SPRINT INTERVAL TRAINING DURING INPATIENT REHABILITATION AFTER SPINAL CORD INJURY

By

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Abstract

During inpatient rehabilitation, arm-ergometry training is utilized to improve the physical capacity of patients with a sub-acute spinal cord injury (SCI) to a level that is desirable for performing activities of daily living (ADLs). Previous work has demonstrated that ≥ 20 minutes of moderate-intensity continuous training (MICT) during inpatient rehabilitation, at a frequency of ≥ 3 times per week, is useful for increasing the physical capacity of these patients. However, considering that inpatient rehabilitation is an intensive program, and given the trend towards a shortened length of stay during inpatient rehabilitation, performing MICT on the arm-ergometer can consume a valuable amount of therapy time. Low-volume sprint interval training (SIT) is a time-efficient alternative to MICT for improving indices of physical fitness in healthy and diseased populations. To date, however, there are no published studies comparing SIT to MICT in persons with sub-acute SCI undergoing inpatient rehabilitation.

The purpose of this thesis was to evaluate the efficacy of a five-week, thrice weekly low-volume SIT protocol on the arm-ergometer and compare fitness outcomes to traditional MICT in patients with sub-acute SCI undergoing inpatient rehabilitation. Participants with sub-acute SCI undergoing inpatient rehabilitation were recruited and randomly allocated to the SIT or MICT training group. Both types of training utilized the same 2 min. warm-up and 3 min. cool-down. SIT consisted of 3 x 20 sec. "all-out" cycle sprints (≥ 100% of peak power output [PO_{peak}]), interspersed with 2 min. of low active-recovery (≈ 10% of PO_{peak}; total time commitment, 10 mins). MICT involved 20 min. of arm cycling (45 – 60% of PO_{peak}; total time commitment, 25 mins). SIT elicited a higher relative

heart rate response, and ratings of perceived exertion than MICT. Following training, we found similar improvements in maximal and sub-maximal physical capacity across groups. Both exercise modes were equally well tolerated, and enjoyable, and there were no differences in self-efficacy across groups.

The significance of this work is that it is the first randomized-controlled trial comparing SIT to MICT on the arm-ergometer in individuals with sub-acute SCI undergoing inpatient rehabilitation. The fact that SIT is palatable and can promote similar increases in physical capacity as MICT, despite less than half the time commitment and training volume, means that clinical rehabilitation specialists can now offer a new, more time-efficient, exercise training strategy to elicit improvements in their patients.

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Dedication

I would like to dedicate this thesis to Giovanni Sturino.
Riposa in Pace, Nonno.

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List of Abbreviations

AD – Autonomic dysreflexia
ADLs – Activities of daily living
AMPK – AMP-activated protein kinase
ASIA – American spinal injury association
CAD – coronary artery disease
CAMKII – Ca^{2+}/calmodulin-dependent protein kinase II
CNS – Central nervous system
CV – Cardiovascular disease
ESES – Exercise self-efficacy scale
HIIT – High-intensity interval training
HR – Heart rate
HR_{peak} – Peak heart rate
LOS – Length of stay
MAPK – Mitogen-activated protein kinase
MICT – Moderate-intensity continuous training
OH – Orthostatic hypotension
PACES – physical activity enjoyment scale
PAG – physical activity guidelines
PGC-1α – peroxisome-proliferator activated receptor γ co-activator
PO_{peak} – Peak power output
PNS – Parasympathetic nervous system
Q – Cardiac output
QoL – Quality of life
RCT – randomized controlled trial
RPE – ratings of perceived exertion
SCI – Spinal cord injury
SIT – Sprint interval training
SNS – Sympathetic nervous system
SV – Stroke volume
TSI – Time since injury
VO_{2peak} – peak oxygen uptake

Chapter I: Literature Review

1.1 Spinal Cord Injury

1.1.1 Incidence, Etiology, Demographics, and Pathophysiology

The spinal cord is a component of the central nervous system (CNS) that acts as a bidirectional neural conduit for communication and integration between the brain and its motor, sensory and autonomic targets throughout the body. Spinal Cord Injury (SCI) results in a loss of motor, sensory and/or autonomic function below the level of the lesion[1,2]. There are currently an estimated 86,000 Canadians living with a SCI, an impairment occurring at a rate of approximately 600 per year [1]. SCI most commonly results from a traumatic event, such as motor vehicle accidents or falls and occurs most commonly in Caucasian, middle-aged men [1,2]. Subsequently, these individuals experience a host of unique physical, and psychological changes throughout their lives including, but not limited to, impaired ability to perform activities of daily living (ADLs) and reduced independence.

Traumatic SCI is divided into primary and secondary injury phases. The primary injury phase is defined by the immediate physical traumatic event to the spinal cord, which can be classified as ether penetrating (e.g., knife wounds) or blunt (e.g., accidents) injuries. A cascade of biochemical, intracellular, and physiological insults to the neuraxis describes the secondary injury phase [3]. The secondary injury phase can be further subdivided into immediate (time since injury [TSI]: seconds), early acute (TSI: minutes to hours) and sub acute (TSI: days to weeks) phases [4]. Immediately following primary damage, disruption of the vasculature results in acute hemorrhage and central nervous system ischemia [3,4]. Over days and weeks following primary damage, the failure for

neurons in the spinal cord to reuptake glutamate (glutamate excitotoxicity) and the introduction of numerous cytotoxic by-products (e.g., pro-inflammatory cytokines, vasoactive compounds, reactive oxygen species) into the local microenvironment initiates a cascade of pro-apoptotic signals and cell death [3,4].

1.1.2 Defining SCI

If trauma to the spinal cord always occurred in the same anatomical location and resulted in the same physiological transection, classification of SCI would be quite simple. However, as the primary mechanism for a traumatic SCI is hyperextension, flexion-rotation, and/or compression, the spinal cord is rarely severed and remains anatomically intact [5]. As a result, more than half of the survivors of traumatic SCI will experience varying degrees of motor, sensory, and autonomic impairment, making the classification of individuals with SCI challenging, yet important. In order to accurately classify and examine individuals with SCI, the degree of impairment is dependent upon both (1) the level of the injury and (2) the severity of the lesion.[5]

Individuals with SCI are described as presenting lesions affecting sensorimotor function of all the limbs or the lower extremities alone. Tetraplegia is defined as lesions that occur in the cervical segments of the spinal cord and manifests as an impairment or loss of sensorimotor function in the arms, trunk, legs and pelvic organs [5]. Paraplegia is defined as injuries that occur in the thoracic, lumbar, or sacral segments of the spinal cord. Individuals with paraplegia demonstrate spared arm functioning, and depending on the level of injury, limitations in the trunk, and/or pelvic organ regions may be involved [5].

About two decades ago, the Committee of American Spinal Injury Association (ASIA) developed uniform standards to assist with accurate and consistent classification of individuals with SCI. This standard allowed individuals with SCI to be systematically examined and classified according to the amount of sensorimotor function sparred below the level of the lesion. According to ASIA, the severity of a SCI can be classified into one of five categories (A-E), with each category representing a unique amount of sensory and/or motor function preserved caudal to the level of the injury. ASIA level A represents a complete SCI, where there is no sensory or motor function preserved in the sacral segments S4 – S5 [5]. It is important to note that some individuals with a 'complete' SCI may still have preserved motor and/or sensory function between the level of the injury; this is referred to as the zone of partial preservation [5]. Level B is defined as an incomplete SCI in which there is only sensory function preserved below the neurological level and in S4-S5[5]. Level C and D are also described as incomplete injuries and there is preservation of some motor function below the level of the injury [5]. For level C injuries, more than half of the significant muscles (below the injury level) have a muscle grade point less than 3 (0= total paralysis, 5= normal muscle strength), whereas individuals with level D injuries have a muscle grade point greater than or equal to 3 in at least half of the significant muscles [5]. Lastly, level E represents an individual with normal sensory and motor function.

1.1.3 Medical and Health Consequences of SCI

Loss of sensorimotor and autonomic function below the level of the injury results in prominent health-related consequences. In particular, when reduced mortality rates [6,7] are coupled with extreme sedentary lifestyles [8] and physical deconditioning [9], young persons with chronic SCI experience an accelerated risk for the development of co-morbidities. For example, DeVivo and colleagues [6] found that young and middle-aged individuals living with SCI are 23- and 8-times more likely to develop cardiovascular disease (CV) than the age-matched able-bodied population, respectively. Not surprisingly, individuals aging with SCI are at a heightened risk of developing insulin resistance, dyslipidemias, changes in vascular structure and function, and autonomic dysregulation [10]. Deep vein thrombosis, pressure ulcers, urinary tract infections, autonomic dysreflexia (AD), orthostatic hypotension (OH), and neurogenic bowel and bladder are commonly reported secondary complications [10].

Following a traumatic SCI, individuals become more susceptible to experiencing psychosocial difficulties. Approximately 1 in 5 individuals with SCI will develop depression and anxiety in their lifetime, which is a higher rate compared to the general population [11]. Reduced quality of life (QoL), decreased functional status, and the inability to remain autonomous and perform ADLs throughout the community are commonly reported in this population [12]. Socioeconomic status declines rapidly following injury, and this can be attributed to the financial burden of living with a SCI. For example, the cost of living for an individual with incomplete paraplegia following the first year of injury is estimated to be $270,900, with each subsequent year costing upwards to $27,000 [13]. The

costs of living with a SCI tend to be the most expensive for individuals with higher-level complete lesions [13].

1.2 Rehabilitation of SCI

1.2.1 Primary Goals and Treatment Phases Following SCI

Prior to WWII, life expectancy following SCI was extremely poor [14]. Over the past several decades, advancements in medical care and the acute management of SCI have dramatically improved life expectancy to resemble that of the able-bodied population [7]. Despite improvements in life expectancy, and progressions in our understanding of the pathophysiology involved with SCI, there still remains to be an effective therapy in completely restoring sensorimotor function below the level of the injury. Spontaneous recovery of sensorimotor function following traumatic SCI has been documented, however, the degree of recovery is extremely variable, and highly dependent upon the level and the completeness of the injury. As a result, a vast majority of individuals sustaining initial trauma to the spinal cord will experience a host of debilitating physiological, functional, and psychosocial disabilities for the remainder of their lives. The combined effect of secondary complications with what is typically an extremely sedentary lifestyle [15] leads to physical deconditioning and reduced physical capacity of persons with SCI. Individuals with SCI appear to have difficulty coping with the physical strain of ADLs, and give low ratings of QoL [15,16]. With all of this in mind, the primary purpose of rehabilitation following SCI has shifted considerably over the past five

decades, from extension of lifespan to enhancement of functional recovery, management of secondary complications, and augmenting physical capacity.

The rehabilitation process of SCI is long, expensive, exhausting (for the patient) and requires a multidisciplinary approach. Each rehabilitation program is unique and tailored to meet the patient's abilities and needs, however, the structure and primary goals of treatment phases following SCI tend to remain relatively constant across patients. The rehabilitation of individuals with SCI can be divided into two-phases: acute (TSI, 0 – 4 weeks), and sub-acute (TSI, 2 – 26 weeks). Acute rehabilitation begins immediately following primary damage to the spinal cord with admittance to acute hospitalization. Acute hospitalization typically consists of a 2- to 4-week bed rest period, with common interventions including early surgical decompression, systemic steroid therapy, and augmentation of mean arterial pressure [4]. The primary goal of this rehabilitation phase is to stabilize the patient's neurological symptoms from the secondary damage of the injury.

Upon discharge from acute hospitalization, the patient enters into the sub-acute phase, which consists of inpatient and outpatient rehabilitation. During SCI inpatient rehabilitation, the clinical team works together to augment functional recovery, and prepare the patient for a return to home setting or an independent living environment [17-19]. Patients undergo intensive physical reconditioning and are taught to how to manage and prevent common complications of living with a SCI. The length of stay (LOS) for inpatient rehabilitation can range anywhere between 5- to 15-weeks, and is highly dependent on the level and the completeness of the injury (see next section for more detail) [19]. Thereafter, patients begin to integrate themselves back into the community and

are admitted to outpatient rehabilitation, making frequent clinic visits (≈ 3 times a week until about 52 weeks post-injury) to undergo further physical reconditioning. Although all treatment phases following SCI are extremely important in facilitating recovery and maximizing independence, the following section will provide an in depth discussion of inpatient rehabilitation.

1.2.2 Inpatient Rehabilitation: Overview

Admittance to SCI inpatient rehabilitation immediately following acute hospitalization is extremely important, as a delay in starting rehabilitation may negatively influence the patients' functional recovery [20]. As briefly described above, one of the primary goals during sub-acute inpatient rehabilitation is to prepare the patient for a return to home setting and convey to the patient that living with a SCI will be different, but can still be fulfilling. The specialized rehabilitation team is multidisciplinary and each member plays a unique role that is vital for optimal care and recovery following SCI. Due to the unique physiological and psychosocial consequences of suffering from a traumatic SCI, the SCI rehabilitation team is typically composed of physiatrists, physiotherapists, occupational therapists, speech-language therapists, psychologists and social workers [18,19]. Once the patient's ASIA grade, level of injury and prognosis for sensorimotor recovery are determined at the onset of rehabilitation, the SCI clinical team can begin to formulate long- and short-term functional goals for the patient that should be met one-year following injury [21]. Functional goals will vary depending upon the level of the lesion, and it is important to note that the outcome may not always be achieved due to factors such as

age, sex and comorbidities [21]. Coordination of the SCI rehabilitation team with the patient and family members of the patient is extremely important to ensure a timely and safe reintegration back into the community.

1.2.3 Inpatient Rehabilitation: Length of Stay

Over the past five decades, there has been a 65% decrease in the average LOS during SCI inpatient rehabilitation in the United States [22]. According to the 2016 annual report from the National Spinal Cord Injury Statistical Center [22], average LOS during SCI clinical rehabilitation in the early 1970's was ≈ 98 days (complete tetraplegia: 142 days, incomplete paraplegia: 68 days), whereas the average LOS in 2016 was approximately ≈ 35 days (complete tetraplegia: 52 days, incomplete paraplegia: 29 days). There is no literature capturing the trends in decreased LOS during clinical rehabilitation in Canada over the past several decades, however the average LOS across all Canadian SCI inpatient rehabilitation sites in 2012 ranged from ≈ 41 to 150 days [23].

The debilitating disability, health complications, and around-the-clock assistance associated with SCI place a financial burden on the medical-system. Costs associated with the initial hospitalization are substantial, and a major driver of costs is the length of time the injured individual remains in sub-acute rehabilitation prior to community integration [24]. Munce and colleagues [24] examined the direct costs of health care utilization from the initial hospitalization to 1 year after discharge among 600 individuals with traumatic SCI living in Ontario. Findings from this population-based study revealed that across all institutional and community settings, the largest cost-driver to the health-care

system for the fiscal years 2003 – 2004, 2004 – 2005 and 2005 – 2006 was inpatient rehabilitation, which was estimated to cost 11-million-, 10-million-, and 13-million-dollars, respectively [24]. On a per-patient per-year basis, the average cost for total hospital utilization in 2005 was $123,674 [24]. In comparison, the mean per-patient per-year costs for patients with cancer is $39,155 [25].

Reducing the mean LOS during SCI inpatient rehabilitation could diminish the financial burden placed on the health-care system, however, if rehabilitation costs were to be reduced solely by reducing the LOS, consequences may arise such as increased frequency of developing secondary complications and higher likelihood of re-admission back into a hospital setting following discharge [23]. It is important that clinicians and researchers strive to create innovative SCI rehabilitation programs that are cost-efficient, time-efficient and just as effective as the current standard of practice.

1.2.4 Inpatient Rehabilitation: Physical Therapy

Physical therapy, occupational therapy, speech language pathology, therapeutic recreation, social work/care management and nursing beside education are some of the common therapies offered during SCI clinical rehabilitation [19]. In 2011, Whiteneck and colleagues [19] published information on the type and amount of therapies offered to individuals with sub-acute SCI undergoing inpatient rehabilitation in the United States. Based on the total hours of treatment throughout sub-acute rehabilitation, physical therapy accounted for 31% of total therapy time, which can be estimated to be 500 minutes of physical therapy for the patient per workweek (100 minutes / day) [19]. There is

no published literature on therapy time during Canadian SCI rehabilitation, however, given that one of the primary goals of SCI rehabilitation is to physically condition the patient and increase independence in a broad spectrum of physical skills, we would expect to see a larger proportion of total therapy time being allocated to physical therapy, as is seen in the United States.

According to Natale and colleagues [18], physical therapy consists of 19-treatment activities such as transfers, wheelchair mobility skills, pre-gait, over ground walking, musculoskeletal treatments and modalities, aquatic exercises, and resistance and aerobic training. Although working towards independent ambulation is one of the most important goals for individuals with low-level SCI, muscular and cardiovascular conditioning of the upper extremities is pertinent for all SCI levels [18]. After SCI, to compensate for the loss of motor control and muscular strength in the lower body, patients must predominately rely on muscles in the upper extremities to perform ADLs. With this in mind, physiotherapists use a variety of equipment to help the patient regain upper extremity muscular strength and conditioning such as weight machines, bands, dumbbells and arm-ergometers [18].

1.3 Exercise In Individuals With SCI

1.3.1 Acute Physiological Responses to Exercise Stress

The Autonomic Nervous System plays a vital role during physical activity or exercise, in which it is responsible for mediating adjustments to the heart and vasculature in order to meet the metabolic demand (e.g., ATP) of active skeletal muscle mass. Inhibition of the parasympathetic nervous system (PNS), and activation of the sympathetic nervous system

(SNS) contributes to exercise induced increases in heart rate (HR), cardiac contractility (e.g., stroke volume [SV]), and thus, cardiac output (Q = SV x HR) [27]. Stimulation of epinephrine release from the adrenal medulla, and vasoconstriction in the non-exercising muscles facilitates the redistribution of Q and enhances oxygen- and micronutrient-delivery to the exercising muscles [27].

Compared to the able-bodied population, individuals with SCI experience blunted physiological responses during a bout of arm-ergometry [28-30]. Altered hemodynamic responses to exercise in individuals with SCI can be attributed to sympathetic denervation, which is a separation of cardiac, vascular, and total SNS control from the brain. As SNS pre-ganglionic neurons exit at various segments along the spinal cord (T1 – L2) [31], there is a direct association between the degree of sympathetic denervation and the level and neurological completeness of the lesion (the higher and more severe the injury, the greater the degree of sympathetic denervation) [29-31]. Therefore, during exercise, individuals with tetraplegia have lower HR, SV, and Q than persons with paraplegia.

During exercise, the lack of sympathetic innervation in individuals with SCI causes significant pooling of blood in the lower extremities, which diminishes the increase in venous return and SV according to the Frank-Starling mechanism [32]. The capacity for an individual with SCI to compensate for a reduced SV is highly dependent upon the level of the lesion. For example, individuals with a lesion level at or above the 5th thoracic vertebrae [31] will have impaired cardiac sympathetic innervation, meaning that reductions in SV cannot be compensated by an increase in HR, resulting in a decreased Q.

On the other hand, individuals with injury levels below the 5th thoracic vertebrae (intact cardiac sympathetic innervation) may experience an exaggerated HR response during exercise, which is thought to be an adaptive response to maintain Q [33,34]. This idea is supported by work from Schmid and colleagues [30], in which subjects with paraplegia require a higher HR response to work at the same relative intensity as able-bodied individuals. As the SNS plays a key role in regulating various physiological processes during an acute bout of exercise, sympathetic dysfunction following SCI diminishes the physiological responses to exercise normally achieved in able-bodied individuals [10].

In addition to a blunted autonomic response to exercise, persons with SCI have lower peak oxygen uptakes (VO_{2peak}) and reduced peak work capacities (e.g., peak power output [PO_{peak}]) than the able-bodied population [10], and this can be attributed to somatic dysfunction. The Somatic Nervous System is responsible for voluntary control of movements via skeletal muscle, and damage to the spinal cord disrupts efferent motor pathways, resulting in paralysis below the level of the injury. Individuals with cervical lesions display impaired voluntary motor control of upper extremity muscles, limiting the amount of muscle mass available to serve as prime movers during arm-ergometry [10,28,29]. Although upper extremity function is spared in individuals with paraplegia, denervation of the abdominal muscles and the intercostal results in a strong restrictive ventilatory impairment during exercise [35]. Reduced functional muscle mass and/or denervation of muscles responsible for respiration and stabilization shrinks exercise efficiency and peak exercise capacity. The end result in this population is exercise intolerance, physical deconditioning, and difficulty performing ADLs.

1.3.2 Endurance Training: Arm Ergometry

Persons with a newly acquired SCI can spend up to 4 weeks of bed rest during acute care [36], and the detrimental whole-body effects of such a prolonged bed rest has been documented in healthy individuals [36]. Compared to the able-bodied population, the lack of motor control in the lower limbs following SCI can likely exacerbate the negative consequences of an elongated bed-rest period. Exercise training, particularly cardiovascular or aerobic training may mitigate the physiological deterioration that results from sustained immobilization, and improve physical function to a level that is desirable for performing ADLs. Efforts to achieve an optimal level of fitness through chronic aerobic training should ideally start during inpatient rehabilitation.

After SCI, there is insufficient motor control and muscular endurance in the lower extremities to support safe and efficacious voluntary endurance training (e.g., leg ergometry) [10]. However, sparing of upper extremity muscle function in persons with SCI makes it possible to employ upper limb voluntary endurance training such as swimming, wheelchair propulsion, and arm-ergometry; the latter is most commonly found in clinical settings across Canada [23]. The arm-ergometer is portable, inexpensive, and easy to calibrate, which makes the device one of the most favored arm-exercise modalities [38]. Compared to wheelchair propulsion training on the treadmill, arm-ergometry training is less strenuous and more tolerable, and individuals are at a lower risk of developing shoulder over-use injuries. In addition, individuals with higher levels of injury (e.g., persons with tetraplegia) who maintain some upper extremity function can participate in

arm-ergometry training, given that their hands can be affixed to the pedal of the ergometer using tensor bandages.

To date, there have been several studies exploring the use of arm-ergometry training as an adjunct to SCI clinical rehabilitation [29,35,39,41,42]. For example, Valent and colleagues [39] found that individuals performing arm-ergometry training regularly during inpatient rehabilitation had significantly higher PO_{peak}, VO_{2peak}, upper-body strength, and pulmonary function than individuals not performing arm-ergometry training. It is important to note that this was an observational study where participants subjectively reported the frequency and intensity of training, and there was no controlled training protocol. Nonetheless, this study demonstrated the beneficial effect of regular arm cycling during inpatient rehabilitation.

DeGroot and colleagues [41] reported significant increases in indices of physical capacity (PO_{peak}, VO_{2peak}) following 8 weeks of either high-intensity (70 – 80% HR reserve) or low-intensity (40 – 50% HR reserve) arm-ergometry training in individuals with paraplegia. However, the study utilized a small sample size (n=6) and included only one participant with tetraplegia. These findings have been replicated in individuals with incomplete tetraplegia undergoing 12 weeks of high-intensity arm cycling [29], although the authors failed to quantify/publish the training intensity. Recently, a case study [42] found improvements in VO_{2peak}, PO_{peak}, a timed functional wheeling task, and orthostatic tolerance in a 22 year old with a complete cervical SCI following 10 weeks of an aerobic exercise training circuit (arm-ergometry, sliding motion, wheeling; 5 min each station, 30 min total). Moreover, the participant's exercise tolerance improved in terms of both

exercise duration and intensity. Although all the studies described above are in accordance with the newly developed physical activity guidelines (PAG) for adults with SCI (≥ 20 minutes of moderate-intensity cycling, at a frequency of ≥ 2 times / week) [43], the time devoted to training and the total training duration was still quite high. Given the trend towards increasingly shorter LOS for inpatient rehabilitation in both Canada (≈ 41 days) [23], and the United States (≈ 35 days) [22], performing arm-ergometry training that follows the PAG recommendations can consume a considerable amount of valuable rehabilitation time.

1.3.3 Risks of Exercise when Performed by Individuals with SCI

The health benefits of performing exercise in the able-bodied population and following SCI are clear, but there are some risks to performing exercise. Individuals with SCI can experience some of the same risks when performing exercise as the able-bodied population [10]. However, due to impaired autonomic regulation and greater reliance on the upper extremities to perform ADLs, individuals with SCI are more likely to experience a negative event when performing exercise. AD, OH, and shoulder over-use injuries are unique to individuals with SCI and commonly reported during and/or following exercise.

AD is characterized by a sudden rise in blood pressure (minimum 20 mmHg) when noxious stimuli are presented acutely below the level of the lesion [31]. The rise in blood pressure is usually accompanied by other clinical symptoms such as bradycardia, profuse sweating or flushing of the skin, pounding headache, and nausea [31]. However, in some individuals, AD can occur without any of these symptoms, and this condition is

known as asymptomatic AD. In healthy individuals, sympathetic inhibition normally suppresses the unrestricted autonomic reflex following exposure to noxious stimuli. However, following SCI, supralesional sympathetic inhibition is lost, and as a result, AD occurs [31]. The level and completeness of the injury are critical factors for the presence of AD. It is understood that AD is three times more likely to occur in complete than incomplete injuries [44], and occurs in individuals with high-level SCI above the T6 level [45]. Bowel and bladder distension before emptying is the most common stimuli for triggering AD [31,44,45]. Other noxious stimuli that can trigger AD include venous thromboembolism, bone fracture, sudden temperature change, feverish episodes and exercise [45,46]. Ashley and colleagues [46] found that individuals with SCI at injury levels above T6 consistently demonstrated a response suggestive of AD (sudden rise in systolic blood pressure, followed by a fall in HR) while performing functional electrical stimulation assisted hydraulic resistance training

Whereas a sudden rise in blood pressure clinically defines AD, OH and post-exercise hypotension are characterized by a sudden reduction in blood pressure during an orthostatic challenge (e.g., moving to an upright posture from a supine position), and following a bout of exercise, respectively. After SCI, the interruption of descending sympathetic pathways from the brainstem to the vasculature that would normally cause vasoconstriction and maintain blood pressure is impaired [31]. The result is blood pooling in the vasculature below the level of the injury, reduced venous return, as well as low arterial blood pressure. Symptoms of hypotension after SCI are no different from the able-bodied population [47], and include light-headedness, blurred vision, fatigue, nausea,

and dyspnea. Similar to AD, the severity and level of injury to the descending cardiovascular autonomic pathways is directly associated with the prevalence of hypotension. OH is most common in the sub-acute phase of SCI, occurring in 74% of individuals admitted to inpatient clinical rehabilitation [36]. King and colleagues [48] found that post-exercise hypotension is more prevalent in persons with SCI than able-bodied subjects during a bout of continuous maximal arm ergometry.

After SCI, there is an extensive reliance on the upper limbs for performing ADLs, which leads to a greater prevalence of shoulder over-use injuries and musculoskeletal pain in this population. As the shoulder joints (and surrounding musculature) are not well suited to perform repetitive tasks, manual wheelchair users are at a greater risk of developing over-use injuries than electric wheelchair users. Special precautions should be taken to prevent over-use injuries for individuals with SCI participating in persistent upper-body exercise.

1.4 Interval Training

1.4.1 Terminology

High-intensity interval training (HIIT) or sprint interval training (SIT) encompasses brief, intermittent bursts of vigorous intensity exercise, interspersed with periods of low-active recovery. There are a wide variety of interval training protocols utilized throughout the literature, where the exercise intensity is defined as a percentage of the maximal physiological response to a graded exercise test (e.g., VO_{2peak}, PO_{peak}, and peak HR [HR_{peak}]). For simplicity, the current review will employ terminology proposed from

Weston and colleagues [49] to differentiate HIIT and SIT. HIIT typically involves 'near-maximal' efforts at 85 – 95% of maximal HR, whereas SIT represents 'all-out' efforts, or at intensities corresponding to ≥100% of VO_{2peak} [49].

There is a growing body of evidence suggesting that SIT induces physiological adaptations comparable to traditional moderate-intensity continuous training (MICT), despite a substantially lower exercise volume (e.g., work per unit time) and time commitment [50-52]. In healthy individuals, a commonly studied low-volume SIT model is repeated Wingate Tests, which consist of a 30s 'all out' cycling effort at a supramaximal workload. In one session of low-volume SIT, participants usually perform 4 – 6 work bouts separated with 2 – 4 minutes of active recovery, for a combined total of 2 – 3 minutes of intense exercise.

1.4.2 Physiological Adaptations to SIT: Evidence from Healthy Populations

Traditional MICT has been shown to enhance cardiorespiratory fitness (as measured by VO_{2peak}), which can reduce the risk for developing CV, and all-cause mortality. Studies have demonstrated that SIT can also effectively improve one's cardiorespiratory fitness [50-52]. Gillen and colleagues [50] had sedentary men complete either a very brief SIT protocol, involving one minute of intense exercise per session, or a traditional MICT (45 minutes per session) protocol for 12 weeks (3 times per week). The authors found similar improvements in VO_{2peak} (≈ 6-mL/kg/min), despite a five-fold lower time commitment and exercise volume in the SIT group. In addition, improvements in VO_{2peak} have been reported (≈ 3.5-mL/kg/min) following just 2- [52]or 6-weeks [51] of low-volume SIT in

healthy young men. These findings are clinically relevant given that a 3.5 mL/kg/min (1-metabolic equivalent [MET]) improvement in cardiorespiratory fitness is associated with a 15% and 19% reduction in all-cause mortality and CV [53]. It should be noted that, based off a previous report by Collins and colleagues [54], 1-MET for persons with SCI should be adjusted to 2.7 mL/kg/min.

Improvements in VO_{2peak} following MICT and HIIT/SIT may be explained by (1) increasing oxygen availability to skeletal muscle (central adaptations) and/or (2) improving the capacity of skeletal muscle to extract and use available oxygen (peripheral adaptations). Central adaptations to exercise training are generally attributed to an increase in Q, due to a greater SV [55]. A recent meta-analysis [56] evaluated the effects of low-volume SIT on VO_{2peak} across 13 studies and concluded that central adaptations to exercise are limited and more equivocal compared with the effects on muscle oxidative capacity. For example, several studies report increases in glycogen buffering capacity, skeletal muscle fuel utilization (e.g., shifting from carbohydrate to fat oxidation), maximal activities of mitochondrial enzymes, and mitochondrial biogenesis following SIT of varying durations [50-51,57], yet improvements in resting SV were only found following 7 weeks [58], but not 4 weeks [59] of SIT. Collectively, evidence seems to support the notion that improved skeletal muscle oxidative potential following SIT precedes improvements in cardiovascular fitness.

It is noteworthy that low-volume SIT/HIIT results in comparable [50-52] increases in skeletal muscle oxidative potential as MICT, despite reduced time commitments and training volumes. It has been suggested that the differences in exercise intensity across

MICT and SIT can partly explain these adaptations [60]. Compared to MICT, exercising at greater relative intensities as seen with SIT causes greater cellular stress, and accumulation of metabolites, ions and reactive oxygen species [61,62]. This in turn increases the phosphorylation and activity of various kinases such as AMP-activated protein kinase (AMPK), Ca^{2+}/calmodulin-dependent protein kinase II (CaMKII), and mitogen-activated protein kinase (MAPK) [63,64]. A downstream target of these kinases is peroxisome-proliferator activated receptor γ co-activator (PGC-1α), which functions as a transcriptional co-activator of several mitochondrial genes, and has emerged as a key regulator of mitochondrial biogenesis and many of the oxidative adaptations to aerobic exercise [61]. Thus, compared to lower intensity exercise (e.g., MICT), higher intensity exercise (e.g., SIT) results in greater messenger RNA expression, protein expression, and nuclear translocation of PGC-1α [64-66]. These signaling events coincide with increases in transcription of several mitochondrial genes [66].

1.4.3 Cardiovascular Safety of Performing SIT

Due to the relatively high exercise intensities attained during SIT or HIIT, concern has been raised over the safety of interval training in clinical populations. However, there is growing evidence of the safety of HIIT in various clinical populations (e.g. patients with coronary artery disease [67], diastolic dysfunction [68], and type II diabetes mellitus [68,69]). Rognmo and colleagues [70] followed 5000 patients with coronary artery disease undergoing either HIIT or MICT during cardiac rehabilitation. The risk of a cardiovascular event was low after both HIIT and MICT, with 2 non-fatal cardiac arrests

occurring over the course of 50,000 exercise hours in the HIIT group [70]. In the SCI population, no adverse events were reported SCI following 6- [71] and 8-weeks [72] of HIIT + functional electrical stimulation in persons with chronic injuries. However, the cardiovascular safety of an interval training program involving 'all-out' efforts (e.g., SIT) in various clinical populations such as persons with SCI has yet to be investigated.

1.4.4 Considerations for Application of SIT in Individuals with SCI

Due to cardiac sympathetic denervation with injury levels at or above the 5th thoracic vertebrae [31], HR responses will rarely exceed 120bpm during exercise. As a result of this, it can be difficult to gauge exercise intensity in individuals with tetraplegia using HR values, but there is a growing body of literature supporting the utility and efficacy of Borg's Rating of Perceived Exertion (RPE) scores to assess and prescribe exercise intensity in this population [73] According to Goosey-Tolfrey and colleagues [74], an RPE of 12/20 corresponds to moderate-intensity exercise, whereas an RPE of 16/20 corresponds to 'vigorous-intensity' exercise.

Special precautions specific to SCI should be considered while implementing high intensity exercise such as SIT. Exercise is considered to be a noxious stimulus capable of evoking an episode of AD, but it is currently unknown whether higher-intensity exercise increases the probability of AD occurring. Another area of concern with SIT in the SCI population is the development of shoulder over-use injuries. Given the quick generation of relatively high forces with SIT, one might predict that this type of training might induce, or exacerbate pre-existing shoulder and/or arm musculature pain. Pain in the

upper extremities during SIT should be closely monitored, as it can negatively impact one's ability to perform ADLs.

Persons with SCI face several environmental and psychosocial barriers to engage in physical activity, and because of this, it is unknown whether this population can adhere to chronic interval training. However, a recent scoping review [75] of 1300 participants (consisting of able-bodied, and various clinical populations) concluded that interval training can evoke similar/greater levels of perceived enjoyment than MICT. Astorino and colleagues [76] demonstrated that persons with chronic SCI experienced more enjoyment undergoing one session of HIIT and SIT, compared to traditional MICT. The unique structure of low-volume interval training (e.g., brief, intermittent periods of intense exercise, minimal time commitment) can reduce the perception of difficulty, provide a sense of accomplishment following each bout, and thus, increase the feeling of one's pleasure [76,77]. High levels of enjoyment with interval training can mean that individuals with SCI are more likely to incorporate and adhere to this form of exercise training.

Epidemiological studies [78,79] indicate that vigorous-intensity exercise offers superior cardiovascular benefits than moderate-intensity exercise, however, persons with chronic [8] and sub-acute [80] SCI generally spend little to no time performing high-intensity physical activity. Moreover, a recent randomized controlled trial [79] demonstrated that performing MICT for at least 20 minutes, twice weekly (e.g., adhering to the PAG for persons with SCI) was an insufficient training stimulus to promote clinically meaningful changes in biomarkers of cardiovascular health. The advantage of employing HIIT or SIT

is that it enables deconditioned individuals (e.g. persons with SCI) to perform vigorous-intensity exercise by incorporating periods of low-active recovery in between the short bouts of maximal effort. This notion is supported by recent work from Astorino and colleagues [82], where one session of SIT or HIIT elicited significantly higher metabolic, cardiovascular, and cardiorespiratory strain than MICT in individuals with chronic SCI. To date, however, there are no well-controlled training studies comparing HIIT or SIT to traditional MICT on the arm-ergometer in individuals with SCI, despite a recent call to action for further research in this field [83].

1.5 Summary and Statement of Purpose

Arm-ergometry training is frequently used during SCI inpatient rehabilitation for improving the physical capacity of patients in preparation for a return-to-home setting. Given the move towards a shortened LOS during SCI clinical rehabilitation, performing traditional MICT on the arm-ergometer can consume a valuable amount of therapy time. Low-volume SIT has been shown to be a time-efficient alternative to MICT for improving indices of physical fitness in both healthy and diseased populations. Little is known regarding the efficacy of SIT in persons with SCI. The purpose of this thesis was to evaluate the efficacy of a five-week, thrice weekly low-volume SIT protocol on the arm-ergometer and compare fitness outcomes to traditional MICT in patients with sub-acute SCI undergoing inpatient rehabilitation.

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Chapter II: Sprint Interval Training During Inpatient Rehabilitation After Spinal Cord Injury: A Randomized Controlled Trial.

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2.1 Abstract

Objective: To evaluate the efficacy of a five-week sprint interval training (SIT) protocol in individuals with sub-acute spinal cord injury (SCI) on the arm-ergometer.

Design: Randomized controlled trial.

Setting: Inpatient rehabilitation program.

Participants: Individuals with sub-acute SCI (N=20; time since injury, 2 – 26 weeks; age, 46 ± 16 years), with either tetraplegia (n=9; C2 – C7; ASIA, C – D), or paraplegia (n= 11; T4 – L4 ASIA, A – D) undergoing inpatient rehabilitation.

Interventions: Participants were randomized to SIT (n=10) or moderate-intensity continuous training ([MICT]; n =10). SIT consisted of 3 x 20 sec. 'all-out' cycle sprints (≥ 100% of peak power output [PO_{peak}]) interspersed with 2 min of active recovery (10% of PO_{peak}; total time commitment, 10 mins). MICT involved 20 min of cycling (45-60% of PO_{peak}; total time commitment, 25 mins). Heart rate (HR) and Borg's Rating of Perceived Exertion (RPE; 6 – 20) were monitored throughout training sessions.

Main Outcome Measures: Maximal (PO_{peak}) and sub-maximal exercise performance on the arm-ergometer, and exercise for self-efficacy (ESES) were assessed pre- and post-intervention. Exercise satisfaction, and pain were assessed at the end of the intervention.

Results: During training, relative HR (% HR_{peak}) and RPE was higher in the SIT group (MICT: HR, 83.8 ± 7.2%; RPE, 12 ± 1; SIT: HR, 104.9 ± 9.3%; RPE, 16 ± 1; $p < 0.001$). Following training, PO_{peak} increased by 36 ± 25%, with no difference between groups ($p < 0.001$). Relative HR: power output relationship improved similarly in both groups after training ($p < 0.001$), such that participants could perform higher power outputs for a given

submaximal HR. There was no difference in training adherence, ESES, exercise enjoyment, and pain across groups ($p > 0.05$).

Conclusions: Five weeks of SIT on the arm-ergometer in individuals with a sub-acute SCI improved PO_{peak}, and sub-maximal arm-ergometry performance to the same extent as MICT, despite less than half the time commitment. Both modes of exercise were equally tolerated and enjoyable.

2.2 Introduction

There are currently an estimated 86,000 Canadians living with a spinal cord injury (SCI), an impairment occurring at a rate of 600 per year [1]. SCI is commonly characterized by damage to the somatic and autonomic nervous system, resulting in skeletal muscle paralysis below the level of the lesion [2]. SCI can result in secondary complications including reduced skeletal muscle mass, neurogenic bowel and bladder, arm/shoulder over-use injuries, and urinary tract infections [3,4]. The combined effect of these complications with what is typically an extremely sedentary lifestyle [5] leads to physical deconditioning and reduced physical capacity of persons with SCI. Individuals with SCI often have difficulty coping with the physical strain of activities of daily living (ADLs), and give low ratings of quality of life (QoL) [5,6]. As a result of these unique complications, the primary goal(s) during SCI rehabilitation are enhancement of functional recovery, management of secondary complications, and augmenting physical capacity.

The rehabilitation process of SCI is long, expensive, exhausting (for the patient), requires a multidisciplinary approach, and consists of two phases (acute and sub-acute). The acute phase of SCI rehabilitation (time since injury [TSI], 0 – 4 weeks) begins immediately following injury with admission to acute clinical care, and consists of a 2 – 4 week bed rest period in order to stabilize symptoms from the initial trauma [7]. Following this, patients enter the sub-acute phase of their injury (TSI, 2 – 26 weeks) [8], and are admitted to inpatient rehabilitation, where the SCI rehabilitation team works together to enhance functional recovery, physically recondition, and prepare the patient for a return to home setting or an independent living environment [9]. Patients undergo a multitude of

therapies, including occupational therapy, therapeutic recreation, and physical therapy. Physical therapy typically utilizes the greatest proportion of therapy time [9], focusing on activities such as: transfers, over-ground walking, musculoskeletal treatments and modalities, aquatic exercises, and resistance and aerobic training [10]. The primary mode for performing aerobic exercise is arm-ergometry, and it has been reported that implementing ≥ 20 minutes of moderate-intensity continuous training (MICT) during SCI inpatient rehabilitation, at a frequency of ≥ 3 times / week, is effective for increasing the physical capacity of these patients [11-14]. Considering that SCI clinical rehabilitation is a comprehensive program, and given the trend towards a shortened length of stay during this phase in Canada (≈ 41 days) [15], performing MICT on the arm-ergometer can consume a considerable amount of valuable rehabilitation time.

Interval training consists of brief, intermittent bursts of vigorous activity, interspersed with periods of low-active recovery [16], which can be broadly classified into two categories: High-intensity interval training (HIIT) typically involves 'near-maximal' efforts at 85 – 95% of maximal heart rate, whereas sprint interval training (SIT) represents "all-out" efforts, or at intensities corresponding to ≥100% of peak oxygen uptake (VO_{2peak}) [17]. Recent work by Gillen and colleagues [18] show that 12 weeks of SIT in previously inactive men improved cardiorespiratory fitness and skeletal muscle mitochondrial content to the same extent as MICT, despite a five-fold lower exercise volume and training time commitment. As lack of time is the most commonly cited barrier to physical activity [19], the minimal training duration and exercise volume of SIT may be desirable for many individuals.

The advantage to employing SIT is that it enables persons with SCI to perform vigorous-intensity exercise by incorporating periods of low-active recovery [20]. This notion is supported by recent work from Astorino et al [21], where one session of SIT elicited significantly higher metabolic, cardiovascular, and cardiorespiratory strain than MICT in individuals with chronic SCI. To our knowledge, there has been only one study evaluating a SIT protocol on the arm ergometer in persons with SCI [22], where significant improvements in VO_{2peak} and peak power output (PO_{peak}) were seen after the two-week training program. To date, however, there are no randomized controlled trials (RCT) comparing the effects of SIT to MICT in individuals with a sub-acute SCI undergoing clinical rehabilitation.

The primary aim of this study was to investigate the efficacy of a five-week, thrice weekly 10 minute SIT program, and compare outcome measures to a traditional 25 minute MICT program on the arm-ergometer in individuals with sub-acute SCI undergoing inpatient clinical rehabilitation. It was hypothesized that five weeks of SIT and MICT would induce similar changes in maximal and sub-maximal exercise performance, self-efficacy for exercise, and exercise enjoyment, despite large differences in training volume and time commitment. It was also hypothesized that SIT would be well tolerated and elicit higher levels of cardiovascular strain than MICT.

2.3 Methods

2.3.1 Participants

Participants were individuals with SCI undergoing inpatient rehabilitation, aged 18 to 65 years, injury level at C2 or below, in the sub-acute phase of their SCI (TSI, 2 – 26 weeks), and received physician clearance to participate in arm-ergometry training. Data collection and training took place at the Regional Rehabilitation Centre, Hamilton Health Sciences, in Hamilton, Ontario, Canada. All study procedures were approved by the Hamilton Integrated Research Ethics Board, and participants gave written informed consent.

2.3.2 Experimental Design

All training sessions and performance tests were completed on the Monark 881E Rehab Trainer (Patterson Medical Supply, Mississauga, ON, Canada). To enhance exercise efficiency, the arm ergometer was positioned such that axis of the crank arm was horizontally aligned with the participants shoulder and the arms were slightly flexed at the furthest point of reach [3]. Participants underwent training sessions and exercise performance tests in the morning, either before or after their routine physical therapy session. Participants were asked to refrain from using the arm-ergometer outside of the training study, however, performing aerobic exercise using other modalities were acceptable (e.g., recumbent stepper - Nu-Step™). Heart rate (HR) was continuously monitored (Polar T31) and Borg Ratings of Perceived Exertion (RPE - 6-20 categorical scale [23]) for both for central (heart and lungs) and peripheral (arms) components were used to gauge exercise intensity throughout training sessions and exercise performance

tests. Participants were asked to empty their bladder immediately before, and refrain from caffeine and alcohol ≥12 hours prior to completing training and exercise performance tests. $PO_{peak,}$ sub-maximal exercise performance, and self-efficacy were assessed at baseline (pre-training), and following five weeks of training (post-training). Exercise enjoyment and pain were assessed following the intervention. Following the final training session, participants were given three days rest prior to completing post-testing.

2.3.3 Training Intervention

Following pre-training assessments, participants were randomly allocated to the MICT group or the SIT group. Exercise sessions were offered to participants at a frequency of three times per week, for five weeks. Adherence to the exercise intervention was expressed as a percentage of the number of sessions completed over the maximum number of sessions that could be completed (15 sessions). All exercise sessions began with a 2-minute warm-up and concluded with a 3-minute cool down (≈10% peak power output [PO_{peak}]), at a self-selected cadence. The SIT protocol was adopted from Gillen and colleagues [18], and consisted of: 3 x 20 second "all-out" efforts at ≥ 100% of PO_{peak}, or at an RPE approximating to 16 ± 1. Each sprint was interspersed by 120 seconds of active recovery at ≈10% PO_{peak}. Individuals randomized to the MICT group underwent arm-ergometry training that is in accordance with the Physical Activity Guidelines (PAG) in individuals with SCI [24]. Specifically, MICT consisted of 20 minutes of arm cycling at a self-selected cadence at 45 – 60% of PO_{peak}, or at an RPE corresponding to 12 ± 1. Central and peripheral RPE, and HR were recorded at the end of each sprint (SIT group)

or at 5, 10, 15, and 20 minutes of exercise (MICT group). Total training duration for each session (including warm-up and cool-down) was 10 minutes for SIT and 25 minutes for MICT. For participants that could not initially complete the full duration of a training session, training progression involved gradually increasing the duration over the first week of training to meet the desired training session duration (either 25 mins MICT or 10 mins SIT). Thereafter, as soon as trainers noted decreases in RPE during the training, training intensities (e.g., flywheel resistance) were adjusted to maintain the target RPE of 16 for SIT and 12 for MICT.

2.3.4 Graded Maximal Workload Test

Participants underwent a maximal graded exercise test on the arm-ergometer to assess PO_{peak}. Participants first warmed up on the arm-ergometer for 1 minute with no resistance. Thereafter, power output was increased in a ramp-like matter by 10 W/min for persons with paraplegia, and 5 W/min for persons with tetraplegia [25]. Participants were asked to maintain a constant, self-selected cadence between 60 – 80 revolutions per minute. Participants continued to pedal until one of the following criteria were met: (i) volitional exhaustion, (ii) they were unable to maintain their self-selected pedaling cadence for 20 consecutive seconds (iii) reported RPE was > 19, or (iv) they demonstrated any symptoms requiring immediate cessation of the test according to ACSM guidelines (increased nervous system symptoms [e.g., blurred vision, dizziness, headache], chest discomfort) [26]. PO_{peak} was defined as the highest workload participants could maintain for at least 30 seconds.

2.3.5 Discontinuous Sub-Maximal Arm-Ergometry Test

The Discontinuous University of Toronto Arm Crank Protocol [27] was used to assess the HR/power output relationship at three sub-maximal workloads. Participants performed three 5-minute steady state workloads on the arm-ergometer at power outputs approximating RPE's of 8, 10 and 12 [28]. Participants were given a minimum of 2 minutes, and a maximum of 5 minutes of rest in between each workload.

2.3.6 Exercise Satisfaction

Participants completed the Physical Activity Enjoyment Scale (PACES) in order to assess the level of enjoyment with the training intervention they received. The PACES entails 18 bi-polar items (e.g., I enjoy it, I hate it) that is scored on a 1 – 7 likert scale. The PACES is a valid and reliable measure that has been previously used in the SCI population [29].

2.3.7 Self-Efficacy

Perceived self-efficacy for exercise was measured using the SCI Exercise Self Efficacy Scale (ESES) [30]. The SCI ESES consists of 10 questions and instructs respondents to indicate on a four-point likert scale (1 = not true at all, 4 = always true) how confident they are with regards to performing and carrying out regular physical activities and exercises. The SCI ESES contains high internal consistency (chronbach's $\alpha = 0.926$) [30].

2.3.8 Pain

Pain perceptions were measured using the questionnaire created by Pelletier and colleagues [31]. Using a 7-point scale, participants rated how much shoulder pain, bodily

pain, and physical discomfort they typically experience throughout the day and how much they experienced during arm-ergometry training (1 = none, 7 = extreme pain).

2.3.9 Statistics

Independent *t* tests were performed to determine group differences in baseline characteristics. A three-way mixed ANOVA was used to examine differences in exercise workload, heart rate, RPE, and PO_{peak} across group (SIT vs. MICT), injury level (paraplegia vs. tetraplegia), and time (weeks 1 – 5). For the sub-maximal arm-ergometry test, workload (workloads 1 – 3) was included as a fourth factor in the ANOVA. Tukey's post hoc test was used where appropriate. Effect sizes were determined using partial eta-squared (η^2_p) and reported as small, 0.009; medium, 0.058; and large, 0.137 [32]. Mann-Whitney *U*-tests were used to compare results between groups regarding pain, self-efficacy, and exercise enjoyment. Wilcoxon signed-rank tests were used to compare changes in pain, and self-efficacy within each group. Statistical analyses were performed using IBM SPSS Statistics, version 20.0. Significance was set at an alpha level < 0.05. Unless otherwise noted, values are presented as mean± SD.

2.4. Results

2.4.1 Baseline Characteristics, Program Adherence, and Adverse Events

Recruitment and training took place from June 2017 to May 2018 (Fig. 1). Twenty-two participants were randomly allocated to MICT (n=10) or SIT (n=12). Two participants undergoing SIT were unwillingly to continue for reasons unrelated to the intervention.

Twenty participants completed the intervention (MICT n=10, SIT n=10) and were included in the final analyses. There were no differences in participant characteristics between groups (Table 1). The attendance rate was 89.9 ± 13.0% and 86.0 ± 12.4% for the MICT and SIT group, respectively (p=0.501). Out of the 132 SIT training sessions conducted, only one adverse event occurred (an episode of post-exercise hypotension [session #, 1; injury level, T10; ASIA, C]).

2.4.2 Exercise Workload

Workloads during the intervals in the SIT group and during the MICT sessions corresponded to 154.0 ± 55.7% and 64.71 ± 17.2% of the PO_{peak} achieved during the graded maximal workload test at pre-training, respectively ($p<0.001$, $\eta^2_p=0.604$). There was a group x week interaction effect on average exercise volume ($p<0.001$, $\eta^2_p=0.433$), indicating a significantly higher training volume (over the 5 weeks) in the MICT group. Compared to week 1, both groups were able to complete significantly higher exercise volumes at week 5 (MICT: week 1, 27.7 ± 15.4kJ, week 5: 44.8 ± 19.5kJ; SIT week 1: 10.2 ± 6.6kJ; week 5: 15.1 ± 8.7kJ). This result is depicted in Figure 2.

2.4.3 Heart Rate and Rating of Perceived Exertion

Six participants were using HR-lowering medication (Table. 1) throughout the intervention and were excluded from the absolute HR analysis (sample size used: n=14, MICT n=7, SIT n=7). Relative HR was expressed as a percentage of peak HR (HR_{peak}) achieved during the maximal graded exercise test at pre-training. Absolute and relative

mean HR was significantly higher for individuals performing SIT (absolute HR: $p=0.05$, $\eta^2_p=0.330$; relative HR: $p<0.001$; $\eta^2_p=0.646$). Absolute HR was 135.7 ± 29.8 bpm for the SIT group and 119.9 ± 17.0 bpm for the MICT group, corresponding to 104.9 ± 9.3 % and 83.8 ± 7.2 % of HR_{peak}, respectively. There was a trend for a group x level of injury interaction ($p=0.065$, $\eta^2_p=0.301$) effect on absolute HR. In subjects with paraplegia, absolute HR was 163.5 ± 12.8 bpm for the SIT group, and 124.7 ± 19.4 bpm for the MICT group. In participants with tetraplegia, absolute HR was 114.9 ± 17.8, and 112.8 ± 13.3 bpm for the SIT and MICT group, respectively. Absolute and relative HR responses are depicted in Figure. 3.

Following each training session, individuals performing SIT reported a significantly higher central and peripheral RPE than those performing MICT. Central RPE was 15.0 ± 1.7 and 11.0 ± 3.0 ($p<0.01$, $\eta^2_p=0.417$), and peripheral RPE was 15.9 ± 1.3 and 12.3 ± 1.7 ($p<0.001$, $\eta^2_p=0.648$), for the SIT and MICT groups, respectively. These results are depicted in Figure 4.

Desired training intensity was maintained within both groups such that there was no group x time interaction for either HR (absolute HR: $p=0.435$, $\eta^2_p=0.088$; relative HR: $p=0.723$, $\eta^2_p=0.033$) or RPE responses (central RPE: $p=0.102$, $\eta^2_p=0.112$; peripheral RPE: $p=0.263$, $\eta^2_p=0.078$).

2.4.4 Graded Maximal Workload Test

PO_{peak} significantly increased after training ($p<0.001$, $\eta^2_p=0.728$), with no difference between groups ($p>0.05$, $\eta^2_p=0.01$). The SIT and MICT groups increased peak power

output by 39.4 ± 29.8%, and 33.2 ± 24.8%, respectively. These results are depicted in Figure 5.

2.4.5 Discontinuous Sub-Maximal Arm-Ergometry Test

HR (absolute and relative), and RPE (central and peripheral) responses during the discontinuous three-stage arm ergometry test did not change significantly from pre- to post-training, and there was no effect of injury level. Performance (measured by power output) during the three-stage test significantly improved over time ($p<0.001$, $\eta^2_p=0.730$), with no differences between groups (group x time interaction: $p=0.260$, $\eta^2_p=0.079$). As expected, power output was different between individuals with paraplegia versus tetraplegia ($p<0.01$, $\eta^2_p=0.352$). Arm ergometry performance changes in both groups are presented in Figure. 6 and Table. 2.

2.4.6 Exercise satisfaction, self-efficacy, and perceived pain questionnaires

Results of the questionnaires are presented in Table. 3. There were no group differences in exercise enjoyment, self-efficacy, and perceived pain. There was no significant change in self-efficacy over the course of the training intervention. Compared to perceived typical pain, lower mean scores of perceived arm-bike specific pain in both groups support the conclusion that both modes of exercise were well tolerated ($p<0.05$).

2.5 Discussion

The major novel finding from this study was that 5 weeks of SIT on the arm-ergometer in individuals with sub-acute SCI undergoing inpatient rehabilitation improved PO_{peak}, and sub-maximal arm-ergometry performance to the same extent as MICT, despite a lower exercise volume and time commitment. The SIT protocol involved a total of one minute of intense intermittent exercise, within a time commitment of 10 minutes per session [18], whereas MICT consisted of 20 minutes of continuous cycling within a 25 minute total time commitment. In addition, despite SIT eliciting significantly higher cardiovascular (HR) and perceived exertion (RPE) than MICT, both modes of exercise were equally well tolerated and enjoyable.

2.5.1 Program Adherence and Adverse Events

Twenty participants completed the training intervention, and attendance rates for both the SIT (86%) and the MICT (89.9%) group were high. The minimum percentage of exercise sessions attended for determining whether an exercise intervention for persons with SCI is feasible or not remains to be established, however with no significant differences in adherence between groups, we are confident that SIT on the arm-ergometer during SCI inpatient rehabilitation is feasible.

Out of the 132 SIT sessions conducted, only one adverse event (episode of post-exercise hypotension) was reported following a participant's first SIT session. It should be noted that, compared to able-bodied individuals, post-exercise hypotension is more likely to occur in persons with SCI during a bout of arm-ergometry, and this can be

attributed to decreased vasomotor control below the level of the lesion [33]. Nonetheless, results of the current study suggest that there is no greater risk of hypotension performing SIT vs. MICT on the arm-ergometer.

2.5.2 Exercise Responses to SIT and MICT

Individuals performing SIT demonstrated significantly higher relative HR values than those performing MICT, and these HRs were comparable to those reported following a single session of SIT and MICT on the arm-ergometer in individuals with chronic SCI [21]. The relative HRs recorded during SIT are considerably higher than those recorded in individuals with chronic SCI undergoing over ground walking with a robotic exoskeleton [34], and in persons with paraplegia performing circuit training [35], suggesting more cardiovascular strain with SIT. A likely explanation for these findings is that at higher relative exercise intensities, more type II motor units can be recruited, leading to higher cardiovascular responses in SIT than MICT [36].

As expected, there was strong evidence of sympathetic dysfunction during training in the subjects with tetraplegia, such that the HR values for the SIT and MICT group were 114.9 ± 17.8bpm (paraplegia: 163.5 ± 12.8bpm), and 112.8 ± 13.3 bpm (paraplegia: 124.7 ± 19.4 bpm), respectively. The blunted cardiovascular response in subjects with injuries above the level of the 5th thoracic vertebrae can be attributed to an absence of cardiac sympathetic innervation [37]. This sympathetic dysfunction makes it difficult to gauge exercise intensity in persons with tetraplegia using HR values, but there is a growing body of literature supporting the utility and efficacy of RPE scores to assess

exercise intensity in this population [38]. Regardless of injury level, we found RPE (peripheral and central) responses to be significantly higher for individuals performing SIT (≈16) than MICT (≈12). An RPE of 16/20 corresponds to 'vigorous-intensity' exercise [20], which is an exercise intensity that individuals with chronic [5] and sub-acute [39] SCI generally spend little to no time performing.

2.5.3 Maximal and Sub-Maximal Exercise Performance

Following five weeks of SIT or MICT, participants significantly improved their PO_{peak} to a similar degree (39% and 33%, respectively). Previous work in the SCI population has found comparable improvements in PO_{peak} following MICT on the arm-ergometer during SCI inpatient rehabilitation, with time commitments ranging from 25 to 90 minutes/session [10-13]. Clinically meaningful improvement standards with respect to PO_{peak} in individuals with SCI remain to be established, however, the improvements reported in the current study are considerably larger than those reported by Haisma and colleagues [40], where individuals receiving clinical rehabilitation with no arm-ergometry training improved PO_{peak} by only 10%.

We also observed improved sub-maximal power output after both modes of training. Power outputs during all three stages of the sub-maximal arm-ergometry test were significantly higher after training, with no significant differences in sub-maximal HR, relative HR, and RPE. These results suggest that participants could perform significantly more work at a given sub-maximal HR (or RPE) after training. Similar findings were reported, albeit in individuals with chronic SCI, following 9 months of

twice-weekly MICT on the arm-ergometer, and resistance training [28]. These improvements in sub-maximal capacity should have direct impact on the ability to perform ADLs. An increased power output for a given perceived effort (or HR) will mean that people will be able to perform a greater amount of work before getting fatigued. The fact that low-volume SIT can promote similar increases in physical capacity as higher-volume MICT means that clinical rehabilitation specialists can now offer a new, more time-efficient, exercise training strategy to elicit improvements in their patients.

2.5.4 Palatability of Exercise Interventions

Our data demonstrate that both modes of exercise were highly enjoyable, and there were no significant differences in enjoyment across groups. Stork and colleagues [41] conducted a scoping review of 1300 participants drawn from the able-bodied, and various clinical populations and concluded exercise enjoyment for HIIT/SIT to be greater and/or comparable to MICT. The unique nature of low-volume interval training (brief, intermittent periods of intense exercise, minimal time commitment) can lead individuals to perceive SIT to be more enjoyable than other forms of exercise [42].

Participants reported lower perceptions of pain during MICT or SIT compared to the rest of the day, with no differences across groups, indicating that both modes of training were well tolerated. Following SCI, there is an extensive reliance on the upper limbs for performing ADLs, which leads to a greater prevalence of shoulder over-use injuries and musculoskeletal pain in this population [43]. Given the quick generation of relatively high forces with SIT, one might predict that this type of training might pose a

risk to the shoulder and/or arm musculature in people with SCI. The results from the current study refute this, suggesting no specific risk for this type of training.

Subjects in the present study reported relatively high self-efficacy for exercise before training began, and there were no significant changes in self-efficacy following MICT or SIT. These findings have been previously documented for persons with SCI undergoing inpatient rehabilitation [44,45]. These results imply that individuals with SCI undergoing rehabilitation are confident about performing physical activity and exercise. This is not entirely surprising, given the relatively short time post injury and limited experience with adapting exercise to accommodate their abilities [31]. Self-efficacy for exercise may possibly change following discharge from rehabilitation [46], when persons with SCI are required to initiate regular exercise on their own.

2.6 Study limitations

As the study was performed in recently injured individuals in a primary rehabilitation setting, the improvements in physical capacity could be attributed to the usual rehabilitation program and natural processes of recovery/adaptations following SCI. Second, the sample size was relatively small and heterogeneous, which did not allow for stratification based on injury level, injury severity or sex, which limits the ability to draw meaningful conclusions regarding the efficacy of SIT in this population. For example, there were not any females randomized to perform SIT in the current study, however, Metcalfe and colleagues [47] found similar gains in aerobic capacity in able-bodied males and females following 6 weeks of SIT, suggesting that there are no divergent training

adaptations between sexes with this mode of training. Finally, we did not perform any direct measurements of oxygen uptake or muscle strength, so we are unable to determine whether the improvements in power output were due to changes in aerobic capacity or strength, nor whether there would be differences between the two training regimens in these outcomes.

2.7 Conclusion

This is the first RCT comparing SIT to MICT on the arm-ergometer in individuals with sub-acute SCI undergoing inpatient rehabilitation. Our results demonstrate that five weeks of thrice weekly SIT on the arm-ergometer significantly improved indices of physical capacity to the same extent as MICT, despite a substantially lower exercise volume and time commitment. Both modes of exercise were equally well tolerated and highly enjoyable. Given the shortened times of stay in inpatient rehabilitation, the incorporation of SIT may be a more time efficient strategy to improve physical capacity in this population.

2.8 References

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2.9 Tables

Table 1 Baseline participant characteristics.

Parameter		MICT (n= 10)	SIT (n= 10)
Age (years)		45 ± 17	47 ± 15
Sex			
	Male	5 (50)	10 (100)
	Female	5 (50)	0 (0)
TSI (days)		56 ± 42	72 ± 68
Lesion level			
	Tetraplegia	5 (50; C2 – C7)	4 (40; C2 – C4)
	Paraplegia	5 (50; T4 – L4)	6 (60; T8 – L2)
ASIA class			
	A	1 (10)	1 (10)
	B	0 (0)	0 (0)
	C	4 (40)	4 (40)
	D	5 (50)	5 (50)
HR-lowering medication*		3 (30)	3 (30)

NOTE. Values are mean ± SD, n (%) or n (%; range). No significant differences across MICT and SIT. Abbreviations: TSI, time since injury; ASIA, American Spinal Injury Association; HR, heart rate. * β-blockers, Ca^{2+} channel blockers etc.

Table 2 Changes in submaximal exercise responses during the discontinuous three-stage arm ergometry test.

	Central RPE #		Peripheral RPE #		Heart rate (bpm) #		Relative heart rate (% HR_{peak}) #		Power (watts)*,#	
	MICT	SIT	MICT	SIT	MICT	SIT	MICT	SIT	MICT	SIT
Pre-Training										
WorkloadI	8.6 ± 2.3	10.0 ± 2.4	8.5 ± 2.2	10.6 ± 1.7	104.9 ± 23.4	97.1 ± 13.2	79.7± 8.5	78.9 ± 10.3	11.5 ± 4.9	13.1 ± 12.0
WorkloadII	11.7 ± 2.9	12.0 ± 2.2	11.8 ± 2.5	12.8 ± 1.8	115.4 ± 26.5	105.1 ± 16.9	87.4 ± 8.6	85.0 ± 9.8	22.0 ± 10.0	23.3 ± 17.8
WorkloadIII	13.9 ± 3.2	14.1 ± 2.0	14.6 ± 2.2	15.1 ± 1.3	125.1 ± 27.9	116.5 ± 25.1	94.9 ± 9.4	93.2 ± 8.0	29.6 ± 14.1	32.3 ± 21.8
Post-Training										
WorkloadI	9.1 ± 2.0	9.8 ± 1.4	9.9 ± 1.7	11.1 ± 1.5	106.4 ± 20.4	95.4 ± 16.3	81.5 ± 8.5	77.6 ± 13.3	27.5 ± 11.5	22.7 ± 15.0
WorkloadII	11.6 ± 2.2	11.0 ± 1.7	12.3 ± 1.9	12.2 ± 1.7	114.9 ± 19.4	105.4 ± 18.1	88.1 ± 6.1	85.7 ± 14.4	37.3 ± 13.9	33.9 ± 18.7
WorkloadIII	13.7 ± 1.9	13.3 ± 1.5	14.5 ± 1.7	14.9 ± 1.1	124.9 ± 26.3	115.7 ± 18.6	95.2 ± 7.4	94.3 ± 16.2	44.7 ± 16.8	44.9 ± 22.3

NOTE. Values are mean ± SD. No significant differences in exercise responses across MICT and SIT. * Main effect of time (e.g., pre-training vs. post-training; $p < 0.001$). # Main effect of workload (e.g., workload I vs. workload II vs. workload III; $p<0.001$). Relative heart rate, percent (%) of heart rate peak achieved during the graded maximal exercise test at pre-training.

Table 3 Group responses to questionnaires.

	MICT	SIT
PACES	99.8 ± 16.7	106.5 ± 13.7
ESES (week 1)	36.2 ± 3.2	36.1 ± 3.2
ESES (week 5)	34.7 ± 4.9	35.0 ± 4.8
Δ ESES (week 5 – week 1)	-1.5 ± 2.7	-1.2 ± 6.3
Typical pain	9.4 ± 5.6	10.0 ± 4.4
Arm-bike specific pain*	7.0 ± 3.9	6.9 ± 3.1
Δ pain (arm-bike – typical)	-2.4 ± 4.0	-3.1 ± 5.6

NOTE. Values are mean ± SD. No significant differences across MICT and SIT. Abbreviations: PACES, physical activity enjoyment scale; ESES, exercise for self-efficacy scale; Δ, delta. * Main effect of condition (e.g., typical pain vs. arm-bike specific pain; $p < 0.05$).

2.10 Titles and Legends to Figures

Figure 1. Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

Figure 2. Mean exercise volume over five weeks of MICT or SIT. Mean ± SEM are shown. There was a significant group x time interaction ($p<0.001$). ***** Values are significantly different across groups. † Values are significantly different from week 1.

Figure 3. Absolute (a) and relative HR ($\%HR_{peak}$) (b) responses during the training intervention. Responses were assessed across group only (Total; e.g., MICT vs. SIT) and group x injury level (e.g., tetraplegia vs. paraplegia). Mean ± SEM are shown. ***** Denotes a main effect of group ($p \leq 0.05$).

Figure 4. Central (a) and peripheral (b) rating of perceived exertion (RPE) responses across MICT and SIT. Mean ± SEM are shown. For both responses, there was a main effect of group (e.g., MICT vs. SIT; $p < 0.01$). ***** Values are significantly different across groups.

Figure 5. Peak power output (watts) during the maximal graded exercise test at pre-training and post-training. Mean ± SEM are shown. ***** Denotes a main effect of time (e.g., pre-training vs. post-training ; $p < 0.001$).

Figure 6. Relative heart rate (HR)/power output relationships during the three-stage discontinuous submaximal arm-ergometry test at pre-training and after 5 weeks (post-training) of MICT (a) or SIT (b). Mean ± SEM for relative HR and power output are shown. ***** Denotes a main effect of time (e.g., pre-training vs. post-training; $p < 0.001$).

2.11 Figures

Figure 1.

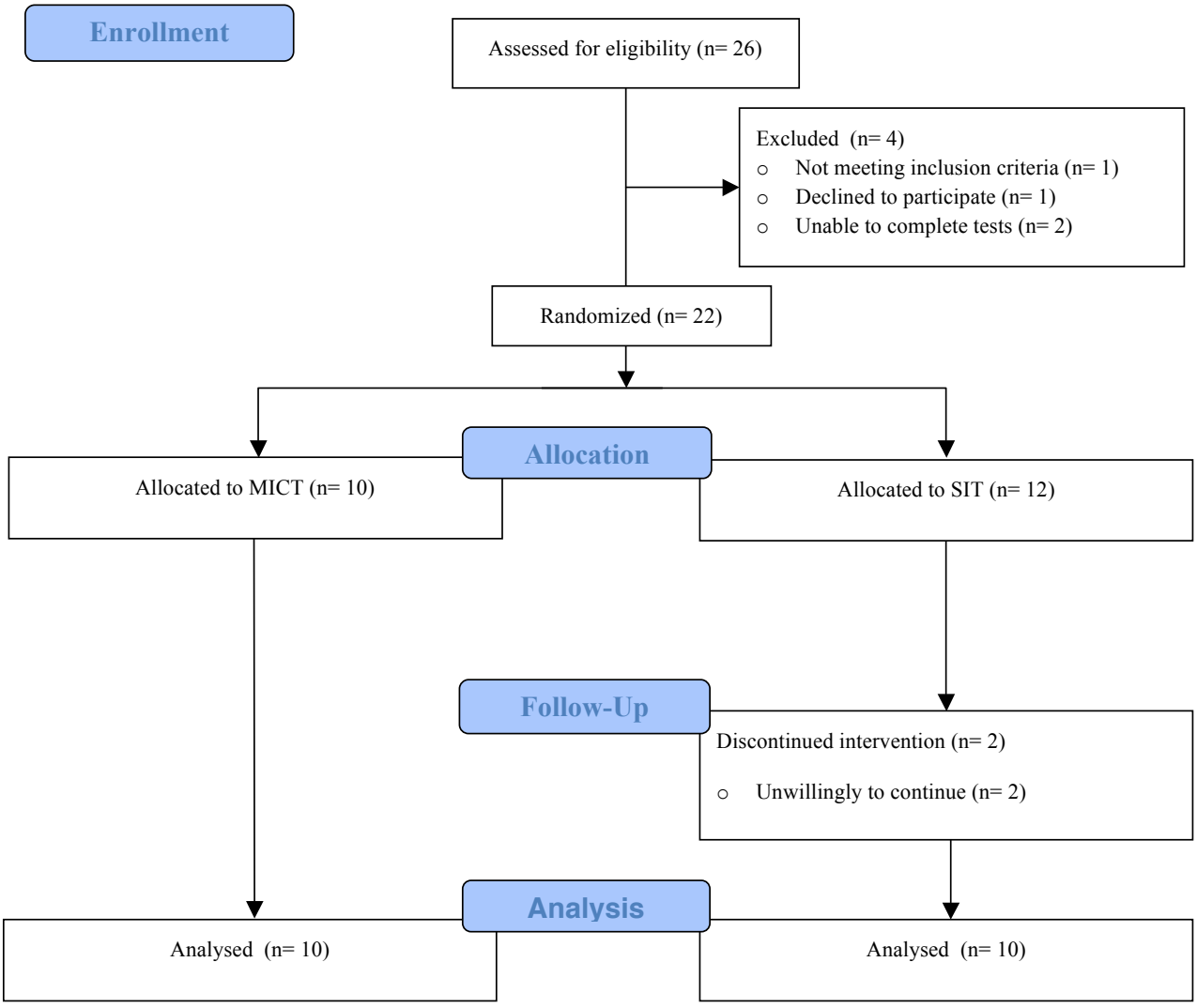


Figure. 2

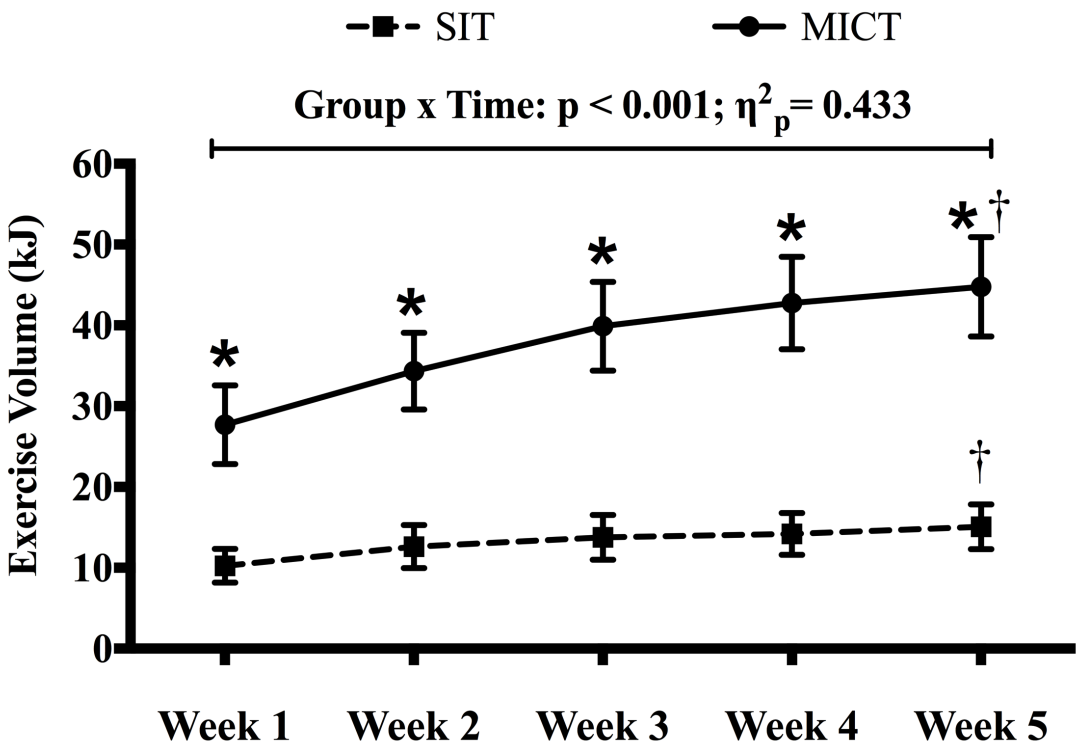

SIT
MICT
Group x Time: p < 0.001; η²p= 0.433
Exercise Volume (kJ)
60
50
40
30
20
10
0
*
*
*
*
*
†
†
Week 1
Week 2
Week 3
Week 4
Week 5

Figure. 3

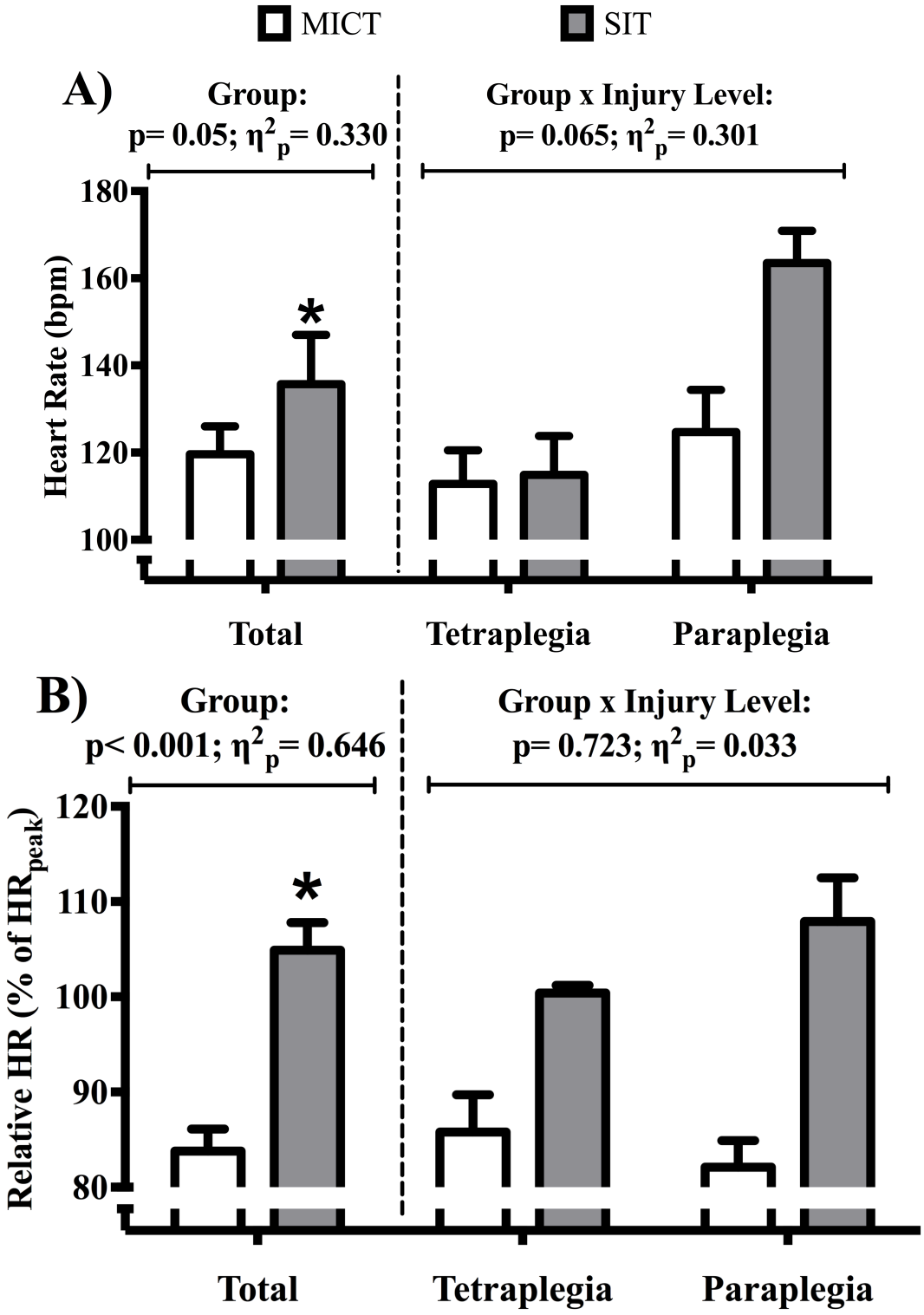

MICT
SIT
A)
Group:
p= 0.05; η²p= 0.330
Group x Injury Level:
p= 0.065; η²p= 0.301
Heart Rate (bpm)
180
160
140
120
100
*
Total
Tetraplegia
Paraplegia
B)
Group:
p< 0.001; η²p= 0.646
Group x Injury Level:
p= 0.723; η²p= 0.033
Relative HR (% of HRpeak)
120
110
100
90
80
*
Total
Tetraplegia
Paraplegia

Figure. 4

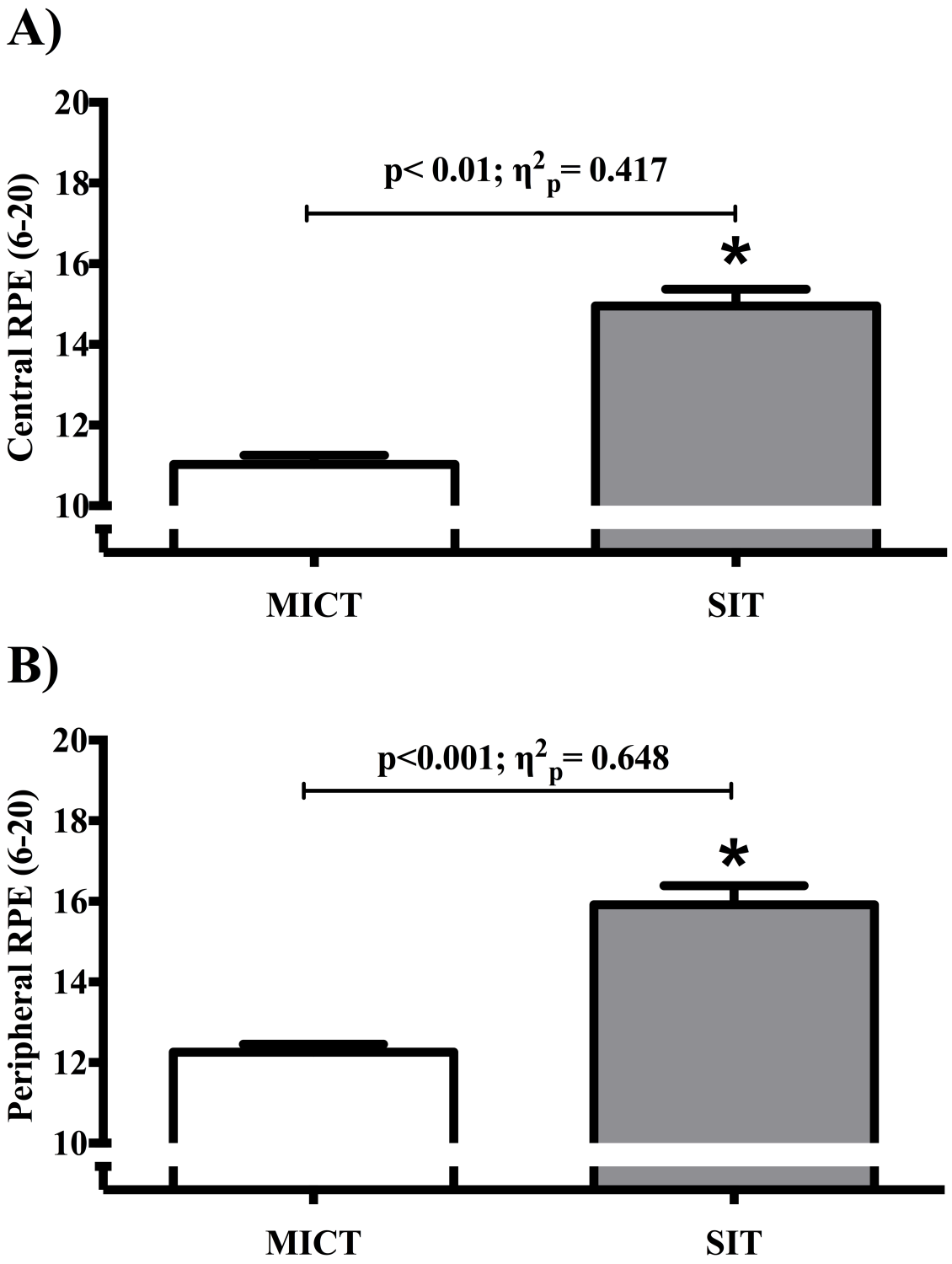

A)
Central RPE (6-20)
20
18
16
14
12
10
p< 0.01; η²p= 0.417
*
MICT
SIT
B)
Peripheral RPE (6-20)
20
18
16
14
12
10
p<0.001; η²p= 0.648
*
MICT
SIT

Figure. 5

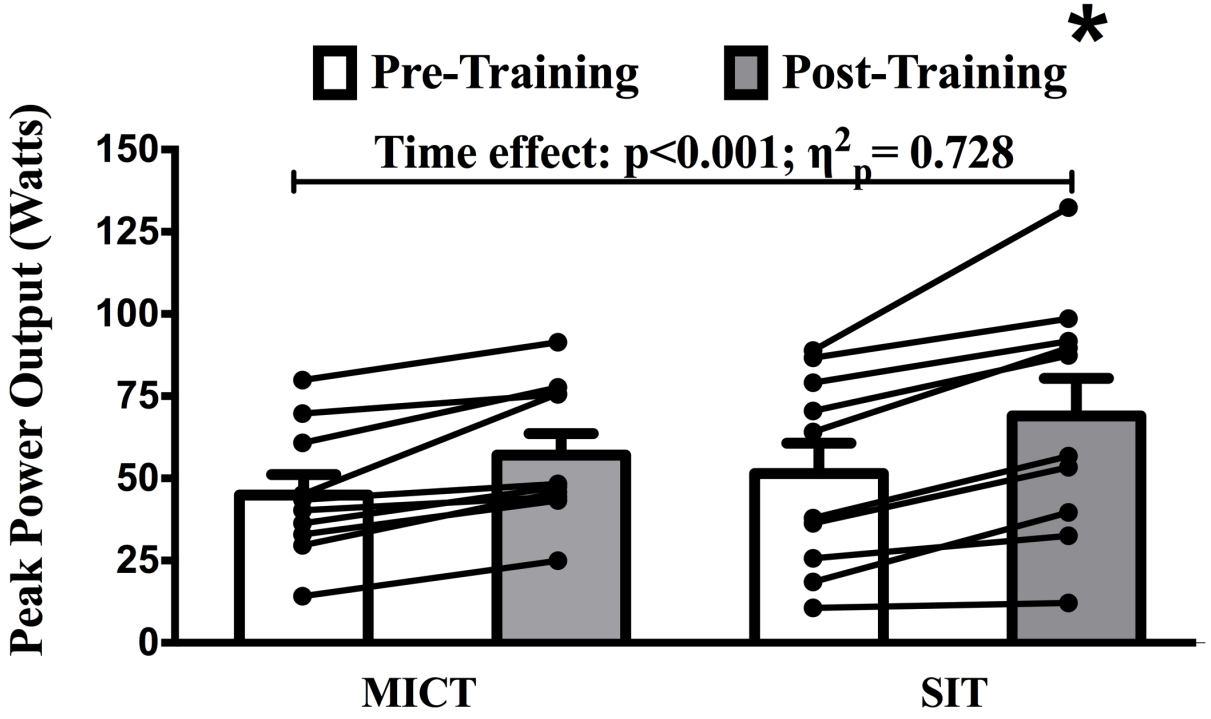
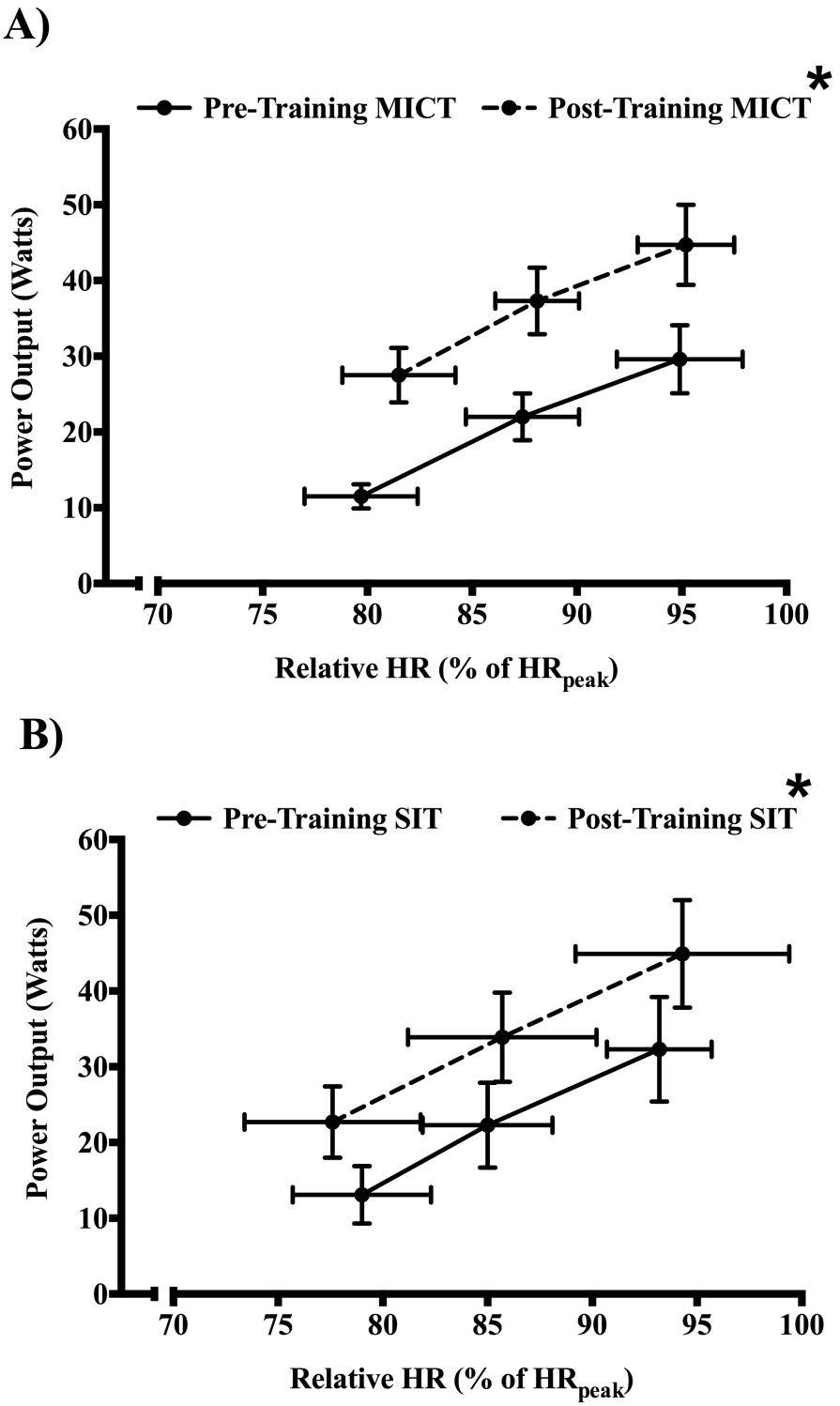

Pre-Training
Post-Training
*
Time effect: p<0.001; η²p= 0.728
Peak Power Output (Watts)
150
125
100
75
50
25
0
MICT
SIT

Figure. 6


A)
Pre-Training MICT
Post-Training MICT
*
Power Output (Watts)
0
10
20
30
40
50
60
70
75
80
85
90
95
100
Relative HR (% of HRpeak)
B)
Pre-Training SIT
Post-Training SIT
*
Power Output (Watts)
0
10
20
30
40
50
60
70
75
80
85
90
95
100
Relative HR (% of HRpeak)

Appendix. A Participant Information Letter and Consent Form

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Department of Kinesiology
Faculty of Science

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IWC
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L8S 4K1

Phone 905.525.9140
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http://www.science.mcmaster.ca/kinesiology

Participant Information Letter

Implementation of a 5-week thrice-weekly Sprint Interval Training (SIT) protocol during Inpatient Spinal Cord Injury (SCI) Rehabilitation

You are invited to participate in a research study conducted by:

Student Investigator: **Jonathan Mcleod**
Graduate Student
Department of Kinesiology
McMaster University
Mcleoj2@mcmaster.ca

Principal Investigator: **Dr. Audrey Hicks**
Department of Kinesiology
McMaster University
(905) 525-9140 ext. 24643

What is the purpose of this study?

You are being asked to participate in a study that will be exploring a new form of exercise training for inpatient rehabilitation after spinal cord injury (SCI). Sprint Interval Training (SIT) has received a lot of attention in the past decade as a more time-efficient strategy in comparison to Moderate Intensity Continuous Training (MICT). The purpose of this study is to determine if SIT is a suitable alternative to the usual standard of practice (MICT) during inpatient SCI rehabilitation. The study will determine if SIT results in improvements in arm bike performance and peak power output. Further, the study will determine if SIT is safe, enjoyable and results in improvements in self-efficacy. We anticipate on recruiting 30 participants over the course of 10 months from the Regional Rehabilitation Centre at the Hamilton General Hospital.

What will my responsibilities be if I participate in this study?

After obtaining your consent, you will be asked to complete all baseline measurements before being randomized to either one of two groups (SIT versus current standard practice MICT). You will have a 50:50 chance of being assigned to the SIT or MICT group. The exercise program will consist of three sessions per week, for a total of 5 weeks. All sessions will begin with a 2 minute warm-up and terminate with a 3 minute cool-down of low-intensity arm cycling. If you are in the SIT group, you will engage in three bouts of "all-out" maximal efforts on the arm bike for 20 seconds. Each bout will be followed by 2 minutes of low-intensity arm cycling. If you are in the MICT group, you will engage in 20-minutes of moderate intensity arm cycling. Every session will be supervised and assisted by trained staff and volunteers.

You will be asked to complete two tests of physical fitness before and after the 5-week study period. The first test is a peak power test, where you will exercise on the arm bike until you can no longer maintain the pedaling cadence. The resistance against the arm pedals will progressively increase throughout the test. During the test, we will be asking for your rating of perceived exertion. The test will continue until we see you have reached your max or you feel like you cannot go any longer. For the second test, you will be asked to arm cycle for 5-7 mins at three different submaximal workloads. Heart rate will be continuously monitored throughout the test and you will be asked to indicate your rating of perceived exertion.

Following the 5-week training study you will be asked to complete two written questionnaires. The first questionnaire will be used to assess your satisfaction and level of enjoyment with the exercise program you were given. The second questionnaire will assess whether you experience any pain during the exercise you performed over the training period. You will be asked to fill out a third questionnaire at baseline testing and following the 5-weeks. This questionnaire will assess your confidence and intentions on being able to perform physical activities and exercise.

What are the possible risks or discomforts?

There are some physical risks while you complete testing and your exercise program. Testing procedures are similar to those associated with any form of strenuous physical activity. These include fatigue, fainting, abnormal blood pressure, irregular heart rhythm, and in very rare instances, heart attack, stroke or death. Every effort will be made to minimize these potential risks by evaluation of preliminary information relating to your health and fitness and by careful observations during testing. We will be monitoring heart rate, blood pressure (if needed) and signs/symptoms of discomfort. Testing will be terminated immediately if you are experiencing symptoms that are not normal. Your muscles may be tired and sore following your sessions and you may feel fatigued. These symptoms should subside on their own without intervention

What are the possible benefits for me or society?

Regular exercise has been demonstrated to be beneficial for people living with a SCI. You may see improvements in your aerobic fitness and muscular strength, quality of

life and mobility if you participate in regular physical activity. The results from this study will provide important information on whether arm cycle SIT is a feasible alternative to the current standard of practice (MICT) during inpatient SCI rehabilitation.

Will there be any payment or reimbursement if I participate in this study?

As regular exercise is already part of the inpatient rehabilitation regime, there is no payment/reimbursement for participation in this study.

What information will be kept private?

Your personal information will not be shared with anyone, except with your consent. The information obtained by me will be kept in a locked cabinet. Your data will be linked to a number. The list linking your number and name, with any other personal information, will be kept separate from the data in a secure place. If the results are published, no names or identifying information will be released or published without your specific consent to the disclosure.

What if I change my mind about participating in the study?

Your participation in this study is voluntary. If you volunteer to be in this study, you may withdraw at any time, even after signing the consent form or part-way through the study, including during any of the tests or during the five week training period. In cases of withdrawal your data will be destroyed unless you indicate otherwise. The investigator may withdraw you from this research if circumstances arise which warrant doing so or it becomes unsafe for you to continue.

Will I find out about the study results?

All participants will be given the opportunity to contact the student investigator (Jonathan Mcleod) at the end of the study to receive a summary of the study results.

Can I get more information about participating as a study subject?

If you have questions or require more information about the study itself, please contact Jonathan Mcleod by email at mcleoj2@mcmaster.ca or by telephone at (647)-628-1287. The information mentioned above will be discussed and all questions clarified prior to any involvement in the study.

If you have any questions regarding your rights as a research participant, you may contact the Office of the Chair of the Hamilton Integrated Research Ethics Board at 905-521-2100 ext. 42013.

CONSENT

I have read the information presented in the information letter about a study being conducted by Jonathan Mcleod, of McMaster University. I have had the opportunity to ask questions about my involvement in this study, and to receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so, and I agree to participate in this study. I will be given a signed copy of this form.

_____
Name of Participant

_____ _____
Signature of Participant Date

Consent form administered and explained in person by:

_____
Name and title

_____ _____
Signature Date

I would like to receive a summary of the study's results. [Yes] [No]

Please send them to this email address:

_____

It is possible that we may wish to contact you in the future regarding follow-up research to this particular study. Please sign below if this is something you are agreeable to (and please provide your email address)

_____ _____

Name Email

_____

Signature

Appendix B. ANOVA Tables

Training Logs

2 x 2 x 5 Repeated Measures ANOVA
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (week 1 – week 5)
Bold values represent statistical significance ($p < 0.05$)

Workloads (% of PO_{peak}):

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	4	1.66	64	0.87	1.91	0.11	0.10
3x1	4	1.17	64	0.87	1.35	0.26	0.07
3x2	4	1.09	64	0.87	1.26	0.29	0.07
1x2x3	4	0.30	64	0.87	0.35	0.84	0.02

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
1	**1**	**298.60**	**16**	**10.106**	**29.514**	**0.00**	**0.60**
2	1	34.032	16	10.106	3.368	0.08	0.17
1x2	1	6.694	16	10.106	0.662	0.42	0.04

Average Work (kJ):

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	**2**	**607.76**	**38**	**17.44**	**34.84**	**0.00**	**0.68**
3x1	**2**	**213.30**	**38**	**17.44**	**12.22**	**0.00**	**0.43**
3x2	2	7.31	38	17.44	0.41	0.70	0.02
1x2x3	2	14.20	38	17.44	0.81	0.47	0.04

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p

1	**1**	**16331.30**	**16**	**850.72**	**19.19**	**0.00**	**0.54**
2	1	1757.88	16	850.72	2.06	0.17	0.11
1x2	1	173.84	16	850.72	0.20	0.65	0.01

Heart Rate (bpm):

Note: N=14 (MICT n=7, SIT n=7)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	4	64.57	40	28.63	2.25	0.08	0.18
3x1	4	27.76	40	28.63	0.97	0.44	0.08
3x2	4	22.94	40	28.63	0.80	0.53	0.07
1x2x3	4	66.94	40	28.63	2.33	0.07	0.18

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
1	**1**	**6885.17**	**10**	**1396.22**	**4.932**	**0.05**	**0.33**
2	**1**	**15270.41**	**10**	**1396.22**	**10.94**	**0.00**	**0.52**
1x2	1	6005.91	10	1396.22	4.30	0.06	0.30

Relative Heart Rate (% of HR_{peak}):

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	**4**	**84.19**	**60**	**20.465**	**4.11**	**0.00**	**0.21**
3x1	4	10.59	60	20.465	0.52	0.72	0.03
3x2	4	12.76	60	20.465	0.59	0.66	0.03
1x2x3	4	38.54	60	20.465	1.78	0.14	0.11

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
1	**1**	**9417.64**	**15**	**344.47**	**27.34**	**0.00**	**0.65**
2	1	83.71	15	344.47	0.243	0.63	0.01
1x2	1	708.02	15	344.47	2.05	0.17	0.12

Peripheral RPE:

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	4	1.66	64	0.87	1.91	0.11	0.10
3x1	4	1.17	64	0.87	1.34	0.26	0.07
3x2	4	1.09	64	0.87	1.26	0.29	0.07
1x2x3	4	0.30	64	0.87	0.35	0.84	0.02

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
1	**1**	**298.60**	**16**	**10.10**	**29.54**	**0.00**	**0.64**
2	1	34.03	16	10.10	3.36	0.08	0.17
1x2	1	6.69	16	10.10	0.66	0.42	0.04

Central RPE:

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	4	0.55	64	0.93	0.58	0.67	0.03
3x1	4	1.89	64	0.93	2.02	0.10	0.11
3x2	4	0.62	64	0.93	0.66	0.61	0.04
1x2x3	4	0.35	64	0.93	0.38	0.82	0.02

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
1	**1**	**338.93**	**16**	**29.63**	**11.43**	**0.00**	**0.41**
2	1	50.16	16	29.63	1.69	0.21	0.09
1x2	1	10.27	16	29.63	0.34	0.56	0.02

Outcome Measures:

PO_{peak}:

2 x 2 x 2 Repeated Measures ANOVA
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (Baseline vs. Follow-Up)
Bold values represent statistical significance ($p < 0.05$)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
3	**1**	**2043.80**	**16**	**47.60**	**42.93**	**0.00**	**0.72**
3x1	1	49.06	16	47.60	2.02	0.32	0.06
3x2	1	45.97	16	47.60	0.96	0.34	0.05
1x2x3	1	52.27	16	47.60	1.20	0.28	0.07

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
1	1	160.66	16	806.27	0.19	0.66	0.01
2	**1**	**8925.43**	**16**	**806.27**	**11.1**	**0.00**	**0.41**
1x2	**1**	**4808.09**	**16**	**806.27**	**5.96**	**0.02**	**0.27**

Discontinuous Sub-Maximal Arm-Ergometry Test: Central RPE:

2 x 2 x 2 x 3 Repeated Measures ANOVA (Note: Will only display significant ANOVAS)
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (Baseline vs. Follow-Up)
4 = within factor = workload (workload I vs. workload II vs. workload III)
Bold values represent statistical significance ($p < 0.05$)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p

4	**2**	**278.92**	**21**	**2.79**	**99.77**	**0.00**	**0.86**

Discontinuous Sub-Maximal Arm-Ergometry Test: Peripheral RPE:

2 x 2 x 2 x 3 Repeated Measures ANOVA (Note: Will only display significant ANOVAS)
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (Baseline vs. Follow-Up)
4 = within factor = workload (workload I vs. workload II vs. workload III)
Bold values represent statistical significance (p < 0.05)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
4	**2**	**310.26**	**22**	**2.35**	**131.99**	**0.00**	**0.89**

Discontinuous Sub-Maximal Arm-Ergometry Test: Relative HR (% of HR_{peak}):

2 x 2 x 2 x 3 Repeated Measures ANOVA (Note: Will only display significant ANOVAS)
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (Baseline vs. Follow-Up)
4 = within factor = workload (workload I vs. workload II vs. workload III)
Bold values represent statistical significance (p < 0.05)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
4	**2**	**3677.965**	**22**	**45.15**	**81.45**	**0.00**	**0.83**

Discontinuous Sub-Maximal Arm-Ergometry Test: HR (bpm):

2 x 2 x 2 x 3 Repeated Measures ANOVA (Note: Will only display significant ANOVAS)
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (Baseline vs. Follow-Up)

4 = within factor = workload (workload I vs. workload II vs. workload III)
Bold values represent statistical significance (p < 0.05)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
4	**2**	**6453.56**	**18**	**112.86**	**57.18**	**0.00**	**0.78**

Discontinuous Sub-Maximal Arm-Ergometry Test: Power Output (Watts):

2 x 2 x 2 x 3 Repeated Measures ANOVA (Note: Will only display significant ANOVAS)
1 = between factor = group (MICT vs. SIT)
2 = between factor = level of injury (Tetraplegia vs. Paraplegia)
3 = within factor = week (Baseline vs. Follow-Up)
4 = within factor = workload (workload I vs. workload II vs. workload III)
Bold values represent statistical significance (p < 0.05)

Tests of Within-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
4	**2**	**5642.43**	**32**	**31.50**	**106.66**	**0.00**	**0.87**
4 x 2	**2**	**410.64**	**32**	**31.50**	**7.76**	**0.00**	**0.33**
3	**2**	**5054.14**	**32**	**31.50**	**42.88**	**0.00**	**0.73**

Tests of Between-Subjects Effects

Effect	df Effect	MS Effect	df Error	MS Error	F	P-level	η^2_p
2	**1**	**6824.28**	**16**	**786.12**	**8.68**	**0.00**	**0.35**

Appendix C. Raw Data

Training Logs:

Workloads (% of PO_{peak}):

MICT	Week 1	Week 2	Week 3	Week 4	Week 5	Average
S01 (Para)	50.0	83.3	100.0	100.0	100.0	86.7
S05 (Para)	45.5	45.5	54.5	54.5	63.6	52.7
S11 (Para)	28.6	28.6	28.6	28.6	28.6	28.6
S15 (Para)	40.0	60.0	70.0	80.0	80.0	66.0
S17 (Para)	50.0	50.0	66.7	66.7	83.3	63.3
Paraplegia						
MEAN	**42.8**	**53.5**	**64.0**	**66.0**	**71.1**	**59.5**
SD	**9.0**	**20.2**	**25.9**	**26.8**	**27.0**	**21.2**
SE	**4.0**	**9.0**	**11.6**	**12.0**	**12.1**	**9.5**
S06 (Tetra)	42.9	57.1	71.4	57.1	57.1	57.1
S07 (Tetra)	57.1	85.7	100.0	100.0	100.0	88.6
S18 (Tetra)	33.3	33.3	66.7	100.0	100.0	66.7
S20 (Tetra)	42.9	71.4	77.1	94.3	85.7	74.3
S23 (Tetra)	55.6	55.6	60.0	66.7	77.8	63.1
Tetraplegia						
MEAN	**46.4**	**60.6**	**75.0**	**83.6**	**84.1**	**70.0**
SD	**9.9**	**19.6**	**15.3**	**20.3**	**17.9**	**12.1**
SE	**4.4**	**8.7**	**6.8**	**9.1**	**8.0**	**5.4**
Group Total						
MEAN	**44.6**	**57.1**	**69.5**	**74.8**	**77.6**	**64.7**
SD	**9.1**	**19.1**	**20.9**	**24.3**	**22.7**	**17.2**
SE	**2.9**	**6.0**	**6.6**	**7.7**	**7.2**	**5.4**
SIT						
S02 (Para)	120.0	130.0	130.0	140.0	150.0	134.0
S03 (Para)	116.7	116.7	150.0	166.7	183.3	146.7
S10 (Para)	141.7	166.7	166.7	166.7	166.7	161.7
S12 (Para)	123.1	123.1	123.1	123.1	123.1	123.1
S14 (Para)	118.2	127.3	127.3	136.4	136.4	129.1

S16 (Para)	116.7	133.3	158.3	166.7	166.7	148.3
Paraplegia						
MEAN	122.7	132.9	142.6	149.9	154.4	140.5
SD	9.6	17.6	18.2	19.2	22.2	14.3
SE	3.9	7.2	7.4	7.8	9.1	5.8
S04 (Tetra)	116.7	166.7	216.7	233.3	233.3	193.3
S13 (Tetra)	60.0	60.0	80.0	120.0	120.0	88.0
S19 (Tetra)	100.0	140.0	100.0	140.0	140.0	124.0
S21 (Tetra)	180.0	300.0	313.3	333.3	333.3	292.0
Tetraplegia						
MEAN	114.2	166.7	177.5	206.7	206.7	174.3
SD	49.9	99.8	108.8	97.8	97.8	89.8
SE	25.0	49.9	54.4	48.9	48.9	44.9
Group Total						
MEAN	119.3	146.4	156.5	172.6	175.3	154.0
SD	30.0	61.6	66.7	65.2	64.7	55.7
SE	9.5	19.5	21.1	20.6	20.5	17.6

Average Work (kJ):

MICT	Week 1	Week 2	Week 3	Week 4	Week 5	Average
S01 (Para)	31.1	39.8	49.1	54.2	50.7	45.0
S05 (Para)	61.4	54.2	67.4	70.7	82.3	67.2
S11 (Para)	10.5	14.8	16.0	17.3	17.1	15.1
S15 (Para)	32.2	47.0	51.6	60.8	57.0	49.7
S17 (Para)	23.5	23.8	25.6	30.1	31.7	26.9
Paraplegia						
MEAN	**31.7**	**35.9**	**41.9**	**46.6**	**47.8**	**40.8**
SD	**18.7**	**16.3**	**20.8**	**22.2**	**24.9**	**20.3**
SE	**8.4**	**7.3**	**9.3**	**9.9**	**11.1**	**9.1**
S06 (Tetra)	25.5	40.1	46.0	38.1	38.7	37.7
S07 (Tetra)	34.7	43.1	49.0	51.0	55.5	46.7
S18 (Tetra)	3.8	6.6	11.6	16.1	20.3	11.7
S20 (Tetra)	23.2	31.6	36.6	37.9	39.6	33.8
S23 (Tetra)	31.2	42.3	46.0	51.4	**54.8**	45.1
Tetraplegia						
MEAN	**23.7**	**32.7**	**37.8**	**38.9**	**41.8**	**35.0**
SD	**12.0**	**15.3**	**15.4**	**14.4**	**14.4**	**14.1**
SE	**5.4**	**6.8**	**6.9**	**6.4**	**6.5**	**6.3**
Group Total						
MEAN	**27.7**	**34.3**	**39.9**	**42.8**	**44.8**	**37.9**
SD	**15.4**	**15.0**	**17.4**	**18.1**	**19.5**	**16.7**
SE	**4.9**	**4.7**	**5.5**	**5.7**	**6.2**	**5.3**
SIT						
S02 (Para)	12.0	13.0	13.6	14.9	16.6	14.0
S03 (Para)	5.6	6.5	9.2	10.8	11.6	8.7
S10 (Para)	20.8	30.4	32.1	31.7	32.8	29.6
S12 (Para)	18.5	18.8	18.5	19.4	19.6	19.0
S14 (Para)	14.0	16.0	16.9	16.0	17.9	16.2

S16 (Para)	14.1	17.4	20.5	19.2	20.7	18.4
Paraplegia						
MEAN	**14.2**	**17.0**	**18.5**	**18.7**	**19.9**	**17.6**
SD	**5.3**	**7.9**	**7.8**	**7.1**	**7.1**	**6.9**
SE	**2.2**	**3.2**	**3.2**	**2.9**	**2.9**	**2.8**
S04 (Tetra)	7.2	9.8	12.3	13.0	15.4	11.5
S13 (Tetra)	1.2	1.7	2.3	4.1	2.8	2.4
S19 (Tetra)	4.0	4.9	4.0	4.5	4.7	4.4
S21 (Tetra)	5.0	7.7	8.3	8.4	8.7	7.6
Tetraplegia						
MEAN	**4.4**	**6.0**	**6.7**	**7.5**	**7.9**	**6.5**
SD	**2.5**	**3.5**	**4.5**	**4.1**	**5.6**	**4.0**
SE	**1.2**	**1.8**	**2.2**	**2.1**	**2.8**	**2.0**
Group Total						
MEAN	**10.2**	**12.6**	**13.8**	**14.2**	**15.1**	**13.2**
SD	**6.6**	**8.4**	**8.8**	**8.2**	**8.7**	**8.1**
SE	**2.1**	**2.7**	**2.8**	**2.6**	**2.8**	**2.5**

Heart Rate (bpm):

Note: Excluded 6 participants for use of HR-Lowering medication throughout intervention.

MICT	Week 1	Week 2	Week 3	Week 4	Week 5	Average
S01 (Para)	120.3	130.0	130.8	135.1	132.5	129.7
S05 (Para)	149.8	144.3	143.5	151.8	159.4	149.8
S11 (Para)	107.4	103.3	107.5	107.1	104.8	106.0
S17 (Para)	111.8	109.7	110.3	120.3	114.6	113.3
Paraplegia						
MEAN	**122.3**	**121.8**	**123.0**	**128.6**	**127.8**	**124.7**
SD	**19.1**	**18.8**	**17.2**	**19.2**	**24.0**	**19.4**
SE	**9.5**	**9.4**	**8.6**	**9.6**	**12.0**	**9.7**
S06 (Tetra)	91.0	93.1	110.3	98.4	99.4	98.4
S07 (Tetra)	115.3	117.0	109.1	124.8	108.8	115.0
S20 (Tetra)	126.4	130.5	127.3	122.1	117.9	124.8
Tetraplegia						
MEAN	**110.9**	**113.5**	**115.6**	**115.1**	**108.7**	**112.8**
SD	**18.1**	**18.9**	**10.2**	**14.5**	**9.3**	**13.3**
SE	**10.5**	**10.9**	**5.9**	**8.4**	**5.3**	**7.7**
Group Total						
MEAN	**117.4**	**118.3**	**119.8**	**122.8**	**119.6**	**119.6**
SD	**18.1**	**17.8**	**14.1**	**17.5**	**20.5**	**17.0**
SE	**6.9**	**6.7**	**5.3**	**6.6**	**7.7**	**6.4**
SIT						

S12 (Para)	166.9	168.8	167.8	169.2	160.0	166.5
S14 (Para)	176.0	175.8	171.5	170.7	178.3	174.5
S16 (Para)	142.6	148.7	151.0	147.5	157.3	149.4
Paraplegia						
MEAN	**161.8**	**164.4**	**163.4**	**162.5**	**165.2**	**163.5**
SD	**17.3**	**14.1**	**10.9**	**13.0**	**11.4**	**12.8**
SE	**10.0**	**8.1**	**6.3**	**7.5**	**6.6**	**7.4**
S04 (Tetra)	112.4	123.6	113.7	119.7	120.8	118.0
S13 (Tetra)	85.2	84.0	86.6	99.0	97.8	90.5
S19 (Tetra)	119.3	106.0	125.3	114.0	124.0	117.7
S21 (Tetra)	118.6	132.9	135.7	138.0	141.6	133.4
Tetraplegia						
MEAN	**108.9**	**111.6**	**115.3**	**117.7**	**121.1**	**114.9**
SD	**16.1**	**21.5**	**21.2**	**16.1**	**18.0**	**17.8**
SE	**8.0**	**10.8**	**10.6**	**8.1**	**9.0**	**8.9**
Group Total						
MEAN	**131.6**	**134.3**	**135.9**	**136.9**	**140.0**	**135.7**
SD	**32.1**	**33.1**	**30.4**	**27.6**	**27.6**	**29.8**
SE	**12.1**	**12.5**	**11.5**	**10.4**	**10.4**	**11.3**

Relative Heart Rate (% of HR_{peak}):

MICT	Week 1	Week 2	Week 3	Week 4	Week 5	Average
S01 (Para)	77.6	83.9	84.4	87.2	85.5	83.7
S05 (Para)	89.2	85.9	85.4	90.4	94.9	89.1
S11 (Para)	84.6	81.3	84.7	84.3	82.5	83.5
S15 (Para)	77.4	81.9	84.4	84.9	84.5	82.6
S17 (Para)	70.8	69.4	69.8	76.1	72.5	71.7
Paraplegia						
MEAN	**79.9**	**80.5**	**81.7**	**84.6**	**84.0**	**82.1**
SD	**7.1**	**6.4**	**6.7**	**5.3**	**8.0**	**6.4**
SE	**3.2**	**2.9**	**3.0**	**2.4**	**3.6**	**2.8**
S06 (Tetra)	88.4	90.4	105.9	95.5	96.5	95.3
S07 (Tetra)	79.5	80.7	84.6	86.1	75.0	81.2
S18 (Tetra)	73.4	75.4	75.4	71.9	84.2	76.1
S20 (Tetra)	91.6	94.6	92.3	88.5	85.4	90.5
Tetraplegia						
MEAN	**83.2**	**85.3**	**89.6**	**85.5**	**85.3**	**85.8**
SD	**8.3**	**8.8**	**12.9**	**9.9**	**8.8**	**8.7**
SE	**3.7**	**3.9**	**5.8**	**4.4**	**3.9**	**3.9**
Group Total						

MEAN	**81.4**	**82.6**	**85.2**	**85.0**	**84.6**	**83.8**
SD	**7.4**	**7.5**	**10.1**	**7.1**	**7.8**	**7.2**
SE	**2.3**	**2.4**	**3.2**	**2.3**	**2.5**	**2.3**
SIT						
S02 (Para)	108.6	118.0	115.5	117.1	115.9	115.0
S03 (Para)	124.2	124.4	136.7	132.4	118.2	127.2
S10 (Para)	97.9	91.4	92.9	105.4	99.4	97.4
S12 (Para)	105.6	106.8	106.2	107.1	101.3	105.4
S14 (Para)	103.5	103.4	100.9	100.4	104.9	102.6
S16 (Para)	95.1	99.1	100.7	98.3	104.9	99.6
Paraplegia						
MEAN	**105.8**	**107.2**	**108.8**	**110.1**	**107.4**	**107.9**
SD	**10.3**	**12.2**	**15.6**	**12.7**	**7.8**	**11.3**
SE	**4.2**	**5.0**	**6.4**	**5.2**	**3.2**	**4.6**
S04 (Tetra)	96.1	105.6	97.2	102.3	103.3	100.9
S13 (Tetra)	95.7	94.4	97.3	111.2	109.9	101.7
S19 (Tetra)	99.4	88.3	104.4	95.0	103.3	98.1
S21 (Tetra)	89.9	100.7	102.8	104.6	107.3	101.0
Tetraplegia						
MEAN	**95.3**	**97.3**	**100.4**	**103.3**	**105.9**	**100.4**
SD	**4.0**	**7.5**	**3.7**	**6.7**	**3.2**	**1.6**
SE	**2.0**	**3.8**	**1.9**	**3.3**	**1.6**	**0.8**
Group Total						
MEAN	**101.6**	**103.2**	**105.4**	**107.4**	**106.8**	**104.9**
SD	**9.7**	**11.3**	**12.6**	**10.8**	**6.1**	**9.3**
SE	**3.1**	**3.6**	**4.0**	**3.4**	**1.9**	**2.9**

Central RPE (6 – 20):

MICT	Week 1	Week 2	Week 3	Week 4	Week 5	Average
S01	12.7	12.5	13.0	14.5	12.0	12.9
S05	14.0	12.7	12.7	12.0	12.3	12.7
S06	14.7	13.7	16.3	16.3	14.0	15.0
S07	10.0	11.3	11.3	11.0	9.5	10.6
S11	14.7	14.7	14.0	14.3	15.7	14.7
S15	6.3	6.3	7.0	7.0	7.0	6.7
S17	10.7	10.7	10.0	9.3	9.3	10.0
S18	11.3	11.7	11.7	10.3	12.7	11.5
S20	7.0	6.0	6.0	6.0	6.0	6.2
S23	11.7	9.3	10.0	9.0	9.0	9.8
MEAN	**11.3**	**10.9**	**11.2**	**11.0**	**10.8**	**11.0**
SD	**2.9**	**2.9**	**3.1**	**3.3**	**3.1**	**3.0**
SE	**0.9**	**0.9**	**1.0**	**1.1**	**1.0**	**0.9**
SIT						
S02	14.0	16.0	15.7	17.3	17.0	16.0

S03	15.0	17.0	17.0	17.0	19.3	17.1
S04	13.7	14.3	15.3	15.0	16.0	14.9
S10	14.7	13.7	14.3	13.0	16.0	14.3
S12	17.3	17.7	17.7	17.0	17.0	17.3
S13	13.0	12.3	12.0	14.0	11.7	12.6
S14	17.0	17.0	17.0	16.0	16.0	16.6
S16	15.0	13.3	13.0	12.5	13.0	13.4
S19	12.0	13.3	14.5	12.0	14.0	13.2
S21	12.0	14.0	15.0	15.0	15.0	14.2
MEAN	**14.4**	**14.9**	**15.2**	**14.9**	**15.5**	**15.0**
SD	**1.8**	**1.9**	**1.8**	**2.0**	**2.2**	**1.7**
SE	**0.8**	**0.8**	**0.8**	**0.9**	**1.0**	**0.8**

Peripheral RPE (6 – 20):

MICT	Week 1	Week 2	Week 3	Week 4	Week 5	Average
S01	12.7	12.5	13.0	14.5	14.0	13.3
S05	14.0	12.7	12.7	12.0	12.3	12.7
S06	14.7	13.7	16.3	16.3	14.0	15.0
S07	11.0	12.0	13.0	13.0	10.0	11.8
S11	14.7	14.7	14.0	14.3	15.7	14.7
S15	9.3	9.7	10.0	12.0	10.5	10.3
S17	11.7	12.3	12.0	12.0	11.3	11.9
S18	11.3	12.0	11.7	10.3	12.7	11.6
S20	10.0	10.0	10.7	10.5	10.5	10.3
S23	12.3	10.7	11.0	10.0	10.5	10.9
MEAN	**12.2**	**12.0**	**12.4**	**12.5**	**12.2**	**12.3**
SD	**1.9**	**1.6**	**1.8**	**2.0**	**1.9**	**1.7**
SE	**0.6**	**0.5**	**0.6**	**0.6**	**0.6**	**0.5**

SIT						
S02	14.0	16.7	16.0	17.7	17.7	16.4
S03	15.0	17.0	17.0	17.0	19.3	17.1
S04	14.3	14.7	16.0	15.7	16.0	15.3
S10	17.7	16.3	16.3	17.0	17.0	16.9
S12	17.3	17.7	18.0	18.0	18.0	17.8
S13	14.0	14.3	13.0	14.3	12.7	13.7
S14	17.0	17.0	17.0	16.0	16.0	16.6
S16	15.3	14.7	14.7	14.5	15.0	14.8
S19	14.7	16.7	17.5	16.0	16.0	16.2
S21	11.7	15.0	15.0	15.0	15.3	14.4
MEAN	**15.1**	**16.0**	**16.1**	**16.1**	**16.3**	**15.9**
SD	**1.8**	**1.2**	**1.5**	**1.3**	**1.8**	**1.3**
SE	**0.6**	**0.4**	**0.5**	**0.4**	**0.6**	**0.4**

Outcome Measures:

PO_{peak}:

MICT	Baseline	Follow-Up
S01 (Para)	29.6	45.8
S05 (Para)	79.9	91.4
S11 (Para)	40.3	44.4
S15 (Para)	60.8	77.7
S17 (Para)	36.3	47.4
Paraplegia		
MEAN	49.4	61.3
SD	20.7	21.8
SE	9.2	9.7
S06 (Tetra)	43.5	48.3
S07 (Tetra)	45.1	75.7
S18 (Tetra)	14.2	25.0
S20 (Tetra)	33.0	43.3
S23 (Tetra)	69.8	75.5
Tetraplegia		
MEAN	41.1	53.6
SD	20.2	21.9
SE	9.0	9.8
Group Total		
MEAN	45.2	57.5
SD	19.8	21.0

SE	6.2	6.6
SIT		
S02 (Para)	64.1	89.7
S03 (Para)	36.3	53.4
S10 (Para)	88.9	132.4
S12 (Para)	79.1	91.7
S14 (Para)	70.5	87.4
S16 (Para)	86.7	98.6
Paraplegia		
MEAN	70.9	92.2
SD	19.4	25.3
SE	7.9	10.3
S04 (Tetra)	37.9	56.8
S13 (Tetra)	10.6	12.1
S19 (Tetra)	25.7	32.6
S21 (Tetra)	18.5	39.6
Tetraplegia		
MEAN	23.2	35.3
SD	11.6	18.5
SE	5.8	9.2
Group Total		
MEAN	51.8	69.4
SD	29.4	36.5
SE	9.3	11.5

Discontinuous Sub-Maximal Exercise Test (Central RPE):

MICT	Workload I_Week 1	Workload I_Week 5	Workload II_Week 1	Workload II_Week 5	Workload III_Week 1	Workload III_Week 5
S01 (Para)	12.0	7.5	15.0	11.0	18.0	15.5
S05 (Para)	9.0	10.0	11.0	10.0	13.0	12.0
S11 (Para)	12.5	12.5	15.5	15.5	16.5	15.5
S15 (Para)	6.0	7.0	6.0	10.0	8.0	12.0
S17 (Para)	9.0	9.0	12.0	13.0	14.0	14.0
Paraplegia						
MEAN	**9.7**	**9.2**	**11.9**	**11.9**	**13.9**	**13.8**
SD	**2.6**	**2.2**	**3.8**	**2.4**	**3.8**	**1.8**
SE	**1.2**	**1.0**	**1.7**	**1.1**	**1.7**	**0.8**
S06 (Tetra)	7.0	11.0	13.0	14.5	17.5	17.0
S07 (Tetra)	7.0	10.5	14.0	12.0	16.0	14.0
S18 (Tetra)	6.0	9.5	11.0	12.0	13.0	13.0
S20 (Tetra)	8.0	6.0	9.0	9.0	12.0	12.5
S23 (Tetra)	9.0	8.0	10.5	9.0	11.0	11.0
Tetraplegia						
MEAN	**7.4**	**9.0**	**11.5**	**11.3**	**13.9**	**13.5**
SD	**1.1**	**2.0**	**2.0**	**2.3**	**2.7**	**2.2**
SE	**0.5**	**0.9**	**0.9**	**1.0**	**1.2**	**1.0**
Group Total						
MEAN	**8.6**	**9.1**	**11.7**	**11.6**	**13.9**	**13.7**
SD	**2.3**	**2.0**	**2.9**	**2.2**	**3.2**	**1.9**
SE	**0.7**	**0.6**	**0.9**	**0.7**	**1.0**	**0.6**

SIT	Workload I_Week 1	Workload I_Week 5	Workload II_Week 1	Workload II_Week 5	Workload III_Week 1	Workload III_Week

S02 (Para)	8.0	9.0	12.0	9.0	16.0	11.5
S03 (Para)	10.0	10.0	13.0	13.0	14.5	14.5
S10 (Para)	13.5	11.0	14.0	11.0	13.0	13.0
S12 (Para)	11.0	8.0	12.0	10.0	15.5	12.0
S14 (Para)	12.5	12.5	13.5	13.5	14.0	14.0
S16 (Para)	7.0	8.0	8.0	9.5	12.0	12.0
Paraplegia						
MEAN	**10.3**	**9.8**	**12.1**	**11.0**	**14.2**	**12.8**
SD	**2.5**	**1.8**	**2.2**	**1.9**	**1.5**	**1.2**
SE	**1.0**	**0.7**	**0.9**	**0.8**	**0.6**	**0.5**
S04 (Tetra)	11.0	11.0	14.0	11.0	16.5	13.5
S13 (Tetra)	10.5	9.0	12.5	9.5	12.5	12.5
S19 (Tetra)	6.0	9.5	8.0	10.0	10.5	13.5
S21 (Tetra)	10.0	10.0	13.0	13.0	16.0	16.5
Tetraplegia						
MEAN	**9.4**	**9.9**	**11.9**	**10.9**	**13.9**	**14.0**
SD	**2.3**	**0.9**	**2.7**	**1.5**	**2.9**	**1.7**
SE	**1.1**	**0.4**	**1.3**	**0.8**	**1.4**	**0.9**
Group Total						
MEAN	**10.0**	**9.8**	**12.0**	**11.0**	**14.1**	**13.3**
SD	**2.4**	**1.4**	**2.2**	**1.7**	**2.0**	**1.5**
SE	**0.7**	**0.4**	**0.7**	**0.5**	**0.6**	**0.5**

Discontinuous Sub-Maximal Exercise Test (Peripheral RPE):

MICT	Workload I_Week 1	Workload I_Week 5	Workload II_Week 1	Workload II_Week 5	Workload III_Week 1	Workloa III_Week
S01 (Para)	12.0	7.5	15.0	11.0	18.0	15.5
S05 (Para)	9.0	10.0	11.0	10.0	13.0	12.0
S11 (Para)	12.5	12.5	15.5	15.5	16.5	15.5
S15 (Para)	6.0	8.0	6.5	10.0	11.5	13.0
S17 (Para)	8.5	10.0	12.0	13.0	15.0	15.0
Paraplegia						
MEAN	**9.6**	**9.6**	**12.0**	**11.9**	**14.8**	**14.2**
SD	**2.7**	**2.0**	**3.6**	**2.4**	**2.6**	**1.6**
SE	**0.3**	**0.2**	**0.4**	**0.2**	**0.3**	**0.2**
S06 (Tetra)	7.0	11.0	13.0	14.5	17.5	17.0
S07 (Tetra)	7.0	12.5	12.0	14.0	16.0	16.0
S18 (Tetra)	6.0	9.5	11.0	12.0	13.0	13.0
S20 (Tetra)	8.0	9.0	11.0	12.0	13.0	15.0
S23 (Tetra)	9.0	9.0	11.0	11.0	12.5	12.5
Tetraplegia						
MEAN	**7.4**	**10.2**	**11.6**	**12.7**	**14.4**	**14.7**
SD	**1.1**	**1.5**	**0.9**	**1.5**	**2.2**	**1.9**
SE	**0.1**	**0.2**	**0.1**	**0.1**	**0.2**	**0.2**
Group Total						
MEAN	**8.5**	**9.9**	**11.8**	**12.3**	**14.6**	**14.5**
SD	**2.3**	**1.7**	**2.5**	**1.9**	**2.3**	**1.7**
SE	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
SIT						
S02 (Para)	8.0	9.0	12.0	9.0	16.0	13.5
S03 (Para)	10.0	10.0	13.0	13.0	14.5	14.5

S10 (Para)	13.5	13.0	15.5	13.0	15.0	16.0
S12 (Para)	12.0	11.0	12.0	13.0	15.0	15.0
S14 (Para)	12.5	12.5	13.5	13.5	14.0	14.0
S16 (Para)	8.0	9.0	9.0	11.5	13.0	15.5
Paraplegia						
MEAN	**10.7**	**10.8**	**12.5**	**12.2**	**14.6**	**14.8**
SD	**2.4**	**1.7**	**2.1**	**1.7**	**1.0**	**0.9**
SE	**0.2**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**
S04 (Tetra)	11.0	11.0	15.0	11.0	16.5	13.5
S13 (Tetra)	11.0	13.0	13.5	12.5	17.0	15.0
S19 (Tetra)	10.0	11.0	11.5	11.5	14.0	15.0
S21 (Tetra)	10.5	11.0	13.0	13.5	16.0	17.0
Tetraplegia						
MEAN	**10.6**	**11.5**	**13.3**	**12.1**	**15.9**	**15.1**
SD	**0.5**	**1.0**	**1.4**	**1.1**	**1.3**	**1.4**
SE	**0.1**	**0.1**	**0.2**	**0.1**	**0.2**	**0.2**
Group Total						
MEAN	**10.7**	**11.1**	**12.8**	**12.2**	**15.1**	**14.9**
SD	**1.8**	**1.5**	**1.8**	**1.4**	**1.3**	**1.1**
SE	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**

Discontinuous Sub-Maximal Exercise Test (Power Output [Watts]):

MICT	Workload I_Week 1	Workload I_Week 5	Workload II_Week 1	Workload II_Week 5	Workload III_Week 1	Workloa III_Week
S01 (Para)	6.6	23.5	13.7	47.4	15.6	48.8
S05 (Para)	18.6	30.2	39.5	50.6	55.3	69.1
S11 (Para)	12.2	13.8	23.5	19.0	25.3	23.3
S15 (Para)	12.9	43.3	26.3	54.5	45.0	62.7
S17 (Para)	14.3	24.7	19.6	30.7	27.1	35.6
Paraplegia						
MEAN	**12.9**	**27.1**	**24.5**	**40.4**	**33.7**	**47.9**
SD	**4.3**	**10.8**	**9.6**	**15.0**	**16.1**	**18.9**
SE	**1.9**	**4.8**	**4.3**	**6.7**	**7.2**	**8.4**
S06 (Tetra)	15.7	26.9	31.6	33.9	39.0	39.7
S07 (Tetra)	13.7	47.4	27.9	49.4	36.1	62.8
S18 (Tetra)	1.9	9.7	4.9	14.1	9.0	22.4
S20 (Tetra)	11.9	26.7	19.2	30.0	22.1	31.6
S23 (Tetra)	7.0	28.6	14.1	43.6	21.6	50.8
Tetraplegia						
MEAN	**10.8**	**27.7**	**20.9**	**31.9**	**26.6**	**39.1**
SD	**6.1**	**15.4**	**11.9**	**14.5**	**13.8**	**17.3**
SE	**2.7**	**6.9**	**5.3**	**6.5**	**6.2**	**7.7**
Group Total						
MEAN	**11.5**	**27.5**	**22.0**	**37.3**	**29.6**	**44.7**
SD	**4.9**	**11.5**	**10.0**	**13.9**	**14.1**	**16.8**
SE	**1.6**	**3.6**	**3.1**	**4.4**	**4.5**	**5.3**
SIT						
S02 (Para)	14.5	27.9	36.5	41.5	43.9	63.6
S03 (Para)	3.0	13.1	7.0	25.9	14.1	39.7

S10 (Para)	38.0	53.2	53.9	69.8	70.6	87.4
S12 (Para)	18.1	30.9	31.4	41.2	42.6	53.4
S14 (Para)	22.4	34.3	37.8	41.8	49.1	49.4
S16 (Para)	21.3	27.5	35.8	48.7	50.8	53.0
Paraplegia						
MEAN	**19.6**	**31.2**	**33.7**	**44.8**	**45.2**	**57.8**
SD	**11.4**	**13.0**	**15.2**	**14.4**	**18.3**	**16.4**
SE	**4.7**	**5.3**	**6.2**	**5.9**	**7.5**	**6.7**
S04 (Tetra)	7.2	16.0	13.8	30.8	20.6	45.6
S13 (Tetra)	1.2	4.0	3.4	7.9	6.0	11.9
S19 (Tetra)	2.3	5.5	5.8	10.4	12.0	16.9
S21 (Tetra)	2.9	14.7	7.2	21.2	13.2	28.3
Tetraplegia						
MEAN	**3.4**	**10.1**	**7.6**	**17.6**	**13.0**	**25.7**
SD	**2.6**	**6.2**	**4.5**	**10.5**	**6.0**	**15.0**
SE	**1.3**	**3.1**	**2.2**	**5.3**	**3.0**	**7.5**
Group Total						
MEAN	**13.1**	**22.7**	**23.3**	**33.9**	**32.3**	**44.9**
SD	**12.0**	**15.0**	**17.8**	**18.7**	**21.8**	**22.3**
SE	**3.9**	**5.0**	**5.8**	**6.0**	**7.0**	**7.4**

Discontinuous Sub-Maximal Exercise Test (Heart Rate):

MICT	Workload I_Week 1	Workload I_Week 5	Workload II_Week 1	Workload II_Week 5	Workload III_Week 1	Workloa III_Week
S01 (Para)	137.5	113.5	144.5	137.5	150.0	155.0
S05 (Para)	114.0	122.5	138.0	133.0	165.5	168.0
S11 (Para)	116.0	105.0	128.0	107.5	127.0	106.0
S15 (Para)	84.5	100.5	92.0	106.0	106.0	108.0
S17 (Para)	116.5	112.0	133.5	121.5	139.0	129.5
Paraplegia						
MEAN	**113.7**	**110.7**	**127.2**	**121.1**	**137.5**	**133.3**
SD	**18.9**	**8.4**	**20.6**	**14.4**	**22.6**	**27.7**
SE	**8.5**	**3.8**	**9.2**	**6.4**	**10.1**	**12.4**
S06 (Tetra)	78.5	81.5	91.0	95.0	114.5	103.0
S07 (Tetra)	122.5	144.5	134.0	140.5	145.0	151.0
S18 (Tetra)	96.0	96.0	102.0	102.0	105.0	114.0
S20 (Tetra)	120.5	115.5	127.5	124.0	131.0	129.0
S23 (Tetra)	62.5	73.0	63.5	82.0	68.0	86.0
Tetraplegia						
MEAN	**104.4**	**109.4**	**113.6**	**108.7**	**112.7**	**116.6**
SD	**21.0**	**27.2**	**20.5**	**23.4**	**29.3**	**24.8**
SE	**9.4**	**12.2**	**9.1**	**10.5**	**13.1**	**11.1**
Group Total						
MEAN	**104.9**	**106.4**	**115.4**	**114.9**	**125.1**	**125.0**
SD	**23.4**	**20.4**	**26.6**	**19.4**	**27.9**	**26.3**
SE	**7.4**	**6.5**	**8.4**	**6.1**	**8.8**	**8.3**
SIT						
S02 (Para)	78.5	71.0	84.5	76.0	92.5	86.5
S03 (Para)	81.0	98.5	84.0	111.0	86.5	127.5

S10 (Para)	90.0	102.0	100.0	106.0	108.0	122.0
S12 (Para)	103.5	107.0	109.5	109.5	130.5	118.0
S14 (Para)	114.0	122.5	135.0	138.5	167.0	148.0
S16 (Para)	107.0	87.5	115.0	97.5	131.0	111.5
Paraplegia						
MEAN	**95.7**	**98.1**	**104.7**	**106.4**	**119.3**	**118.9**
SD	**14.6**	**17.5**	**19.5**	**20.3**	**29.9**	**20.2**
SE	**6.0**	**7.2**	**8.0**	**8.3**	**12.2**	**8.2**
S04 (Tetra)	96.0	74.0	112.5	91.5	123.0	98.5
S13 (Tetra)	84.0	82.5	85.0	87.0	84.0	93.0
S19 (Tetra)	114.0	108.0	120.0	120.0	126.0	126.0
S21 (Tetra)	103.0	101.0	105.0	117.0	116.0	126.0
Tetraplegia						
MEAN	**99.3**	**91.4**	**105.6**	**103.9**	**112.3**	**110.9**
SD	**12.6**	**15.8**	**15.1**	**17.0**	**19.3**	**17.6**
SE	**6.3**	**7.9**	**7.5**	**8.5**	**9.6**	**8.8**
Group Total						
MEAN	**97.1**	**95.4**	**105.1**	**105.4**	**116.5**	**115.7**
SD	**13.2**	**16.3**	**17.0**	**18.1**	**25.2**	**18.6**
SE	**4.2**	**5.2**	**5.4**	**5.7**	**8.0**	**5.9**

Exercise Satisfaction (PACES):

MICT	PACES
S01	90.0
S05	95.0
S06	68.0
S07	99.0
S11	111.0
S15	86.0
S17	98.0
S18	107.0
S20	126.0
S23	118.0
MEAN	**99.8**
SD	**16.7**
SE	**5.3**

SIT	PACES
S02	122.0
S03	116.0
S04	92.0
S10	111.0
S12	98.0
S13	116.0
S14	102.0
S16	79.0
S19	109.0
S21	120.0
MEAN	**106.5**
SD	**13.7**
SE	**6.1**

Exercise for Self-Efficacy (ESES):

MICT	ESES Wk 1	ESES Wk 5
S01	31.0	31.0
S05	40.0	40.0
S06	32.0	28.0
S07	37.0	37.0
S11	38.0	36.0
S15	33.0	25.0
S17	38.0	38.0
S18	36.0	36.0
S20	37.0	38.0
S23	40.0	38.0
MEAN	**36.2**	**34.7**
SD	**3.2**	**5.0**
SE	**1.0**	**1.6**

SIT	ESES Wk 1	ESES Wk 5
S02	35.0	35.0
S03	38.0	37.0
S04	37.0	39.0
S10	40.0	38.0
S12	33.0	32.0
S13	36.0	38.0
S14	29.0	38.0
S16	39.0	23.0
S19	37.0	37.0
S21	37.0	33.0
MEAN	**36.1**	**35.0**
SD	**3.2**	**4.8**
SE	**1.4**	**2.1**

Perceived Pain:

MICT	Pain_Throughout Day	Pain_Armbike specific
S01	4.0	4.0
S05	12.0	5.0
S06	15.0	13.0
S07	3.0	5.0
S11	7.0	3.0
S15	15.0	13.0
S17	18.0	7.0
S18	12.0	11.0
S20	4.0	3.0
S23	4.0	6.0
MEAN	**9.4**	**7.0**
SD	**5.6**	**3.9**
SE	**1.8**	**1.2**

SIT	Pain_Throughout Day	Pain_Armbike specific
S02	9.0	3.0
S03	18.0	3.0
S04	8.0	10.0
S10	6.0	6.0
S12	7.0	7.0
S13	7.0	7.0
S14	6.0	5.0
S16	13.0	13.0
S19	17.0	6.0
S21	9.0	9.0
MEAN	**10.0**	**6.9**
SD	**4.4**	**3.1**
SE	**2.0**	**1.4**