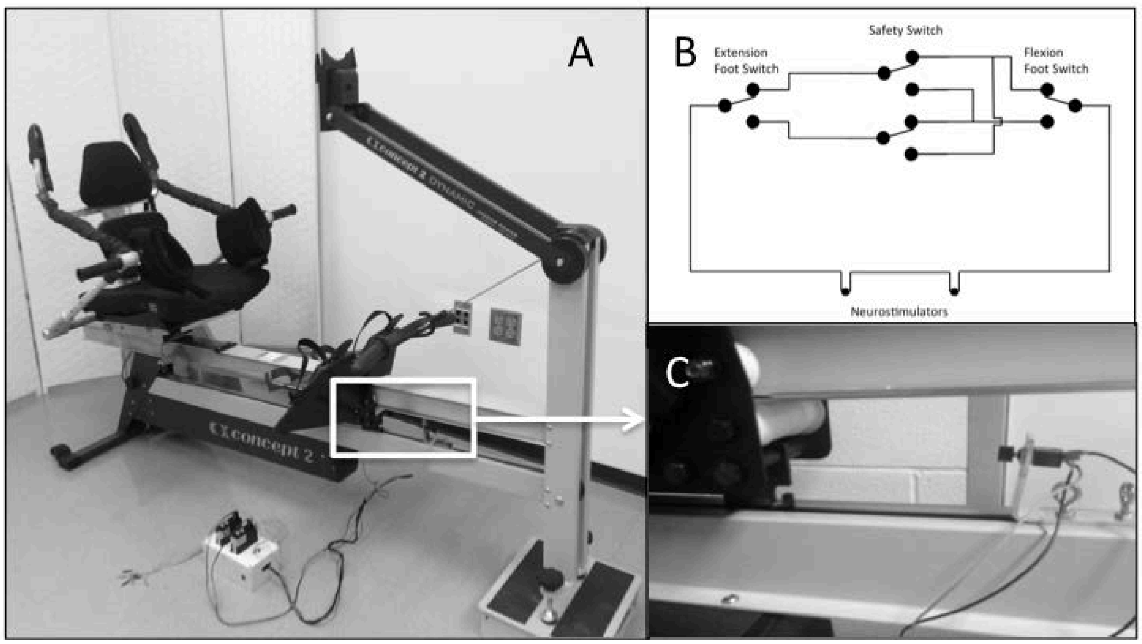

Figure 1: FES-Assisted rowing device

Exercise Program

Participants were familiarized with the FES-assisted rowing machine prior to the first training session in order to ensure participants could tolerate the activity. If the force of the electrically stimulated muscle contraction was not sufficient to extend and flex the legs, the footplate motion was assisted by the investigators. Participants trained with the FES-assisted rower three days per week for 6 weeks (18 total sessions). During each session participants were required to accumulate a total of 30 minutes of FES-assisted rowing. The majority of participants performed 10, 3-minute intervals with one minute rest in between intervals, in addition to warm-up and cool-down. During each session, participants transferred onto the ergometer and were secured with a lap belt and chest strap. The switches were adjusted along the track of the footplate to the point of full knee extension and maximal knee flexion. Participants rowed at a self-selected stroke rate. While rowing, participants were instructed to monitor their power output (W), which was displayed on the ergometer monitor. Prior to each session, participants were informed of their average power output from the previous session, and were instructed to match or exceed the power output for that day's exercise. Heart rate was monitored during activity using a heart rate monitor (Garmin) synced to the ergometer monitor display.

Pre and Post-testing Protocols

Aerobic Fitness

Peak oxygen consumption was assessed using a graded exercise test on an upper body ergometer (UBE) and during FES-row training sessions. For both tests, metabolic measures were taken using an open circuit spirometry metabolic cart (Parvo). For the UBE protocol, participants performed arm ergometry at 60 revolutions per minute with increasing resistance every minute until 3 of 5 criteria for maximal oxygen consumption were met (>85% age predicted HR max, RPE $\geq$ 17, RER $\geq$ 1.1, plateau in oxygen consumption, volitional fatigue).[21] Total testing time was 8 to 12 minutes. For the FES-row test, participants performed the last 2 intervals of their 3rd and 18th training sessions while expired gasses were collected.

Body Composition

Body composition was analyzed pre and post training using DXA (GE Lunar). Total body bone mineral density (BMD) and body composition were measured, along with changes in thigh lean mass, which was defined as a hexagon with points at lateral aspect of the greater trochanters and lateral aspects of the tibial plateaus. Weight was measured pre and post training using a standard wheelchair scale.

Upper Body Strength and Scapular Stabilization

Isokinetic strength and scapular stabilization (muscle activity of upper and lower trapezius) were collected using an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) integrated with surface EMG (ADinstruments, Inc., Colorado Springs, CO). Bipolar surface electrodes were placed over the muscle belly, in line with the fibers of the upper and lower trapezius. A reference electrode was placed over the clavicle. Signals were amplified with a differential amplifier (ADinstruments, Inc., Colorado Springs, CO) with a high input impedance (>15Ω at 100 Hz), a common mode rejection ratio of 85 dB at 60 Hz, and a bandwidth (-3 dB) of 20 to 2,000 Hz. Root mean square (RMS)-processed signals were collected in real time with a sampling rate of 2000 Hz using a 16-bit A/D board (ADinstruments, Inc., Colorado Springs, CO). In pilot testing our test/retest reliability was consistently greater than 0.9.

Participants were positioned on the dynamometer and resting level of electrical activity of the upper and lower trapezius was recorded. EMG signal quality was then verified and maximal electrical activity was determined by having the participant perform maximal voluntary isometric contractions (MVIC) against a stationary lever arm for each muscle group.

For the LT muscle, the attachment was positioned diagonally overhead in 160 degrees of forward flexion and 145 degrees of abduction. Participants were instructed to keep their elbow straight while applying a backward force on the attachment as if they were winding up to throw a ball. For the UT muscle, the attachment was positioned at 90 degrees of arm abduction and 5 degrees of horizontal flexion. Participants were instructed to keep their elbow straight while applying an upward force as if they were going to perform a jumping jack. Participants performed three 5sec maximum voluntary isometric muscle contractions against the attachment while receiving encouragement from the principle investigator. A 15sec pause occurred between each contraction. EMG data collected during the MVICs were used to create a normalization reference for each participant. After signal filtering, the average RMS value for the middle 3 seconds of each contraction were averaged to determine the normalization value for each muscle group.

Table 1: Upper Extremity Strength Testing

Test	**Seat Back**	**Arm Position**	**Dynamometer Position**	**Movement**
Abduction/ Adduction	75°	Scapular Plane 0° elbow flexion	10° tilt Aligned with posterior acromion	30° - 150° abduction
Internal/ External Rotation	85°	45° abduction 30° forward flexion 90° elbow flexion	50° tilt Aligned with olecranon process	10° IR to 75° ER
Push/Pull	85°	90° supination (thumb up) Hand below shoulder 0° abduction	0° tilt Aligned with elbow when hand is in the lap	0 - 30 cm push

Isokinetic testing consisted of three protocols (Table 1): abduction (ABD) and adduction (ADD) in the frontal plane internal (IR) and external rotation (ER) in the scapular plane and closed chain flexion (push) and closed chain extension (pull) in the sagittal plane at waist level. We included the novel test of closed-chain flexion and extension for two reasons; 1) a multi-joint activity may better indicate function of the entire shoulder girdle than isolated single-joint movements, and 2) manual wheelchair use is a chest-dominant activity that would logically favor increased push versus pull strength, however this hypothesis has not been tested previously.

After setting the range of motion limits for each test, participants were familiarized with the motion and speed, and were instructed to stop testing if the motion was too painful. For all tests, participants were stabilized with a lap belt, footrest and belt across the contralateral shoulder. After familiarization repetitions, gravity correction was performed with the arm in a relaxed position. Participants then performed 5 maximal repetitions at 60 degrees/s with verbal encouragement from the PI and study staff. During the maximal isokinetic movements, EMG data from the two trapezius parts were collected synchronously with the arm movement.

Raw isokinetic dynamometer signals were analog/digital converted (16-bit resolution) at 2000 Hz. Signals were converted to force, position and velocity following standardized calibrations. Range of motion markers were automatically generated to define 60–120 degrees of ABD/ADD, 0–20 degrees of IR/ER, and 5–15 cm of push/pull.

Raw EMG signals were analog/digital converted (16-bit resolution) at 2000 Hz, and were low and high-pass filtered. A 35ms moving average was used to smooth the signal. The average RMS values over 60–120 degrees of arm abduction were averaged across the five repetitions. The mean amplitude EMG signal, expressed as a percentage of MVIC was used to assess the activity of the two trapezius parts during arm abduction.

Shoulder Pain

Shoulder pain was assessed using the Wheelchair User's Shoulder Pain Index (WUSPI). The WUSPI is a reliable, validated measure of shoulder pain specific to manual wheelchair users. The 15 item survey asks participants to indicate how much pain they have experienced doing each task in the past seven days. The score ranges from 0 – 150, with lower scores indicated less pain and higher function.[22]

Participation and Quality of Life

Participation was assessed using the Assessment of Life Habits survey (LIFE-H). The LIFE-H is a validated measure specific to adults with physical disabilities.[23] The survey consists of 77 items addressing participation with measures of how much difficulty the person has, and how much and what type of assistance is needed to perform the activity. The LIFE-H addresses the majority of relevant Activities and Participation constructs from the International Classification of Function, Disability and Health.[24,25]

Quality of life was assessed using the Quality of Life Index, spinal cord injury version (QOL-SCI). The QOL-SCI is a 37 item survey that asks participants to rate first how satisfied they are with an aspect of daily living, and then to rate how important that aspect is to them. The QOL-SCI has shown excellent internal consistency and concurrent validity.[26-28]

Qualitative Feedback

At the conclusion of FES-row training and after post-testing, participants had the option to participate in a qualitative interview about their experience with the study. Open-ended questions were asked during an in-person interview while the PI took detailed notes. Participants provided feedback about how they felt the study affected their pain, health, quality of life and energy level. They were also asked to identify their most and least favorite parts of participating in the study and how they might utilize the FES-assisted rowing machine if it was available in a fitness center.

Data Analysis

Data were first analyzed to determine if a difference existed between the pre- and post-test values (paired t-test, $\alpha = 0.05$). If a difference existed, then linear regression was used to determine if other variables significantly predicted these changes. All analyses were performed using SPSS version 22 (SPSS Inc., Chicago, IL, USA).

Results

Ten participants completed 18 training sessions within the 6-week time frame. Participant characteristics are presented in Table 2. Participants' average heart rate (HR) during training was 86.1 ± 7.8% of max HR achieved during the graded exercise test and 76.7 ± 9.4% of age-predicted max HR.

Table 2: Participant Demographics

Participant	Sex	Years since injury	Lesion level	ASIA score
1	M	3	T7	C
2	F	24	T10	A
3	M	6	T7	B
4	F	2	T7	B
5	M	11	T7	A
6	M	21	T7	A
7	M	32	T12	A
8	M	37	T12	C
9	M	39	T5	A
10	M	6.5	T4	C

Participants significantly increased their distance rowed from 4054 ± 815 to 4312 ± 869m ($p=0.014$), and rowing power output from 36.1 ± 19.0 W to 42.8 ± 24.7 W ($p=0.026$). Changes in aerobic fitness

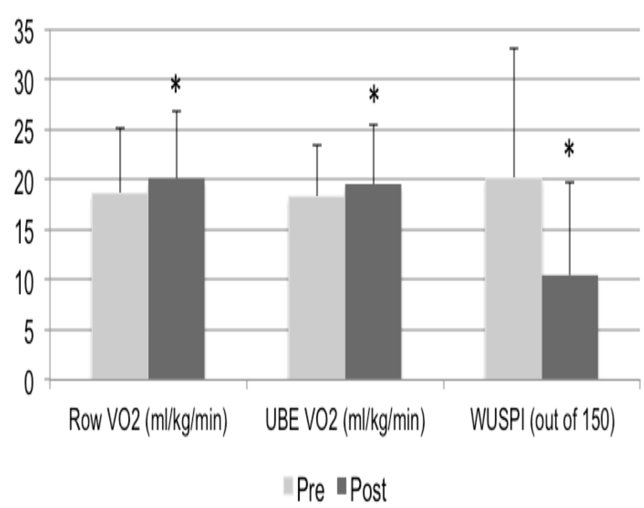

Figure 2: Pre-post changes in aerobic fitness and shoulder pain. *Indicates significant pre-post differences p<0.05)

and shoulder pain are shown in Figure 2. VO_2 peak for the FES-Row condition increased by 8.1% (p=0.034) and also increased by 7.1% in the UBE graded exercise test (p=0.024). Shoulder pain in the participant identified more painful shoulder decreased by 47.8% (p=0.002). There were no significant changes in body composition (p=0.638), body weight (p=0.18), thigh lean mass (p=0.11), quality of life (p=0.96), or participation (p=0.74) (Table 3).

Table 3: Changes in body composition, Quality of Life and Participation

	QOL-SCI		LIFE-H		Body Mass (Kg)		% Body Fat		Thigh Lean Mass (Kg)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Mean	11.1	12.2	7.8	7.7	85.1	85.1	36.9	36.7	11.9	11.6
SD	4.3	7.1	2.6	2.6	19.6	19.6	5.9	6.2	4.1	4.2

Table 4 shows the changes in upper body strength and muscle activation. There was a significant increase in dominant internal rotation strength from 37.3 ± 15.1 to 41.6 ± 18.3, however there were no other significant changes in upper extremity strength or muscle activity (p > 0.05).

Table 4: Strength Changes

	More Painful Pre		More Painful Post	
	Mean	***SD***	**Mean**	***SD***
UT:LT	1.6	*0.7*	1.4	*0.5*
ABD (Nm)	46.5	*16.1*	45.9	*18.9*
ADD (Nm)	45.1	*27.3*	44.3	*21.8*
IR (Nm)	38.2	*16.3*	38.2	*18*
ER (Nm)	28.2	*8.7*	28.0	*9.0*
PUSH (Kg)	55.7	*22.2*	55.9	*25.4*
PULL (Kg)	41.3	*12.7*	39.5	*11.7*

There was a significant correlation between change in power output and change in VO_2, both for the FES-Row condition (r = 0.62, p = 0.049) and UBE graded exercise test (r = 0.58, p = 0.041).

Discussion

Our results demonstrate that a six-week FES-assisted rowing intervention can improve aerobic fitness and decrease shoulder pain in manual wheelchair users with SCI. FES-assisted rowing on our device improved oxygen consumption both during the rowing activity and on the UBE graded exercise test. These results are consistent with oxygen consumption values reported for hybrid training[9,29] and for relative changes in peak VO_2.[18,19,30] Linear regression indicated that those participants who had greater improvements in power output had a significantly greater increase in VO_2 peak. We found no significant change in body composition, body weight or thigh lean mass. When considering the length of our intervention (6 weeks), it is not that surprising despite the fact that others have reported some favorable improvements in body composition measured via bioelectrical impedance analysis (decreased fat mass, increased lean mass) and a non-significant improvement in VO_2 peak as measured by UBE graded exercise test.[17] Lower extremity FES-assisted resistance training interventions have shown increases in thigh lean mass with short training interventions, suggesting that it may be necessary to perform isolated progressive resistance training if increases in thigh lean mass are desired.[31-33]

The FES-assisted rowing machine developed by our lab utilizes the Concept 2 Dynamic Indoor Rower, which allowed us to separate the movement of the legs from the force created by the arms. This allowed for participants who have very low electrically stimulated force output in their legs to begin rowing without the need for any remedial FES resistance training and because the force of the arms was mechanically uncoupled from the legs, participants did not have leg strength limiting their arm power output.

Although the resistance applied to the legs via elastic band tension was progressed throughout training, our device design may not have influenced the effects on body composition and thigh lean mass because the resistance applied to the legs was likely lower than the forces obtained by maintaining the arm-leg force couple or during electrically stimulated progressive resistance training. We also utilized two battery-powered stimulation units, which were limited to stimulation at 100mA, which may have been insufficient to progress stimulated leg force sufficiently. Despite the lack of improvement in body composition and thigh lean mass, aerobic fitness improved and the activity was well tolerated, indicating that FES-assisted rowing with our lab's design is an effective manner of improving aerobic fitness while getting contractile activity from all four extremities. Additionally, we observed that with the improved design, participants were able to row with form and technique that is typical of able-bodied rowing.

On average, our participants' shoulder pain was reduced by 10 points on the WUSPI. The minimal detectable change in WUSPI scores is 5.5 points, suggesting that our intervention resulted in both clinical and statistical significance for the participants' most painful shoulder.[22] Arm-crank ergometry has previously been shown to be ineffective at reducing shoulder pain, as measured by the WUSPI (11.5 to 8.5).[6] While two previous resistance training programs have shown significant decreases in WUSPI scores (-26.2 points[11] and -36.3 points[7]), FES-assisted rowing may be a viable option for decreasing shoulder pain while also improving aerobic fitness without the need for multiple interventions.

The mechanism for the reduction in shoulder pain requires further study as our measures of upper extremity strength and muscle activation did not change significantly. In qualitative interviews, participants generally stated that their shoulder pain had decreased. Previous work in our lab demonstrated an increased UT:LT activation ratio indicating poor scapular stabilization in adults with impingement. We expected to see a decrease in this ratio if participants had a decrease in shoulder pain, however this was not observed. Participants also stated in qualitative interviews that they enjoyed having both their arms and legs involved in the activity and that they enjoyed having rowing as an alternative to arm crank or wheelchair pushing for aerobic exercise. Several participants who consistently monitor their exercise heart rate noticed that their heart rate was higher during the FES-assisted rowing than during their normal aerobic activities. Although we did not objectively measure this difference, this is in agreement with previous studies comparing arms-only versus hybrid activities.[8,9]

No significant changes in quality of life or participation as measured by the QOL-SCI and LIFE-H surveys were observed. Upon examination of our qualitative exit interviews, we believe that a ceiling effect may have occurred because participants were independent community-dwelling adults who scored at the very high-end for both surveys. Participants stated in their qualitative interviews that they felt their quality of life had improved. Three participants stated that they felt their transfers and wheelchair propulsion required less effort, which made daily activities easier. Participants consistently stated that they had more energy throughout the day, and one participant noted a significant improvement in sleep quality. Several participants noted that they had less fatigue when sitting unsupported and felt that their posture had improved.

Safety is always a concern when working with adults with SCI so we monitored several outcomes throughout the study. These included skin health where the electrodes were applied, prevention of pressure ulcers while using the FES-assisted rower, monitoring for autonomic dysreflexia and ensuring safe transfers onto and off of the ergometer. The investigators and participant monitored the skin under the electrodes after each session and there were no issues observed. Additionally, we did not have any blood pressure or transfer issues throughout the course of the study. Safety concerns have been raised about the use of FES associated with fracture in the lower extremities. All participants in our study were pre-screened and had typical bone mineral density for their age and were therefore at a very low risk of fracture from the force of electrically stimulated muscle contraction and no issues were encountered.

In the qualitative interviews, participants stated that they enjoyed the activity and would be very likely to use a similar device if it were available in a fitness center. Participants consistently stated that wearing the mask for the metabolic cart was their least favorite part of the study, while having a power goal every day was their favorite part of the study. Given the low injury risk level and potential to both increase aerobic fitness and decrease shoulder pain, it is reasonable to conclude that FES-assisted rowing without a mechanical arm-leg force couple is an acceptable exercise alternative for people with SCI, in particular those with shoulder pain.

Conclusion

The FES-assisted rowing intervention utilized in this study was effective at improving aerobic fitness and decreasing shoulder pain in this population. Additionally, training with the device was both safe and enjoyable for people with SCI. We did not observe a measurable increase in upper extremity muscle strength; therefore it is still warranted to recommend progressive resistance training in addition to aerobic training in this population. The design of our ergometer can be improved so that it is not necessary to have an external person to assist with set-up and movement of the footplate. This may be accomplished by incorporating a motor-driven footplate similar to the motor driven seat design of Kim et al., 2014.

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DISCUSSION AND CONCLUSIONS

The final chapter of this dissertation will focus on the results of the previous chapters as they relate to exercise interventions, health and wellness in manual wheelchair users with SCI. The discussion will provide a synthesized understanding of exercise interventions in SCI, shoulder pain and muscle balance, and the effectiveness of FES-assisted rowing to improve shoulder pain and aerobic fitness in SCI.

Methodological quality and outcome measures in exercise interventions for adults with spinal cord injury

My dissertation inquiries began by examining previous exercise interventions for adults with SCI. In this study we sought to determine which outcome measures were being assessed most frequently and which categories of the International Classification of Function, Disability and Health were covered. Additionally we evaluated the studies for methodological quality.

Prevailing opinion in special population research states that all four categories of the ICF (body structure, body functions, activities and participation and environmental factors) should be evaluated in studies for adults with SCI. In our evaluation of outcome measures in exercise interventions for adults with SCI, we found that the vast majority of outcome measures (62%) examine items from the categories of body functions, 14% of outcomes measures examined Body Structures, 12% evaluated activities and participation and (8%) were related to environmental factors, quality of life or were otherwise not coded. Outcomes measures evaluating items from Activities and Participation were largely focused on the activity of 'Walking' as it related to quality of gait after an intervention such as body-weight supported treadmill training. Quality of life is not directly coded in the ICF, however the number and quality of daily activities performed is highly correlated with quality of life, and therefore, it is important to evaluate activities and before and after an exercise intervention in special populations.

We found that the methodological quality of these studies was generally low due to lack of randomization, unblended participants or assessors, non-representativeness of the sample and lack of adjustment for confounding variables. Many of the items that reduced a study's methodological quality were related to insufficient sample sizes. For example, general statistical rules indicate that there should be an additional 10 participants for every confounding variable included in a model.[31] Most studies had fewer than 10 participants, and therefore did not have enough power to adjust for confounding variables if any existed. Recruiting a representative sample and adjusting for factors such as lesion level and completeness is also problematic when sample size is small. In our cross-sectional study and intervention, we had a variety of lesions levels, level of completeness and years since injury, making our sample representative, however we lacked a sufficient number of people to statistically stratify our sample.

Exercise interventions for adults with spinal cord injury generally have low methodological quality and focus largely on the categories of body functions and body structures in their outcomes. These results informed our future studies, and we attempted to fulfill the necessary requirements to improve methodological quality, and to include evaluation of Activities and Participation and quality of life in our outcome measures.

Muscle balance and scapular stabilization in manual wheelchair users with spinal cord injury and impingement

During our systematic review of exercise interventions for adults with SCI, I found that adults with SCI frequently experience decreased aerobic fitness and a high incidence of shoulder pain. This lead to further exploration of these issues and exposed the problem of muscle imbalance in manual wheelchair users with SCI, and that their shoulder pain is frequently attributed to subacromial impingement syndrome. Current physical therapy practice to treat impingement in manual wheelchair users with SCI is largely based on findings from able-bodied adults with impingement; oftentimes this population was overhead athletes and workers. Because daily manual wheelchair use is profoundly different from overhead activities, we believed that there could potentially be an underlying difference in the muscle imbalance pattern for manual wheelchair users with SCI. This was an important evaluation because a difference in muscle imbalance pattern would indicate that a different therapeutic exercise program should be applied in this population.

The most important finding from this study was that manual wheelchair users with SCI who have subacromial impingement present with impaired scapular stabilization similar to the results from studies in able-bodied adults. This indicates that treatment protocols targeting scapular stability are appropriate in both populations. We did not find any differences in rotational strength or muscle balance between shoulders with and without impingement, or between able-bodied and SCI. Physical therapy practice frequently employs rotator cuff strengthening as a part of impingement treatment, however our results indicate that these exercises may be of lesser importance if they are not also targeting scapular stability.

We also found that adults with SCI, regardless of if they have impingement or not, are weak in pulling and arm adduction strength, indicating a weakness in the posterior shoulder. Lack of scapular stability is also related to weak posterior shoulder musculature (decreased activity in lower trapezius). Together, these results indicate that manual wheelchair users with SCI may benefit from prophylactic strengthening of the posterior shoulder girdle, which may prevent onset or recurrence of shoulder pain.

Effectiveness of functional electrical stimulation assisted rowing to improve shoulder pain and aerobic fitness in manual wheelchair users with spinal cord injury

The first two studies of this dissertation greatly informed the rationale and methods for the final intervention study. First, adults with SCI have low aerobic fitness and a high incidence of shoulder pain that is influenced by weak posterior shoulder musculature. Second, it is important to evaluate changes in outcome measures related to activities and participation because of their influence on quality of life.

FES-assisted rowing was selected because of its potential to be an ideal activity for manual wheelchair users with SCI. Three main benefits were identified. First, FES-assisted exercise increases the cardiovascular demand of an activity, which in turn leads to greater increases in aerobic fitness. Second, rowing induces repeated activation of the posterior shoulder musculature, which can potentially increase strength and improve shoulder pain. Finally, FES-assisted rowing has the potential to both increase aerobic fitness and decrease shoulder pain in a single activity, which is important for a population that identifies lack of time as a barrier to exercise.

We chose three evaluation tools to ensure that we examined activities and participation and quality of life for our intervention study. We used two survey measures to evaluate activities and participation and quality of life (LIFE-H and QOL-SCI respectively). We also elected to perform qualitative exit interviews that specifically asked participants to describe how they felt the intervention effected their health, daily function and quality of life. We were unable to detect any differences in Activities and Participation or quality of life using the LIFE-H or QOL-SCI surveys, however qualitative interviews indicated that participants felt that they had improved their overall health, energy and quality of life at the end of the intervention. This is an important finding to consider for high-functioning people with physical disabilities due to the likelihood that a ceiling effect may conceal changes in quality of life or participation.

Improving shoulder pain and aerobic fitness in a single activity is highly desirable for adults with SCI because increased shoulder pain decreases physical activity levels which is associated with increased pain, causing a vicious cycle of decreasing physical activity and increased pain. Improving both factors in a single activity is desirable because adults with SCI frequently identify lack of time as a barrier to performing physical activity. We found that FES-assisted rowing was effective to improve aerobic fitness and shoulder pain in adult manual wheelchair users with SCI.

Our rationale for using FES-assisted rowing as an activity that could potentially decrease shoulder pain and improve aerobic activity was based on the increased cardiovascular demand of FES-assisted exercise and repetitive activation of the posterior shoulder musculature during rowing. We found a significant improvement in aerobic fitness after the 6-week intervention. Although we saw a significant improvement in shoulder pain, we did not observe any changes in posterior shoulder strength, which was our assumption for the activity's ability to reduce pain.

Implications for future studies and rehabilitation

The results of this dissertation imply three major implications for future studies and rehabilitation. First, we must recognize and attempt to overcome challenges associated with human subjects research in special populations. Second, it is important to consider therapeutic interventions and rehabilitation may differ for adults with SCI compared to able-bodied adults. Finally, exercise interventions in SCI should include evaluation of effects on quality of life and participation, which may require qualitative inquiry.

Human subjects research in special populations frequently suffers from a lack of methodological quality due to small sample sizes. In our studies, we attempted to recruit a representative sample and were clear in our reporting as to who made up our sample and how we attempted to maximize validity of the results. Our final intervention data included 10 participants, which many would consider to be a sufficient sample for a pilot study, but not a higher level of evidence. It would be beneficial for future interventions to create a research plan that includes a small pilot group, followed by a larger multi-site trial in order to increase sample size and potentially control for confounding variables that are frequently observed in SCI and other special populations. Other study designs such as baseline-intervention-withdrawal designs would allow for investigators to perform multiple comparisons without the need for a separate control group and larger sample size.

Another important finding and implication from this study was that shoulder pain attributed to subacromial impingement can be treated similarly in adults with SCI as in able-bodied adults, but a special emphasis should be placed on posterior shoulder strength and less emphasis on rotational strength. This concept is applicable to other aspects of rehabilitation and wellness for adults with SCI. In therapeutic interventions, clinicians must consider the demands placed upon the individual with a disability and determine if their intervention may need to be adjusted from the able-bodied model. This is particularly important in physical therapy, but also applies to general practice. For example, if a person with a SCI does not have activation of the intercostal muscles and has chest congestion, they may require a different intervention to relieve congestion because they cannot clear mucus as effectively from their lungs as an able-bodied person.

Our systematic review revealed important information concerning which aspects of health and function are being addressed in exercise interventions, with the majority of outcomes falling into the categories of body structures and body functions. We concluded in that study that exercise interventions should also include aspects of activities and participation, and quality of life. We used both survey and qualitative inquiries to examine these factors. In the final analysis, we found that qualitative inquiry was more informative as to how the intervention was helpful. As stated previously, interventions for special populations often have a small sample sizes, therefore it is reasonable to suggest that researchers should take the time to include a qualitative exit interview for their participants in order to gauge the participants' personal perceptions of the intervention's effectiveness and to provide a more well rounded picture of the intervention outcomes.

Taken together, the results of this dissertation have contributed to the knowledge of health and wellness in manual wheelchair users with SCI. We found that shoulder rehabilitation protocols based in able-bodied adults are likely appropriate in SCI, however clinicians should consider the unique demands of wheelchair propulsion when creating their rehabilitation plan. Additionally, we observed that FES-assisted rowing is effective to improve aerobic fitness and shoulder pain in SCI, however future work should be conducted to improve the device and investigate the mechanism for improvement in shoulder pain. Finally, we saw that qualitative inquiry is effective for describing an intervention's effects on activities and participation and quality of life. These results show that FES-assisted rowing is a promising mode of exercise to improve overall health and wellness in manual wheelchair users with SCI.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on January 24, 2017. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56.

Principal Investigator:	SILVERMAN, SUSAN REBECCA
Co-Investigator(s):	HERMAN, CASSANDRA L MALONE, LAURIE
Protocol Number:	**F131028008**
Protocol Title:	*Effectiveness of FES – Assisted Rowing to Improve Aerobic Capacity and Shoulder Pain in Adult Manual Wheelchair Users with Spinal Cord Injury*

The IRB reviewed and approved the above named project on 1/7/2015. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received FULL COMMITTEE review.

IRB Approval Date: 1/7/2015

Date IRB Approval Issued: January 21, 2015

IRB Approval No Longer Valid On: January 7, 2016

Identification Number: IRB00000726

Albert Oberman MD, MPH (ns)

Albert Oberman, M.D., MPH
Vice Chair of the Institutional Review
Board for Human Use (IRB)

Partial HIPAA Waiver Approved?: Yes

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.

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