SUBMAXIMAL MEASURES OF CARDIOVASCULAR FITNESS IN INDIVIDUALS WITH SPINAL CORD INJURY

by

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ABSTRACT

Background: The prevalence of cardiovascular disease in individuals with spinal cord injury (SCI) is as high as or greater than in the general population, yet assessment of cardiovascular fitness rarely occurs in individuals with SCI.

Purpose: 1) To review current literature and develop guidelines to assist clinicians in choosing appropriate submaximal tests for the evaluation of cardiovascular fitness in individuals with SCI; 2) to design a submaximal single-stage arm ergometer test (SSSAET) for use in individuals with SCI; and 3) to determine the test-retest reliability and criterion validity of this exercise test.

Methods: A systematic review of the literature was done to identify and evaluate arm exercise tests that submaximally measure cardiovascular fitness in individuals with SCI. To evaluate the SSSAET, 30 subjects with SCI were assessed using the American Spinal Injury Association (ASIA) scale, isometric strength testing, a physical activity questionnaire, the SSSAET, and a VO2peak test. Test-retest reliability of the SSSAET was determined by having subjects complete the SSSAET on two days, separated by one week. Criterion validity was determined by comparing the results from the SSSAET with the VO2peak test.

Results: The literature review identified six submaximal arm exercise tests for measuring cardiovascular fitness in individuals with SCI, but all tests featured limitations that prevented widespread clinical use. Test-retest reliability of the SSSAET was excellent (ICC=0.81-0.90). As well, correlations between VO2peak and outcomes of the SSSAET ranged from r=0.63-0.92, indicating good to excellent criterion validity.
Conclusions: Clinical recommendations were provided for the existing arm exercise test protocols. Testing showed that the SSSAET has acceptable test-retest reliability and criterion validity, however further research is necessary before the SSSAET will be ready for implementation as a clinical tool to assess baseline and changes in cardiovascular fitness in individuals with SCI.
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LIST OF ABBREVIATIONS

ACSM – American College of Sports Medicine
ASIA – American Spinal Injury Association
BP – Blood pressure
CAD – Coronary artery disease
CAFT – Canadian Aerobic Fitness Test
CCSE – Cognitive capacity screening examination
CI – Confidence interval
CINAHL – Cumulative Index to Nursing and Allied Health Literature
CSTF – Canadian Standardized Test of Fitness
ECG – Electrocardiogram
EMBASE – Excerpta Medica
HR – Heart rate
ICC – Intraclass correlation coefficient
L/min – Litres of oxygen per minute
mL/kg/min – Millilitres of oxygen per kilogram body mass per minute
PASIPD – Physical Activity Scale for Individuals with Physical Disabilities
PO – Power output
RER – Respiratory exchange ratio
RPE – Rate of perceived exertion
SCI – Spinal cord injury
SD – Standard deviation
SEE – Standard error of estimate
SEM – Standard error of measurement
SSSAET – Submaximal single-stage arm ergometer test
$V_E$ – Ventilation
$VO_2$ – Oxygen consumption
$VO_2$peak – Peak oxygen consumption
W – Watts
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Chapter 1: Introduction

1.1 Introduction

Currently, there are approximately 36,000 Canadians living with a spinal cord injury (SCI). Each year in Canada, there are an estimated 1,050 new injuries that result in some level of permanent paralysis or neurological deficit (Canadian Paraplegia Association, 1997). The medical management of SCI has improved dramatically over the last 30 years, enabling individuals with SCI to have a life expectancy resembling that of the general population (DeVivo et al. 1999; Krause et al. 2004). Accordingly, chronic diseases, specifically cardiovascular diseases, are now much more prevalent in individuals with SCI. The muscle paralysis associated with SCI imposes a more sedentary lifestyle, and it is suspected that this sedentary lifestyle contributes to the high prevalence of cardiovascular diseases in this population (Bauman et al. 1998; Bauman and Spungen 1994; Brenes et al. 1986; Dallmeijer et al. 1997; Dearwater et al. 1986; Demirel et al. 2001; Janssen et al. 1997). Today, SCI rehabilitation programs are increasingly intensive in their attempt to maximize cardiovascular fitness and include activities such as arm ergometry, functional electrical stimulation ergometer cycling, strength training and partial-body-weight supported treadmill training (Davis 1993; Kirshblum 2004).

In order to determine an individual’s level of cardiovascular fitness, some type of fitness assessment should be conducted. Maximal fitness tests are the most accurate type of fitness test (Taylor et al. 1955), but these require expensive equipment and medical personnel to
monitor the subject. Submaximal exercise tests are a safe and less expensive alternative to maximal tests, but most involve lower limb exercise (e.g. walking, cycling) and cannot be completed by individuals with SCI. Although SCI rehabilitation programs include components that aim to increase cardiovascular fitness, clinicians are currently not able to quantitatively determine whether or not these interventions have been successful. A reliable and valid submaximal arm exercise test is clearly required.

The first objective of this thesis was to investigate the evidence surrounding current submaximal arm exercise tests. Upon review of the literature, a lack of evidence for these current tests warranted the development of a new submaximal arm exercise test. Accordingly, a new test was designed, and its reliability and criterion validity were measured. This process has been separated into two studies; the first examines the submaximal arm exercise tests that have previously been presented in the literature, and the second describes the new submaximal arm ergometer exercise test, with specific focus on its reliability and validity.

The following section presents concepts and definitions of selected physiological principles that are relevant to the studies presented in this thesis. Following this section, a brief literature review is included, and the theses purposes, research questions and hypotheses are presented.
1.2 Selected exercise physiology concepts

The concepts and relationships that will subsequently be described hold true for able-bodied individuals, and those with spinal cord lesions below T6. As will be discussed later in this chapter, spinal cord lesions above T6 can disrupt the sympathetic nerves innervating the heart, and drastically alter an individual's response to exercise.

1.2.1 Cardiovascular fitness, cardiac output and oxygen consumption

An individual's cardiovascular fitness reflects the maximal amount of oxygen consumed by their body during each minute of near-maximal exercise. Values for peak oxygen consumption ($VO_2^{\text{peak}}$) are expressed in litres of oxygen used per minute (L/min), or more commonly, relative to body weight in millilitres of oxygen per kilogram body mass per minute (mL/kg/min). Individual values can range from 10 mL/kg/min in individuals with cardiovascular and respiratory diseases, to more than 80 mL/kg/min in elite runners and cross-country skiers (McArdle et al. 2001). $VO_2^{\text{peak}}$ takes into account both an individual's maximal cardiac output, and the maximal amount of oxygen that can be extracted from the blood by their working muscles. Cardiac output is calculated as heart rate (HR) * stroke volume (the volume of blood ejected from the heart each beat).

The health of the cardiovascular system, specifically the heart, can be measured by parameters other than $VO_2^{\text{peak}}$. Determining cardiac output, left ventricular end diastolic volume, and ejection fraction provides valuable information on the heart's contractility and
ability to pump sufficient blood through the body. Echocardiography uses sound waves
directed at the chest wall to produce a moving picture of the heart, and can be used to assess
cardiac dimensions and function. Cardiac output can be determined non-invasively using
foreign gas (carbon dioxide or acetylene) rebreathe techniques (McArdle et al. 2001). These
different techniques are used both at rest and during maximal exercise and complement the
information provided in a VO₂peak test to present a more comprehensive picture of heart
health and function.

1.2.2 Heart rate

Heart rate is expressed as the number of heart beats per minute. Resting HR is dependent
on physical fitness, with fitter individuals having a lower resting HR. The resting HR of a
young infant is higher than an adult, but in adults, resting HR is not age dependent. Maximal
HR is age related over the entire lifespan (Hagberg et al. 1985); with increasing age, maximal
HR declines, and in able-bodied populations, can be approximated by the equation: maximal
HR = 220 – age.

1.2.3 Power output

During cardiovascular exercise, individuals continuously exert forces either through their
arms (e.g. during arm ergometry) or their legs (e.g. during treadmill running or leg cycling).
The application of these forces relative to time is expressed as an individual’s power output
(PO) (Robergs and Roberts 1997), and is typically measured in Watts (W). PO can be thought of as the intensity of the exercise.

1.2.4 Oxygen consumption – power relationship

The relationship between oxygen consumption (VO₂) and PO is generally linear, with increased workloads requiring an increase in oxygen consumption. During incremental exercise, VO₂ increases in a manner that is dependent on the rate of increase in PO. Figure 1.1 presents the change in VO₂ during two different protocols (dashed line – ramp protocol; solid line – 50 W increments every 3 minutes) for the same individual. The ramp protocol shows a linear increase in VO₂ with PO, and a plateau in VO₂ at VO₂peak, while the step protocol reveals a “staircase” effect of increasing VO₂. During the three minute stages in the early part of step protocol, the VO₂ is able to reach steady state. Later in the test however, the relative intensity increment and absolute intensity are too great for steady state to be achieved, and the increase in VO₂ appears more linear until VO₂peak is attained (Robergs and Roberts 1997). In individuals with SCI, the linear increase in VO₂ with PO remains, but the slope of this line changes with lesion level. The slope of this line is steeper for able-bodied individuals than for those with paraplegia, who in turn have a steeper slope than those with tetraplegia (Schmid et al. 1998). During submaximal exercise at a constant PO, VO₂ initially increases exponentially, and then reaches a steady state (Figure 1.2).
1.2.5 *Oxygen consumption – heart rate relationship*

There is a general linear relationship between HR and VO₂. Figure 1.3 illustrates this relationship in two individuals of different fitness levels. Both individuals are undergoing a VO₂peak test, and it can be seen that for both individuals, HR increases proportionately with

**Figure 1.1** Relationship between VO₂ and PO: Linear increase with a ramp protocol (dashed line), “staircase” effect seen when PO increases in three minute stages (solid line) (adapted from Robergs and Roberts 1997)

**Figure 1.2** Change in VO₂ during the transition from rest to submaximal exercise at a constant PO (adapted from Robergs and Roberts 1997)
VO₂. Although both individuals show a linear relationship, the same HR corresponds to different VO₂ values in each subject. The slope of this line is different for everyone, with a steeper slope generally indicating a less fit individual. When exercising at a given VO₂, approximately the same cardiac output is required to supply the oxygenated blood to the working muscles, regardless of fitness level. Generally, individuals with increased fitness have a higher stroke volume, so a lower HR is required to obtain the needed cardiac output. This higher stroke volume coupled with the unchanged maximum HR translates into increased cardiovascular fitness.

![Graph showing linear relationship between HR and VO₂ for two individuals with different cardiovascular fitness levels](image)

**Figure 1.3** Linear relationship between HR and VO₂ for two individuals with different cardiovascular fitness levels (adapted from McArdle et al. 2001)

1.2.6 Heart rate – power output relationship

Similar to the relationship between HR and VO₂, HR increases approximately linearly with increases in PO. This relationship is also influenced by cardiovascular fitness level, with
fitter individuals having a lower HR for a given PO. Figure 1.4 illustrates the HR-PO relationship from two individuals during a VO2peak test. The line with the steeper slope belongs to the less fit individual. A similar trend is seen individuals with SCI; those with paraplegia (who are often more physically fit) tend to have a steeper slope than those with tetraplegia (Schmid et al. 1998).

![Figure 1.4 Linear relationship between HR and PO for two individuals with different cardiovascular fitness levels (adapted from McArdle et al. 2001)](image)

During submaximal exercise at a constant PO, HR initially increases exponentially, then plateaus to a steady state. Figure 1.5 illustrates the responses of two different individuals to steady state submaximal exercise at the same PO. The light line at the higher steady state HR represents a less fit individual. Recall that PO and VO2 are linearly related, so for these individuals working at the same PO, the same amount of oxygen is required by the working
muscles, and thus their cardiac output needs are the same. As outlined previously, the individual with a higher fitness level has an increased stroke volume, so a lower HR is required to produce the cardiac output needed to deliver sufficient oxygenated blood to the working muscles.

**Figure 1.5** HR response to six minutes of submaximal steady state exercise at the same constant PO for two individuals with different cardiovascular fitness levels

### 1.2.7 Blood lactate

Lactate is produced in active muscles during carbohydrate metabolism. At rest and during low intensity exercise, lactate is used by the muscle at the same rate that it is produced and blood lactate levels remain low and constant (~1 mmol/L at rest and < 4 mmol/L during steady state exercise) (Robergs and Roberts 1997). During more intense exercise, lactate is produced faster than it is used by the working muscle and it accumulates in the blood. Increased lactate decreases blood pH, and results in a condition of lactic acidosis. The acidic
environment that results with the increase in lactate is partially responsible for the fatigue and pain of the exercising muscle (Robergs and Roberts 1997). In healthy individuals, lactate levels can increase up to 14-16 mmol/L during intense exercise (Robergs and Roberts 1997), but in individuals with SCI, even maximal exercise only produces lactate levels of 9-10 mmol/L (Flandrois et al. 1986).

1.3 Pathophysiology of SCI

1.3.1 SCI and motor system dysfunction

Interruption of the spinal cord results in impairment within the motor system. Depending on the anatomical location of the lesion within the spinal cord, an individual will have partial or full paralysis of their upper and/or lower limb muscles. Lesions in the lumbar or thoracic regions of the spinal cord typically result in paraplegia with impairment to the lower limb and trunk muscles. Cervical lesions result in tetraplegia, with lower limb, trunk and upper limb muscle impairment. In addition to the muscle paralysis, the absence of functional muscle mass in the lower extremity limits the capacity of the cardiovascular system by eliminating the skeletal muscle pump that aids in returning blood to the heart (Hopman et al. 1993).
1.3.2 SCI and sympathetic nervous system dysfunction

As well as the motor system limitations, many individuals with SCI, especially those with higher level lesions, have diminished sympathetic output from the sympathetic nervous system (Wecht et al. 2001). Without adequate sympathetic stimulation, a number of autonomic and cardiovascular complications arise. Complications that have important implications during exercise are hypotension (Dela et al. 2003), bradycardia (Wecht et al. 2001), and impaired thermoregulation (Price and Campbell 1999).

1.3.3 Exercise implications

Arm exercise uses smaller and weaker muscles relative to leg exercise. Using these smaller muscles immediately limits the maximal PO, and thus the VO\textsubscript{2peak} that can be attained during arm exercise. As well, without the leg muscle pump actively working to return blood to the heart during exercise, blood pools in the legs and decreases blood pressure (BP).

Without adequate stimulation from the sympathetic nervous system, normal cardiovascular responses to exercise such as vasoconstriction in less active tissue (e.g. kidneys, gastrointestinal tract), vasodilation in skeletal muscle, increases in HR, and increases in stroke volume are impaired. The sympathetic nerves that innervate the heart are located from T1 to T7 (Barron and Blair 1999), so individuals with lesions above T1 have a very limited ability to increase their HR, stroke volume, heart contractility and cardiac output.
(Freyschuss and Knutsson 1969). For individuals with intact sympathetic stimulation of the heart, the increase in HR at the start of and during lower intensity exercise is primarily due to inhibitory parasympathetic stimulation sent through the vagus nerves. During higher intensity exercise, the further increases in HR are due to a combination of additional parasympathetic inhibition and activation of the sympathetic nerves to the heart (Nóbrega and Araújo 1993). In individuals with complete tetraplegia, the sympathetic innervation to the heart is still intact, but signals that originated in the central nervous system cannot be transmitted to the sympathetic nerves because of the injury within the spinal cord. In these individuals, the HR increase in response to exercise is due to the withdrawal of vagal parasympathetic tone, and as a result, maximal exercising HR rarely exceeds 100-125 beats/minute (Davis 1993). Without the ability to substantially increase cardiac output, an individuals’ capacity for exercise is severely limited.

Clearly, testing cardiovascular fitness in individuals with SCI requires special considerations. The following chapters 1) present a thorough literature review on submaximal exercise tests that have been designed for use in individuals with SCI, and 2) propose a new submaximal arm ergometer exercise test, with specific focus on its reliability and validity.
1.4 Purpose

The purpose of this study was twofold: 1) to systematically review current literature that investigates submaximal cardiovascular exercise testing in individuals with SCI, and 2) to design a submaximal single-stage arm ergometer test (SSSAET) for use in individuals with SCI and to determine its test-retest reliability and criterion validity.

1.5 Research questions and hypotheses

1.5.1 Research question 1: Have any submaximal exercise tests that can be used clinically to estimate cardiovascular fitness in individuals with SCI been presented in the literature?

Hypothesis: Submaximal exercise tests that can be used clinically to estimate cardiovascular fitness in individuals with SCI are lacking.

1.5.2 Research question 2: Is the SSSAET reliable when performed on two separate occasions, and is it a valid measure of cardiovascular fitness for individuals with SCI?

Hypothesis 1: The steady state HR and VO₂ responses during the SSSAET will be reliable when measured on two separate occasions.

Hypothesis 2: Power output and steady state VO₂ and HR during the SSSAET will correlate with VO₂peak.
Chapter 2: A systematic review of submaximal exercise tests for individuals with spinal cord injury

2.1 Abstract

**Background and Purpose:** Submaximal exercise tests can be useful clinical tools to assess cardiovascular fitness, but the availability of these tests for use in individuals with spinal cord injury (SCI) has not been presented. The purpose of this study was to review current literature and develop guidelines to assist clinicians in choosing appropriate submaximal tests for the evaluation of cardiovascular fitness in individuals with SCI.

**Methods:** A systematic review of the literature was performed to identify and evaluate arm exercise tests that submaximally measure cardiovascular fitness in individuals with SCI. Tests were categorized as predictive or performance tests and evaluated for reliability, validity and responsiveness.

**Results:** Six submaximal exercise tests for measuring cardiovascular fitness in individuals with SCI were identified. Two additional articles were included in this review as they described aerobic training interventions in individuals with SCI and assessed the change in cardiovascular fitness using submaximal exercise tests. The total number of subjects included in the studies was 210. Two predictive tests and 4 performance based tests were identified. Only 2 tests reported reliability and responsiveness (all reported values were acceptable), while 5 tests reported validity values (1 was fair, 2 moderate, and 2 excellent).

**Conclusions:** Clinical recommendations were made, but given the limitations with each of the 6 tests, further research is required to develop and evaluate a submaximal exercise test for individuals with SCI that has strong psychometric properties.
2.2 Introduction

The medical management of acute and chronic SCI has improved dramatically in the last thirty years, enabling individuals with SCI to have a life expectancy resembling that of the general population (Devivo et al. 1999; Krause et al. 2004). Accompanying this longer survival are chronic diseases such as diabetes and cardiovascular disease that were previously uncommon in those with SCI (McGlinchey-Berroth et al. 1995). Over the last thirty years, there has been a shift in the predominant cause of death in individuals with SCI from genitourinary infections to respiratory and cardiovascular diseases (DeVivo et al. 1993; Frankel et al. 1998; Soden et al. 2000).

A number of risk factors for both able-bodied populations and individuals with SCI are indicative of a high risk of developing coronary artery disease (CAD). The American College of Sports Medicine (ACSM) (2000) lists hypertension, high cholesterol, impaired fasting glucose, obesity, family history and a sedentary lifestyle as measurable risk factors that have clinically relevant thresholds for describing an individual’s level of risk for CAD. Many of these risk factors are highly associated. For instance, by increasing an individual’s level of physical activity, not only have they decreased their risk for CAD by moving away from a sedentary lifestyle, but additional positive effects including reduced hypertension, improved fasting glucose levels, increased high density lipoprotein cholesterol levels, and decreased body weight may occur (ACSM 2000). The cross over effects between risk factors makes it difficult to study a single risk factor independently.
Hypertension is one of the risk factors for CAD, so the hypotension that often accompanies a SCI (Noreau et al. 2000) complicates the assessment of CAD risk. The absence of functional muscle mass in the lower extremity eliminates the skeletal muscle pump, resulting in venous pooling. As blood pools in the lower extremities, venous return to the heart is reduced, and cardiac output decreases. This venous pooling is compounded by the lack of sympathetically driven vasoconstriction (Hopman et al. 1993), and can result in severely decreased blood pressure during arm exercise. When looked at independently, this hypotensive state appears to represent a decreased risk for CAD, but epidemiological studies clearly show that individuals with SCI have a risk at least as high, if not higher than the general population (Bauman et al. 1992; DeVivo et al. 1993; Yekutiel et al. 1989), and that this risk cannot be offset by the hypotension accompanying a SCI. In addition to general hypotension, over 50% of individuals with SCI experience orthostatic intolerance (Cariga et al. 2002), and nearly all individuals with SCI experience exertional hypotension (King et al. 1994). Orthostatic hypotension is characterized by a sudden drop in blood pressure when moving from a lying position to a sitting or standing position (McArdle et al. 2001), while exertional hypotension is seen as decreasing blood pressure as exercise progresses (Glaser et al. 1980). Orthostatic hypotension is more prevalent in those with higher level injuries (Cariga et al. 2002).

There are two risk factors that appear to be most associated with increased CAD risk for individuals with SCI. The first is their relatively low level of physical activity. Exercise capacity is limited in these individuals in part because of the impaired cardiovascular responses to exercise (following the SCI and resultant impairment of the sympathetic nervous
system), and the limited available functional muscle mass. In addition to a now pathologically limited exercise capacity, many individuals with SCI also lead a very sedentary lifestyle (Buchholz et al. 2003; Hoffman 1986; Monroe et al. 1998). If lifestyle modifications are made to improve physical fitness, studies of individuals with SCI have shown that not only is CAD risk decreased (Brenes et al. 1986; Dearwater et al. 1986), but individuals also experience decreased strain during activities of daily living (Janssen et al. 1996). The second is the high prevalence of metabolic syndrome within this population. Metabolic syndrome is characterized by a group of metabolic symptoms including abdominal obesity, elevated low density lipoprotein cholesterol and triglycerides, low levels of high density lipoprotein cholesterol, and insulin resistance (Reaven 2002). A combination of these symptoms, most often glucose intolerance and elevated low density lipoprotein concentration, has been observed in up to 50% of individuals with SCI (Zhong et al. 1995). Individuals with metabolic syndrome have been shown to be at increased risk for CAD (McNeill et al. 2005). Studies of individuals with SCI have shown physical activity level (Dallmeijer et al. 1997) and body composition (Janssen et al. 1997) to be associated with lipoprotein levels. A recent study by Manns et al. (2005) found that in individuals with SCI, lower physical activity levels were associated with higher fasting glucose, lower high density lipoprotein concentrations and greater waist circumference measurements.

The measurement of cardiovascular fitness is important in all populations as it can provide an estimate of CAD risk. Measuring cardiovascular fitness is especially important for individuals with SCI, given the high incidence of CAD in this population. Cardiovascular fitness testing can also provide an evaluation of some medical abnormalities, motivate
individuals by helping to establish attainable fitness goals, and be used as a baseline measure for exercise prescription (ACSM 2000).

The gold standard test for measuring cardiovascular fitness is the peak oxygen consumption (VO$_2$peak) test (Taylor et al. 1955). This type of test requires expensive equipment to analyze the respiratory gases and trained personnel to operate the equipment and conduct the tests. In individuals with SCI, impairments to the nervous system change the physiological responses to exercise, and the stresses that are placed upon the cardiovascular and respiratory systems during these maximal tests may place certain individuals at risk. Accordingly, submaximal exercise tests that do not require respiratory gas analysis have been designed to evaluate cardiovascular fitness. Clinicians typically choose to assess cardiovascular fitness using submaximal tests, but the availability of these tests for use in individuals with SCI has not been presented. The purpose of this paper was to systematically review current literature and develop guidelines to assist clinicians in choosing appropriate submaximal tests for the evaluation of cardiovascular fitness in individuals with SCI.

2.3 Methods

Articles were included in this review if they were (1) research studies using submaximal cardiovascular fitness tests for use for individuals with SCI and (2) studies found in the MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), or Excerpta Medica (EMBASE) databases, or in the reference lists of articles found in these databases.
2.3.1 Search strategy

A systematic review of the literature was conducted through the local university’s online library system using MEDLINE (1966 to July week 2, 2005), CINAHL (1982 to July week 3, 2005) and EMBASE (1980 to week 30, 2005). The search strategy for the MEDLINE search is presented in Appendix A. An equivalent search strategy was used for the CINAHL and EMBASE databases with minor modifications due to differences in indexing and syntax in the different databases. Using this search strategy, 117, 75, and 98 articles were found in MEDLINE, CINAHL, and EMBASE, respectively. A total of 201 unique articles were identified using these search strategies. The titles, abstracts, and in some cases the entire article, were reviewed, and those not related to the topic of study were excluded. The articles remaining following the initial screening were then reviewed for additional references.

After eliminating 193 articles that did not meet all the inclusion and exclusion criteria, the submaximal cardiovascular fitness tests that were described in the articles were categorized as either predictive or performance based tests. Typically, predictive tests measure an individual’s heart rate (HR) while exercising at one or more submaximal power outputs (PO), then extrapolate from the linear relationship between HR and VO$_2$ to the age predicted maximal HR where an estimate of VO$_2$peak can be made. Performance tests measure an individual’s response to standardized physical activities, such as the time to cover a certain distance or the maximum distance an individual can walk/run in a given amount of time (Noonan and Dean 2000). The time (or distance) can be used as the sole outcome
measure for the test, but often the time (or distance) is entered into an equation to predict VO$_2$peak.

A description of each of the submaximal cardiovascular fitness tests, as well as the psychometric properties of each test was extracted from the articles and is reported in Table 2.1 (at the conclusion of this chapter). The following criteria was used for evaluating correlation coefficients: 0.0-0.25 poor, 0.25-0.50 fair, 0.50-0.75 moderate to good, 0.75-1.0 good to excellent (Portney and Watkins 2000).

2.4 Results

A total of 6 articles were identified that describe submaximal cardiovascular fitness tests for individuals with SCI (Dwyer and Davis 1997; Franklin et al. 1990; Kofsky et al. 1983; Longmuir and Shephard 1993; 1995; Rhodes et al. 1981). Two additional articles have been included, as they use aerobic training interventions for individuals with SCI (DiCarlo 1988; Hicks et al. 2003) and assess the change in cardiovascular fitness using submaximal exercise tests. In the 8 studies included in this review, sample size ranged from 8 to 49 subjects, with a total of 210 different individuals with SCI participating.

2.4.1 Predictive tests

There have been two submaximal predictive tests developed for estimating VO$_2$peak in individuals with SCI (Table 2.1). The test designed by Kofsky et al. (1983) involved having
49 subjects cycle at 3 submaximal PO’s on an arm ergometer while VO₂ was measured. Of the 49 subjects, there were 8 individuals with tetraplegia, 34 with paraplegia and 7 with unspecified lower limb disabilities. For individuals with tetraplegia, the correlation between PO and measured VO₂ was poor (r=0.12), so these subjects were excluded from further analyses. For the remaining subjects, the correlations of PO with measured VO₂ were excellent (females r=0.85, males r=0.88), and allowed simple regression equations to be developed to predict VO₂ while arm cycling at submaximal POs. These submaximal VO₂ values were then used with the modified Astrand-Ryhming nomogram (Astrand 1960; Shephard 1972) to predict VO₂peak. The Astrand-Ryhming nomogram is reliable and valid (Macsween 2001), and uses an individual’s HR response to cycling at a specific submaximal PO along with age and gender to predict VO₂peak. Kofsky et al. (1983) found the correlations between predicted VO₂peak and measured VO₂peak to be moderate (males r=0.67, females r=0.61).

In a randomized controlled trial of exercise training in individuals with SCI, Hicks et al. (2003) used the protocol presented by Kofsky et al. (1983) to assess submaximal arm ergometry performance. Sixteen subjects with paraplegia arm cycled at 3 submaximal PO’s approximating 40%, 60% and 80% of age-predicted maximal HR, while 18 subjects with tetraplegia arm cycled at intensities that elicited Borg ratings of perceived exertion (RPE) of 1 (very weak), 2 (weak) and 4 (somewhat strong) from Borg’s 10-point RPE scale (Borg 1982). Following a 9-month resistance and aerobic training program, PO during the third submaximal stage increased by 82% for subjects in the intervention group (118% increase for subjects with tetraplegia, 45% increase for subjects with paraplegia), while no change was
observed in the control group. Although the predictive equations developed by Kofsky et al. (1983) were not used in this study, their test protocol was followed, and the submaximal PO's were found to be responsive to those that did and did not undergo exercise training.

The second predictive test is a modified version of the Canadian Aerobic Fitness Test (CAFT) (Longmuir and Shephard 1993; 1995). In this study, 46 individuals with a variety of orthopaedic and neuromuscular impairments, including 9 subjects with SCI, completed up to three submaximal exercise stages on an arm ergometer. The PO of each stage increased by increasing cranking cadence according to age and gender-specific test stages provided by the CAFT. HR was taken at the end of each stage, and if it exceeded a predetermined ceiling count, the test was terminated. Age, body mass, HR during the final testing stage, and oxygen cost of the final testing stage (taken from a table) were entered into the predictive equation from the Canadian Standardized Test of Fitness (CSTF) to estimate VO₂peak. This submaximal test was repeated after approximately one week. The reliability of the predicted VO₂peak over this week was excellent (ICC=0.97), but the correlation between predicted VO₂peak and measured VO₂peak was only fair (r=0.51). Also, although 87% of healthy, able-bodied adults were able to complete the modified CAFT (Longmuir and Shephard 1993), only 35% of subjects with mobility impairments were able to maintain the appropriate arm cycling cadence to complete the test (Longmuir and Shephard 1995).
2.4.2 Performance based tests

Four performance based submaximal exercise tests for individuals with SCI have been presented in the literature (DiCarlo 1988; Dwyer and Davis 1997; Franklin et al. 1990; Rhodes et al. 1981). Each of these tests involves a continuous wheeling task for 12 minutes, with the primary outcome measure being the distance wheeled during that time (Table 2.1). The distance wheeled during 12 minutes of continuous wheeling around a 200 metre track was used by DiCarlo (1988) to measure functional endurance in 8 subjects with tetraplegia. The validity of this test was not determined, but test-retest reliability over separate days was excellent, with an ICC of 0.97 between days. Following a cardiovascular training program done by the same 8 men, DiCarlo (1988) found wheeling distance to increase proportionately to VO$_2$peak, indicating the tests ability to detect change. Both Franklin et al. (1990) and Rhodes et al. (1981) found the distance wheeled in 12 minutes to have moderate to good correlations with VO$_2$peak ($r=0.50$ to $r=0.84$), and used these distances to develop predictive equations for VO$_2$peak. Using 30 male subjects (25 with paraplegia, 2 with post-polio syndrome and 3 with lower limb amputation), Franklin et al. (1990) found the distance wheeled to accurately predict VO$_2$peak (standard error of estimate (SEE)=0.13). Rhodes et al. (1981) tested 30 male subjects with SCI (10 with tetraplegia, 20 with paraplegia) and found the correlations between measured VO$_2$peak and predicted VO$_2$peak to range from $r=0.69$ to $r=0.88$, depending on lesion level. Both of these studies only used male subjects, so Dwyer and Davis (1997) suggested that the study should be repeated with female subjects to increase the generalizability of these findings. They did not, however, find the 12 minute wheeling distance to be correlated to VO$_2$peak. All subjects in the DiCarlo (1988) and
Rhodes et al. (1981) studies had a SCI, but in the study by Franklin et al. (1990), although all subjects were manual wheelchair users, not all subjects had a SCI; those with post-polio and lower limb amputations were also included. The diagnosis of subjects is not included in the Dwyer and Davis (1997) study; it is only stated that all subjects had a lower limb disability.

Of the studies included in this review, only one adverse effect was reported. The wheelchair of one subject in the Franklin et al. (1990) study overturned while he was completing the 12 minute wheeling test, but no serious abrasions or musculoskeletal complications occurred. As none of the studies reported the blood pressure (BP) responses to either the submaximal tests or the validating VO\textsubscript{2}peak tests, it is unknown if any subjects experienced exertional hypotension.

2.5 Discussion

Submaximal exercise tests have several advantages over maximal exercise tests. Physician supervision is not generally required when conducting these tests, because individuals are not attempting to maximize their cardiovascular systems. The exertional hypotension that often accompanies exercise in individuals with SCI has been found to be more frequent and more severe during maximal exercise compared to submaximal exercise (Drory et al. 1990; King et al. 1994). Consequently, during submaximal exercise individuals are at less risk for the lightheadedness and dizziness that can accompany exertional hypotension. Gas analysis equipment is not required to conduct submaximal field tests, so
clinicians do not require extensive training to operate the equipment. As well, less time is typically required to run a submaximal exercise test compared to a maximal test.

The field tests described by DiCarlo (1988), Dwyer and Davis (1997), Franklin et al. (1990) and Rhodes et al. (1981) require minimal equipment, and are inexpensive to administer. Rhodes et al. (1981) found the 12 minute wheeling distance better at predicting VO$_2$peak in individuals with tetraplegia compared to those with paraplegia, and DiCarlo (1988) found a similar wheeling task to be reliable and responsive to an increase in VO$_2$peak in individuals with tetraplegia. The wheeling tests demonstrated, at best, moderate validity in individuals with paraplegia. These tests have only been validated only on 200 and 400 metre tracks, and access to these facilities is rarely available clinically. If a shorter wheeling circuit were used, the wheeler would spend much of their time cornering, and not actively pushing, therefore they would not be able to attain a sufficiently high intensity of wheeling to measure cardiovascular fitness. Additional concerns for this type of exercise test include having a standardized surface for the wheeling to take place on, and use of standard versus lightweight wheelchairs. Wheeling over surfaces with higher levels of friction (gravel or rubberized track versus pavement) and using heavier chairs would likely result in shorter distances wheeled, and an underestimation of cardiovascular fitness. Dwyer and Davis (1997) did not find the distance wheeled to be correlated to VO$_2$peak, but all of their subjects were female wheelchair basketball players with paraplegia or other lower limb disabilities. Although their VO$_2$peak values ranged from 15.7 to 36.2 mL/kg/min the range of the distance wheeled was much less varied (1950-2350 m). As all subjects were physically active, their similar wheeling distances may demonstrate a ceiling effect of this test.
The tests described by Kofsky et al. (1983) and Longmuir and Shephard (1993; 1995) use an arm ergometer and HR monitor, equipment which is likely available in most rehabilitation settings. The practicality of the modified CAFT is limited. Although 87% of healthy, able-bodied subjects were able to complete the modified CAFT (Longmuir and Shephard 1993) only 33% of subjects with mobility impairments (including those with SCI) were able to arm cycle at the required cadences to complete the test (Longmuir and Shephard 1995). Thus, this test is inappropriate for the majority of its intended population.

Most predictive submaximal exercise tests, including the test presented by Kofsky et al. (1983), use an individual's HR response to one or more submaximal PO's to predict an individual's VO₂peak. These predictions are based on the assumption that HR and VO₂ have a linear relationship throughout the range of PO's up to that individual's maximum. It is important to note several issues regarding this assumption. First, HR can vary independently of VO₂ due to a number of factors including hydration status, caffeine intake, haemoglobin levels and emotional state (Rowell et al. 1964). Secondly, in able-bodied individuals, maximal HR is attained at a work rate slightly under VO₂peak, and consequently most predictive equations underestimate VO₂peak (Macsween 2001). Third, predictive tests require the estimation of maximal HR. In able-bodied individuals, age-predicted maximal HR is typically estimated using the equation ‘220-age’ (ACSM 2000), but this has been found to vary five percent with age (Wyndham 1967). This means that VO₂peak is likely to be over or under-estimated for each individual. Although this standard maximal HR equation appears to be valid for individuals with a low paraplegic level SCI (Pare et al. 1993), interruptions to the nervous system at and above T6 alter the HR response to exercise. As
previously discussed, individuals with lesions to the sympathetic nerves higher than T6 have a limited ability to increase their HR and their maximal HR rarely exceeds 100-125 beats/minute. As a result, the traditional predictive equations that rely solely on an individual's HR response to exercise are not appropriate for individuals with a high level SCI. The test presented by Kofsky et al. (1983) used the modified Astrand-Ryhming nomogram (Astrand 1960; Shephard 1972) to predict VO$_2$peak, which is based upon the linear HR-VO$_2$ response to exercise. Although the data from subjects with tetraplegia was not used in the development of the predictive equation, individuals with high level (above T6) paraplegia were included, and their impaired HR response to exercise may in part explain why only moderate correlations between predicted and measured VO$_2$peak were found. Similarly, the arm CAFT described by Longmuir and Shephard (1993; 1995) used subjects HR following their final submaximal stage in the prediction equation for VO$_2$peak.

Although some of the submaximal exercise tests presented in this review have been reported as reliable and/or valid, none are commonly used to evaluate fitness in the intended population, and most have only been validated in a small subset of individuals with SCI, such as athletes, males, or those with paraplegia.

For an exercise test to become a useful outcome measure in a rehabilitation or fitness program, it must be reliable, valid and responsive to change (Streiner and Norman 1995). Of the 6 tests previously discussed (Table 2.1), 2, 5 and 2 described reliability, validity and responsiveness, respectively. Although researchers began describing the measurement
properties of each of these exercise tests, no single test was reported to be reliable, valid and responsive to change.

2.5.1 Recommendations

Of the current tests that have been described, it is recommended that the wheeling test presented by Rhodes et al. (1981) be used to assess cardiovascular fitness in individuals with tetraplegia, while the submaximal test presented by Kofsky et al. (1983) be used for individuals with paraplegia. The wheeling tests (DiCarlo 1988; Dwyer and Davis 1997; Franklin et al. 1990; Rhodes et al. 1981) all have slight methodological differences, but the psychometric properties of each are low in subjects with paraplegia and higher in those with tetraplegia. The main limitation to administering this test is the availability of a large indoor or outdoor track. If a track is not available, the Kofsky et al. (1983) protocol, or a modification of it (Hicks et al. 2003) is a feasible alternative for assessing cardiovascular fitness in individuals with SCI. Hicks et al. (2003) demonstrated that a variation of the Kofsky et al. (1983) protocol is sensitive to change in both individuals with tetraplegia and paraplegia. This fact, along with its stronger validity values in individuals with paraplegia, makes it more appropriate than the wheeling tests for the evaluation of cardiovascular fitness in individuals with paraplegia.

Current tests do exist that can be used to assess cardiovascular fitness in individuals with SCI, but the need remains for a submaximal arm exercise test that has defined measurement properties. With a valid, reliable and responsive assessment tool, therapists will be better able
to educate and provide feedback about cardiovascular fitness to their clients as they progress through a rehabilitation or training program. This information may help to motivate individuals with SCI to increase their physical activity level, and therefore help to decrease their risk for CAD.

2.6 Summary

From the submaximal exercise tests presented in the literature, the following recommendations can be made for the assessment of cardiovascular fitness in individuals with SCI:

- **For individuals with tetraplegia:** If a track is available, the equations developed by Rhodes et al. (1981) should be used. If no track is available, the Kofsky et al. (1983) protocol should be followed.

- **For individuals with paraplegia:** The Kofsky et al. (1983) protocol should be followed.

There are limitations to each of these tests, however, and further research is required to develop and evaluate a submaximal exercise test for individuals with SCI that has strong psychometric properties.
### Table 2.1 Submaximal exercise tests

<table>
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<tr>
<th>Author</th>
<th>Subjects</th>
<th>Protocol of Test(s)</th>
<th>Results/Primary Findings</th>
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<tr>
<td>DiCarlo 1988</td>
<td>8 subjects with tetraplegia; male; mean age 23.6 years; lesion level C5-C7</td>
<td><strong>SUBMAXIMAL PERFORMANCE TEST</strong>&lt;br&gt;Sustained wheelchair propulsion for 12 minutes around a 200 metre indoor track. Total distance covered was measured. This test was repeated 3 times on alternate days.</td>
<td>Pearson product-moment correlation of $r=0.97$ between trials. Following cardiovascular training, propulsion distance increased proportionally to an increase in VO$_2$peak.</td>
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<tr>
<td>Dwyer and Davis 1997</td>
<td>13 subjects (with paraplegia or other lower limb disability); female; mean age 26 years</td>
<td><strong>SUBMAXIMAL PERFORMANCE TEST</strong>&lt;br&gt;Continuous wheeling to &quot;cover the greatest possible distance&quot; in 12 minutes around a 200 metre indoor track. Total distance covered was measured. Arm ergometer VO$_2$peak test also completed.</td>
<td>Correlation between distance wheeled and VO$_2$peak (L/min): $r=0.30$ (p&gt;0.05)</td>
</tr>
<tr>
<td>Franklin et al. 1990</td>
<td>30 subjects (25 with paraplegia, 2 post-polio patients, 3 with lower limb amputation); male; mean age 34.3 years</td>
<td><strong>SUBMAXIMAL PERFORMANCE TEST</strong>&lt;br&gt;Continuous wheeling to &quot;cover the greatest possible distance&quot; in 12 minutes around a 0.1 mile indoor track. Total distance covered was measured. Arm ergometer VO$_2$peak test also completed. Results from submaximal test used to develop predictive equation for VO$_2$peak.</td>
<td>Correlation between distance wheeled and VO$_2$peak (L/min): $r=0.84$ (p&lt;0.001) Regression equation developed: $\text{VO}_2\text{peak (mL/kg/min)} = [\text{distance wheeled (miles)} - 0.370] \times 0.0337$ SEE=0.13</td>
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| Kofsky et al. 1983 | 49 subjects with lower limb disabilities; 42 male, 7 female; mean age 28.3 years; 8 with tetraplegia, 34 with paraplegia, 7 with unspecified lower limb disabilities lesion | **SUBMAXIMAL PREDICTIVE TEST**  
Subjects performed 3 submaximal bouts on the arm crank ergometer, eliciting HR's of approximately 40, 60 & 80% of age-predicted maximum.  
Arm ergometer VO2peak test also completed. Results from the submaximal stages of the VO2peak test were used to develop predictive equations for submaximal VO2. Predicted submaximal VO2 values were used along with the modified Astrand-Ryhming nomogram to predict VO2peak. | Regression equations developed from VO2peak tests to predict VO2 at submaximal PO's (excluding those with tetraplegia):  
For males: VO2 (L/min) = 0.018 [PO (Watts(W))] + 0.40  
For females: VO2 (L/min) = 0.017 [PO (W)] + 0.37  
Correlation between predicted VO2peak value and measured VO2peak:  
For males, r=0.67, for females r=0.61, but large standard deviations for individual submaximal predictions |
| Hicks et al. 2003 | 34 subjects with SCI; male and female (unspecified numbers); mean age 39.3 years; 18 with tetraplegia, 16 with paraplegia | Randomized controlled trial of 9 month resistance and aerobic training program.  
To assess submaximal arm ergometry performance, subjects performed 3 submaximal bouts on the arm crank ergometer, eliciting either HR’s of approximately 40, 60 & 80% of age-predicted maximum (subjects with paraplegia) (from Kofsky et al. 1983) or Borg ratings of perceived exertion of 1 (very weak), 2 (weak) and 4 (somewhat strong) from Borg’s 10-point scale (subjects with tetraplegia). | Following the training program, PO during the third submaximal stage increased by 82% for subjects in the intervention group (118% increase for subjects with tetraplegia, 45% increase for subjects with paraplegia), while no change was observed in the control group. |
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<td>Longmuir and Shephard 1993; 1995</td>
<td>46 subjects with various orthopaedic and neuromuscular impairments including 9 subjects with SCI; 22 male, 24 female; mean age 40 years</td>
<td><strong>SUBMAXIMAL PREDICTIVE TEST</strong> Subjects performed 3 submaximal bouts of exercise at a low resistance on an arm ergometer. Cadence increased with each stage according to age and gender specific test stages (following the protocol of CAFT). VO$_2$peak was predicted using a modified CSTF equation: VO$_2$peak (mL/kg/min) $= 42.5 + 16.6$*oxygen cost of given test stage (L/min) $- 0.12$*body mass (kg) $- 0.12$*HR $- 0.24$*age (years)</td>
<td>Practicality: Appropriate arm cranking rhythms could only be maintained by 35% of subjects</td>
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<td>Reliability of predicted VO$_2$peak: ICC=0.97</td>
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<td>Correlation between measured VO$_2$peak and predicted VO$_2$peak: r=0.51</td>
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<td>This test was repeated after one week. Arm ergometer VO$_2$peak test also completed.</td>
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<td>Author</td>
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| Rhodes et al. 1981 | 30 subjects with SCI; male; mean age 31.0 years; 10 with tetraplegia, 20 with paraplegia | **SUBMAXIMAL PERFORMANCE TEST**  
Continuous wheeling around a 400 metre track for 12 minutes. Total distance covered was measured.  
Wheelchair ergometer VO2peak test also completed. Results from submaximal test were used to develop predictive equations for VO2peak. | Correlation of distance wheeled and VO2peak: For all subjects r=0.80  
For subjects with paraplegia r=0.54  
For subjects with tetraplegia r=0.50  
Three regression equations were developed:
**For all subjects**: VO2peak (L/min) = 0.984 distance (km) + 0.011 systolic BP (resting) - 0.009 diastolic BP (resting) + 0.007 weight (kg) - 1.051  
r=0.85, SEE=0.38 L/min  
**For those with Paraplegia**: VO2peak (L/min) = 0.3 distance + 0.007 systolic BP - 0.022 diastolic BP - 0.11 age (closest year) + 0.013 height (cm) + 0.36  
r=0.69, SEE=0.32 L/min  
**For those with Tetraplegia**: VO2peak (L/min) = 0.003 diastolic BP - 0.122 distance - 0.008 age + 0.01 weight - 0.12 height + 2.652  
r=0.88, SEE=0.16 L/min |
Chapter 3: Reliability and validity of a submaximal arm ergometer test for the evaluation of cardiovascular fitness in individuals with spinal cord injury

3.1 Abstract

**Background and Purpose:** The prevalence of cardiovascular disease in individuals with spinal cord injury (SCI) is as high as or greater than in the general population. Despite the arm exercise tests that have been proposed, the need remains for a submaximal exercise test that is inexpensive, simple to administer in clinics and rehabilitation centres, and can be completed by the majority of individuals with SCI. The purpose of this study was to design a submaximal single-stage arm ergometer test (SSSAET) for use in individuals with SCI, and to determine the test-retest reliability and criterion validity of this exercise test.

**Methods:** Thirty subjects with SCI were evaluated using the American Spinal Injury Association (ASIA) scale, isometric strength testing, a physical activity questionnaire, the SSSAET, and a VO2peak test. To determine the test-retest reliability of the SSSAET, subjects completed the SSSAET on two days, separated by 1 week. Criterion validity was determined by comparing the results of the SSSAET with VO2peak.

**Results:** All subjects were able to complete the SSSAET. Test-retest reliability of steady state VO2 and heart rate (HR) during the SSSAET were excellent; ICC=0.81 and 0.90, respectively. Examination of Bland-Altman plots showed acceptable variability between the SSSAET outcomes on the two testing occasions. The correlation between VO2peak and SSSAET VO2 was excellent (r=0.92), while those between VO2peak and SSSAET HR (r=0.63) and VO2peak and SSSAET power output (PO) (r=0.73) were good.
Conclusions: This study demonstrated that the SSSAET has acceptable values for test-retest reliability and criterion validity. Further testing is necessary before the SSSAET will be ready for implementation as a clinical tool to assess baseline and changes in cardiovascular fitness in individuals with SCI.
3.2 Introduction

With more than 36,000 Canadians living with a SCI (Canadian Paraplegia Association 1997) and the life expectancy of these individuals closely resembling that of the general population (DeVivo et al 1999; Krause et al. 2004), chronic diseases have become more prevalent in this population, and the predominant cause of death has shifted from genitourinary infections to respiratory and cardiovascular diseases (DeVivo et al. 1999; Frankel et al. 1998; Soden et al. 2000). Studies have shown that the prevalence of coronary artery disease in individuals with SCI is at least as high as in the general population (Yekutiel et al 1989; Bauman et al 1992). Consequently, physical fitness needs to be better monitored in individuals with SCI, in part because of its ability to predict cardiovascular disease risk.

Relative to the general population, most individuals with SCI have reduced cardiovascular fitness (VO₂peak) (Davis 1993) and a diminished physical work capacity (Hopman et al. 1998). Inactivity and low VO₂peak are modifiable risk factors associated with cardiovascular disease (American College of Sports Medicine 2000). By improving VO₂peak in individuals with SCI, both the risk for cardiovascular disease (Dearwater et al. 1986) and physical strain during activities of daily living can be decreased (Janssen et al. 1996). Protocols for assessing VO₂peak for individuals with SCI in laboratory settings are highly established (Martel et al. 1991; Walker et al. 1986), but costly specialized equipment and trained personnel are required to conduct these tests.
Submaximal tests have been used widely in able-bodied populations to estimate cardiovascular fitness (Noonan and Dean 2000), but as most involve lower extremity exercise, there are few appropriate tests that can be completed by individuals with SCI. A number of submaximal tests designed for individuals with SCI (Franklin et al. 1990; Kofsky et al. 1983; Longmuir and Shephard 1993; 1995; Rhodes et al. 1981), but each has limitations to widespread use. An arm ergometer equivalent to the Canadian Aerobic Fitness Test (CAFT) (Longmuir and Shephard 1993) was not feasible for individuals with lower limb disabilities because of the high cycling cadences required to complete the test (Longmuir and Shephard 1995). Twelve minute wheeling tests detailed by DiCarlo (1988), Dwyer and Davis (1993), Franklin et al. (1990), and Rhodes et al. (1981) all require large 200 metre tracks, which are not typically available clinically. Finally, a three-stage submaximal arm ergometer test was designed to predict VO$_2$peak in individuals with SCI, but this test was found to be only moderately correlated to measured VO$_2$peak (Kofsky et al. 1983).

Despite the studies that have proposed submaximal arm exercise tests, the need remains for a test that is inexpensive, simple to administer in clinics and rehabilitation centres, and that can be completed by individuals with both paraplegia and tetraplegia. In this study, the submaximal single-stage arm ergometer test (SSSAET) is being proposed as a new test to assess cardiovascular fitness in individuals with SCI. The SSSAET will involve six minutes of submaximal arm ergometry at a constant PO. As steady state physiological responses are typically seen within two to three minutes of submaximal exercise (Hagberg et al. 1978; Whipp and Wasserman 1972), six minutes was chosen as it would illicit steady state exercise,
yet not be so long as to fatigue an untrained individual. A single stage test was chosen as it would be simple to administer clinically, and require less of the clinician’s time.

Thus, the purpose of this study was to design a SSSAET for use in individuals with SCI, and to determine the test-retest reliability and criterion validity of this exercise test.

3.3 Methods

3.3.1 Subjects

Adults with SCI were recruited on a volunteer basis by therapists, a mail-out to past patients from a local rehabilitation centre, and through advertisements placed in a rehabilitation centre and SCI newsletter (Appendix B). Screening of potential subjects was done via a telephone interview to determine if potential subjects 1) had a traumatic SCI at least six months ago; 2) were between 18 and 50 years of age; 3) used a manual or power wheelchair for daily mobility; and 4) were able to independently push an arm cycle ergometer. Individuals were excluded from participating in this study if they had a previous myocardial infarction (one person). The Physical Activities Readiness Questionnaire (Thomas et al. 1992) (see Appendix C) was administered over the telephone to help decide whether or not it was safe for potential subjects to exercise. Eligible subjects gave informed, written consent (see Appendix D) to participate in this study. Ethical approval for this study was obtained from the University of British Columbia and GF Strong Rehab Centre ethics committees.
Sample size calculations were done and are attached in Appendix E. For the validity component of the study it was found that for a two-tailed test with $\alpha = 0.05$, a power of 0.80 and a desired effect size of 0.5, 28 subjects were required.

Cognitive impairment was assessed when potential subjects first arrived at the laboratory using the Cognitive Capacity Screening Examination (CCSE) (Jacobs et al. 1977; Kaufman et al. 1979) (see Appendix F). No subjects were identified as having a cognitive impairment (as indicated by a score of less than 24 out of 30). The psychometric properties of the CCSE and the other assessment tools used in this study are presented in Appendix N.

Classification of SCI: The ASIA assessment was used to classify the completeness of each subject's SCI, as well as to determine their motor and sensory function (ASIA/International Medical Society of Paraplegia 2000) (see Appendix G).

Physical activity level: The physical activity level of all subjects was assessed using the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) (Washburn et al. 2002) (see Appendix H). The PASIPD is a self-report questionnaire that uses an estimate of the number of days per week and hours per day spent in different leisure, household and occupational activities over the past seven days. Total scores are calculated as the sum of the average hours per day multiplied by a metabolic equivalent for all twelve items.
Strength: Upper extremity isometric muscle strength was measured using hand-held dynamometry (Nicholas MMT; Lafayette Instrument; Lafayette, IN). Three maximal voluntary contractions of the elbow flexors and extensors, shoulder flexors and extensors and wrist flexors and extensors were performed bilaterally. Each effort was held for 3 seconds, with at least 30 seconds of rest between trials. The 3 trials were averaged to obtain a mean score for each muscle group. All measurements were taken with the subject seated in their wheelchair, using standard arm positioning (see Appendix I).

Mobility device: Independence in wheeled mobility was evaluated using a pilot 9-category wheeled mobility classification scale for individuals with SCI. Categories ranged from full time power wheelchair users to full time ambulators. Table 3.1 describes each of the categories.

3.3.2 Protocol

For both the SSSAET and cardiovascular fitness test, subjects wore a face mask while respiratory variables (VO₂, VCO₂, ventilation (VE), respiratory exchange ratio (RER)) were continuously measured by a portable metabolic unit performing breath-by-breath gas analysis (Cosmed K4b² system; COSMED; Rome, Italy). Subjects were asked to void their bladders prior to commencing the exercise tests to minimize any episodes of autonomic dysreflexia. Subjects were asked to rate their level of perceived exertion using Borg’s (1970) 16-point rate of perceived exertion (RPE) scale immediately following the tests (see Appendix J). Blood pressure (BP) was recorded at rest, immediately following exercise and throughout
recovery to ensure BP returned to baseline values following the exercise tests. Blood lactate measurements were taken at rest and at the end of the exercise tests using a drop of blood collected from a finger-prick (see Appendix K for protocol). For subjects with insufficient hand grip, elastic straps were used to secure their hands to the handles of the arm ergometer.

Table 3.1 Wheeled mobility categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Relies fully on power wheelchair</td>
</tr>
<tr>
<td>2</td>
<td>Relies primarily on a power wheelchair for community mobility; uses manual wheelchair for exercise only</td>
</tr>
<tr>
<td>3</td>
<td>Relies primarily on a power wheelchair for community mobility; uses manual wheelchair for some household activities</td>
</tr>
<tr>
<td>4</td>
<td>Relies primarily on manual wheelchair; relies on power wheelchair or assistance with long distances or uphill</td>
</tr>
<tr>
<td>5</td>
<td>Relies fully on manual wheelchair and is independent in all home and community activities</td>
</tr>
<tr>
<td>6</td>
<td>Relies primarily on manual wheelchair; able to walk for exercise only at home</td>
</tr>
<tr>
<td>7</td>
<td>Able to use walking for some household activities, but uses a wheelchair in the community</td>
</tr>
<tr>
<td>8</td>
<td>Can walk independently for most activities; relies on a manual wheelchair for long distances</td>
</tr>
<tr>
<td>9</td>
<td>Walks independently for all household and community activities</td>
</tr>
</tbody>
</table>
**SSSAET:** Subjects completed a single, 6-minute stage of submaximal exercise on an arm cycle ergometer (Monark Rehab Trainer 881E; Vansbro, Sweden). An individual PO was subjectively selected for each subject based on their muscle strength, ASIA motor score and physical activity level. The PO was chosen with the aim of eliciting either a steady state HR of 60-70% of age-predicted maximum HR (for subjects with low level paraplegia) or a rating of 11-15 on Borg’s (1970) RPE scale (for subjects with tetraplegia or high level paraplegia). HR was continually recorded using a chest HR monitor (Polar A3; Polar Electro; Woodbury, NY).

Approximately one week after the initial SSSAET, subjects were invited to return to complete a second SSSAET. One week after the second test, each subject underwent a VO₂peak test on an arm ergometer.

**Peak oxygen consumption:** To measure VO₂peak, subjects performed a symptom-limited graded arm cycle ergometer test on an electronically braked arm ergometer (Excaliber; Lode B.V. Medical Technology; Groningen, Netherlands) in the presence of a physician and a kinesiologist. Cardiac stability and HR were monitored by a physician using a 12-lead electrocardiogram (ECG) (Quark C12; COSMED Srl; Rome, Italy) (see Appendix L for electrode placement). Subjects initially sat quietly for two minutes while resting values of HR and respiratory variables were collected. Arm cycling began without resistance at a comfortable, self-selected cadence (between 60-80 rpm). Following a brief warm up, PO increased in a step protocol by either 5 or 10 Watts (W)/min (5 W/min for subjects with tetraplegia (Lasko-McCarthey and Davis 1991), 10 W/min for subjects with paraplegia...
Subjects continued to arm cycle until they reached volitional fatigue (i.e. they were not able to maintain a cycling rate of 30 rpm). American College of Sports Medicine (ACSM) Guidelines (2000) were used to determine whether the test should be terminated early: ST-segment depression >2 mm, increasing nervous system symptoms (i.e. ataxia, dizziness), sustained ventricular tachycardia or chest discomfort (see Appendix M for additional details regarding the VO2peak testing).

3.3.3 Data analysis

Descriptive statistics were calculated for subject characteristics and cardiovascular variables (HR, VO2) during the SSSAET and VO2peak test. Skewness coefficients were calculated and scatter-plots of variables used in the validity analysis visually inspected to ensure outlier and influential data points did not compromise the results.

The final 30 seconds of the physiological data (HR, VO2) during the SSSAET was averaged to get a single representative steady-state value for each subject. The breath-by-breath data obtained during the VO2peak test was averaged at a rate of every 15 seconds to obtain a more accurate measure of VO2peak. The highest value of VO2 (in mL/kg/min) obtained in any 15 second interval during the test was considered to be the VO2peak.

Intraclass correlation coefficients (ICC2,1) and standard error of measurement (SEM) were used to determine the test-retest reliability of steady state VO2 and HR during the
SSSAET. Absolute reliability was evaluated using Bland-Altman plots (Bland and Altman 1986) to determine how individual scores varied on repeated measurement.

Pearson product-moment correlations were used to quantify the relationship between VO$_2$peak and steady state VO$_2$, HR and PO during the SSSAET.

All statistical analyses were performed using SPSS 11.5 software (Statistical Package for the Social Sciences; Chicago, Illinois) using a significance level of $p \leq 0.05$ (two-tailed).

3.4 Results

Descriptive data for the subject characteristics can be found in Table 3.2. A total of 30 subjects participated in this study; 13 with paraplegia, and 17 with tetraplegia. Lesion levels are listed in Table 3.3. Subjects had a mean (standard deviation (SD)) age of 36.3 (9.3) years and a mean (SD) time since SCI of 12.0 (9.8) years. Eighty-three percent of the subjects were male, which is comparable to Canadian statistics (Canadian Paraplegic Association 1997). Subjects in this study ranged from full-time power wheelchair users to individuals that were able to ambulate for exercise.
### Table 3.2 Subject characteristics (n=30)

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Mean</th>
<th>(SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/F)</td>
<td>25/5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>36.3</td>
<td>9.3</td>
<td></td>
<td>19-49</td>
</tr>
<tr>
<td>Time since injury (years)</td>
<td>12.0</td>
<td>9.8</td>
<td></td>
<td>1-34</td>
</tr>
<tr>
<td>ASIA Grade (A/B/C/D)</td>
<td>22/7/0/1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASIA Motor Score (0-100)</td>
<td>41.2</td>
<td>16.7</td>
<td></td>
<td>19-75</td>
</tr>
<tr>
<td>PASIPD score</td>
<td>16.5</td>
<td>9.8</td>
<td></td>
<td>1.0-38.7</td>
</tr>
<tr>
<td>Wheeled mobility category (1/3/4/5/6)</td>
<td>2/1/11/15/1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3.3 Subject lesion levels (number per level)

<table>
<thead>
<tr>
<th>Cervical</th>
<th>Thoracic</th>
<th>Lumbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4 = 6</td>
<td>T1 = 1</td>
<td>L2 = 2</td>
</tr>
<tr>
<td>C5 = 3</td>
<td>T3 = 1</td>
<td>L3 = 1</td>
</tr>
<tr>
<td>C6 = 5</td>
<td>T4 = 2</td>
<td></td>
</tr>
<tr>
<td>C7 = 3</td>
<td>T7 = 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T10 = 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T11 = 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T12 = 1</td>
<td></td>
</tr>
</tbody>
</table>
3.4.1 Peak oxygen consumption

The mean (SD) VO\textsubscript{2peak} value for all subjects was 18.6 (8.4) mL/kg/min, with the range extending from 6.5 to 38.1 mL/kg/min (Table 3.4). The peak HR averaged 129 (29) beats/min, and the mean peak PO attained was 60.2 (36.0) W. Subjects in this study had a wide range of fitness levels, and there was overlap in the physiological responses to exercise between subjects with paraplegia and tetraplegia. During both the VO\textsubscript{2peak} test, and the SSSAET, 15 subjects required their hands to be secured to the handles of the arm ergometer with elastic straps. No VO\textsubscript{2peak} tests were terminated early because of adverse effects or contraindications. One subject experienced self-reported "mild" autonomic dysreflexia midway through the test, which presented as a rapid decrease in HR of 20 beats/min. Seven subjects reported mild light-headedness upon cessation of cycling, and two experienced muscle spasms at low PO's that briefly interrupted their cycling cadence.

3.4.2 SSSAET

All subjects were able to complete the SSSAET. Four subjects experienced mild muscle spasms during their cycling that briefly interrupted their cycling cadence. The mean (SD) steady state VO\textsubscript{2} value was 13.1 (4.2) mL/kg/min, with the range extending from 6.3 to 22.9 mL/kg/min (Table 3.5). HR averaged 103 (21) beats/min, and the mean PO was 27.8 (17.0) W. Similar to that seen in the VO\textsubscript{2peak} test, there was overlap in the both the PO and physiological responses of the subjects with paraplegia and tetraplegia.
Table 3.4 Values during the VO₂peak test

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak PO (W)</td>
<td>60.2</td>
<td>36.0</td>
<td>20-160</td>
</tr>
<tr>
<td>Peak HR (beats/min)</td>
<td>129</td>
<td>29</td>
<td>75-183</td>
</tr>
<tr>
<td>Percent HR maximum&lt;sup&gt;1&lt;/sup&gt;</td>
<td>70.1</td>
<td>14.0</td>
<td>43.6-97.3</td>
</tr>
<tr>
<td>Peak VE (L/min)</td>
<td>42.8</td>
<td>19.5</td>
<td>18.0-113.1</td>
</tr>
<tr>
<td>VO₂peak (mL/kg/min)</td>
<td>18.6</td>
<td>8.4</td>
<td>6.5-38.1</td>
</tr>
<tr>
<td>VO₂peak (L/min)</td>
<td>1.33</td>
<td>0.52</td>
<td>0.74-2.81</td>
</tr>
<tr>
<td>Peak RER</td>
<td>1.14</td>
<td>0.09</td>
<td>0.97-1.34</td>
</tr>
<tr>
<td>Blood lactate (mmol/L)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>6.6</td>
<td>2.8</td>
<td>2.3-15.1</td>
</tr>
</tbody>
</table>

<sup>1</sup> Based on 220-age prediction equation

<sup>2</sup> Only 27 of 30 subjects had their blood lactate tested

Table 3.5 Steady state values during the SSSAET

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSSAET PO (W)</td>
<td>27.8</td>
<td>17.0</td>
<td>10-60</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>103</td>
<td>21</td>
<td>61-142</td>
</tr>
<tr>
<td>Percent HR maximum&lt;sup&gt;1&lt;/sup&gt;</td>
<td>56.0</td>
<td>10.2</td>
<td>35.7-75.7</td>
</tr>
<tr>
<td>VE (L/min)</td>
<td>25.0</td>
<td>5.7</td>
<td>14.7-39.8</td>
</tr>
<tr>
<td>VO₂ (mL/kg/min)</td>
<td>13.1</td>
<td>4.2</td>
<td>6.3-22.9</td>
</tr>
<tr>
<td>VO₂ (L/min)</td>
<td>0.95</td>
<td>0.28</td>
<td>0.55-1.61</td>
</tr>
<tr>
<td>Percent VO₂peak</td>
<td>74.5</td>
<td>13.0</td>
<td>51.0-97.8</td>
</tr>
<tr>
<td>RER</td>
<td>0.89</td>
<td>0.07</td>
<td>0.76-1.04</td>
</tr>
<tr>
<td>Blood lactate (mmol/L)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>3.0</td>
<td>1.3</td>
<td>1.0-6.0</td>
</tr>
</tbody>
</table>

<sup>1</sup> Based on 220-age prediction equation

<sup>2</sup> Only 28 of 30 subjects had their blood lactate tested
Reliability: Twenty of the 30 subjects (8 with paraplegia, 12 with tetraplegia) completed the SSSAET on a second occasion, approximately 1 week after the first test. Steady state ICC's for HR and VO₂ were 0.90 and 0.81, respectively (Table 3.6, Figure 3.1 and Figure 3.2).

The Bland-Altman method (Bland and Altman 1986) showed minimal differences between mean (SD) HR at time 1 (104 (23) beats/min) and time 2 (104 (20) beats/min) for the reliability sample. The mean (SD) difference between time 1 and time 2 was 0 (10) beats/min. As can be seen in Figure 3.3, all but one data point fell within 2 SD of the mean difference, and the data points are equally distributed above and below the mean difference line (11 above, 8 below, and 1 on the line). The outlying data point was an individual with tetraplegia. Test-retest reliability was recalculated without this outlier, and the ICC increased to 0.92 (95% CI 0.81-0.97). Similarly, during the SSSAET minimal differences were seen between mean (SD) VO₂ at time 1 (12.64 (3.71) mL/kg/min) and time 2 (12.26 (3.10) mL/kg/min) for the reliability sample. The mean (SD) difference between time 1 and time 2 was -0.44 (2.07) mL/kg/min (Figure 3.4). Once again, there is only one data point outside 2 SD of the mean difference, and the data points are equally distributed above and below the mean difference line (11 above and 9 below). This outlier was once again an individual with tetraplegia, but a different subject. With this outlier removed, the ICC for VO₂ increased to 0.86 (95% CI 0.67-0.94).
Figure 3.1 Scatter-plot comparing HR during SSSAET test 1 and test 2

Figure 3.2 Scatter-plot comparing VO₂ during SSSAET test 1 and test 2
Table 3.6 Test-retest reliability of HR and VO\textsubscript{2}

<table>
<thead>
<tr>
<th></th>
<th>ICC\textsubscript{2,1}</th>
<th>SEM</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>0.90</td>
<td>7.12</td>
<td>0.75-0.96</td>
</tr>
<tr>
<td>VO\textsubscript{2}</td>
<td>0.81</td>
<td>1.62</td>
<td>0.58-0.92</td>
</tr>
</tbody>
</table>

Figure 3.3 Bland Altman plot of difference in SSSAET HR between time 1 and time 2 versus average HR from time 1 and time 2

Figure 3.4 Bland Altman plot of difference in SSSAET VO\textsubscript{2} between time 1 and time 2 versus average VO\textsubscript{2} from time 1 and time 2
Validity: Using Pearson’s correlations, an excellent, positive, linear correlation was found between the SSSAET VO$_2$ and VO$_2$peak ($r=0.92$) (Figure 3.5), while good correlations were found between SSSAET PO and VO$_2$peak ($r=0.73$) (Figure 3.6) and SSSAET HR and VO$_2$peak ($r=0.63$) (Figure 3.7).

Selected results with subjects split into two groups, those with tetraplegia and those with paraplegia, are presented in Appendix O.

![Figure 3.5 Scatter-plot comparing VO$_2$ during the SSSAET and VO$_2$peak ($r=0.92$)](image-url)
Figure 3.6 Scatter-plot comparing PO during the SSSAET and VO$_2$peak ($r=0.73$)

Figure 3.7 Scatter-plot comparing HR during the SSSAET and VO$_2$peak ($r=0.63$)
3.5 Discussion

Demographic variables (age, sex, time since injury, level of injury) were comparable to Canadian statistics (Canadian Paraplegic Association 1997). The PASIPD is a fairly new measurement tool used for the evaluation of physical activity level of individuals with physical disabilities, so limited data is available for comparison. The mean PASIPD score of the subjects in this study was comparable to that reported by Washburn et al. (2002) in individuals with a variety of locomotor disabilities (including SCI).

Functional walking categories described by Perry et al. (1995) were modified to describe levels of wheelchair use. This new categorical scale was able to provide a description of subjects’ independence in wheeled mobility. As this study only recruited wheelchair users that were able to independently cycle an arm ergometer, it is appropriate that the majority of subjects were described by categories 4 and 5 (independent manual wheelchair users who do and do not require assistance with wheeling long distances or uphill). No subjects were described by categories 7, 8, or 9, as these categories describe full-time ambulators, and not wheelchair users. The use of this scale is promising as a tool to describe the wheelchair use characteristics of different populations, although further research with a broader range of subjects is necessary to determine if the initial categories are sufficient to describe all wheeled mobility levels.

The VO\textsubscript{2}peak values found in this group of SCI subjects were similar to others previously reported in the literature (Coutts et al. 1983; Janssen et al. 2002) indicating that this sample is
representative of the general population of individuals with SCI. This study included individuals with diverse activity levels ranging from sedentary individuals using power wheelchairs to international calibre wheelchair athletes. Using normative categories that were developed from the 20th percentiles of VO2peak values from 146 men with SCI (Janssen et al. 2002), the subjects from this study were categorized as follows: for subjects with tetraplegia, 1 poor, 1 fair, 6 average, 6 good and 3 excellent; for subjects with paraplegia, 2 poor, 4 fair, 3 average, 1 good and 3 excellent. The VO2peak values used by Janssen et al. (2002) to develop the normative categories are from only male subjects, with 40% of them being athletes. It is likely that the 'normative' VO2peak values used to categorize individuals are higher than the true values of the general population of individuals with SCI, thus VO2peak classification of subjects in this study may be underestimated.

All subjects were able to complete 6 minutes of arm ergometry exercise at an individually selected submaximal PO. During the SSSAET, subjects exercised at an average of 74.5% of VO2peak and at 56% of their age-predicted maximum HR, indicating that the exercise was aerobic. Blood lactate immediately following the SSSAET averaged 3.0 mmol/L. The onset of blood lactate accumulation, or the transition to anaerobic exercise, is said to take place when blood lactate concentrations rise above 4.0 mmol/L (Yoshida et al. 1987), so our value of 3.0 mmol/L provides further confirmation that aerobic exercise was occurring during the SSSAET.

Based on the magnitude of acceptable reliability values presented by Andresen (2000) and Fleiss (1981), HR and VO2 measured during the SSSAET have excellent test-retest
reliability. Visual inspection of the Bland-Altman plots reveals fairly equal distribution of test-retest differences above and below zero, suggesting minimal bias with repeated testing. For both HR and VO₂, only one of the 20 subjects in the reliability sample fell outside 2 SD of the mean difference, indicating limited test-retest variation for both variables (Bland and Altman 1986). Both HR and VO₂ have well established relationships with PO, so it is not surprising that reliability was high.

The SSSAET was designed as a submaximal cardiovascular fitness test, and thus it needed to be validated against the gold standard of cardiovascular fitness testing, the VO₂peak test. The correlation between VO₂peak and SSSAET VO₂ was excellent (r=0.92), indicating that those subjects with a high submaximal VO₂, had a high VO₂peak. Submaximal PO and VO₂peak had a lower correlation (r=0.73). It is not surprising that this correlation was weaker, as up to nine subjects cycled at the same PO for the SSSAET, and all did not have the same absolute VO₂peak. The correlation between submaximal HR and VO₂peak was also lower (r=0.63). The SSSAET was designed to have subjects cycle while maintaining a constant PO at 60-70% of their age-predicted maximum HR. As this target HR value is based solely on age, two individuals of the same age but different cardiovascular fitness levels would both be exercising at a similar submaximal HR. The same submaximal HR would be associated with very different VO₂peak values. Thus the correlation between SSSEAT HR and VO₂peak is not a true measure of validity, and was not expected to be high.

One of the difficulties of conducting the SSSAET was determining an appropriate submaximal PO for each subject. In this study, PO for the SSSAET was selected subjectively
based on subjects ASIA motor score, muscle strength and physical activity level. If the initial 
PO was too high (i.e. subjects could not complete 6 minutes, RPE > 15, and/or HR > 70% 
age predicted maximum) or too low (i.e. RPE < 11 and/or HR < 60% age predicted 
maximum), subjects were given a rest period before they attempted a second SSSAET at an 
adjusted PO. Retrospectively, separate algorithms were created for individuals with 
paraplegia and tetraplegia to provide guidelines for SSSAET PO selection (Figures 3.8 and 
3.9). If these algorithms had been used to predict the PO's for the subjects in this study, 11 of 
the 17 subjects with tetraplegia (65%), and 11 of the 13 subjects with paraplegia (85%) 
would have had their PO set appropriately on the first attempt.

<table>
<thead>
<tr>
<th>Diagnosis: TETRAPLEGIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set PO to 10 W if:</td>
</tr>
<tr>
<td>Power wheelchair user</td>
</tr>
<tr>
<td>or</td>
</tr>
<tr>
<td>≤Grade 4 wrist extension</td>
</tr>
<tr>
<td>Set PO to 15 W if:</td>
</tr>
<tr>
<td>Manual wheelchair user</td>
</tr>
<tr>
<td>or</td>
</tr>
<tr>
<td>and</td>
</tr>
<tr>
<td>≤Grade 4 wrist extension</td>
</tr>
<tr>
<td>Set PO to 20W if:</td>
</tr>
<tr>
<td>Manual wheelchair user</td>
</tr>
<tr>
<td>and</td>
</tr>
<tr>
<td>Grade 5 wrist flexion</td>
</tr>
<tr>
<td>and</td>
</tr>
<tr>
<td>Physically active</td>
</tr>
</tbody>
</table>

If 6-min cannot be completed, or RPE >15, rest 10 min & decrease PO by 5 W; continue to decrease PO by 5 W until RPE is between 11 and 15

If after 6-min RPE is between 11 and 15, test is complete

Figure 3.8 SSSAET PO selection algorithm for individuals with tetraplegia
The SSSAET is a practical test that can be administered to individuals of all fitness levels. Unlike the modified arm CAFT, all subjects recruited for this study were able to complete the SSSAET. Functionally, all subjects had a minimum manual muscle testing score of grade 4 for wrist extension. The equipment required to conduct the SSSAET is minimal (arm ergometer, HR monitor, RPE scale), and all pieces are available in most rehab settings.

For the SSSAET to be used clinically, clinicians first need to determine the appropriate PO for an individual to be exercising at using the algorithms provided in Figures 3.7 and 3.8. Baseline outcome variables would be determined by recording clients exercising HR during the final 30 seconds of the 6 minute test, and taking their RPE at the end of the test. At a later
time (i.e. after an intervention aimed at increasing cardiovascular fitness) the SSSAET should be re-administered at the same PO that was used pre-intervention. A decrease in HR and/or RPE may indicate an increase in VO₂peak, while an increase in HR and/or RPE may indicate a decrease in VO₂peak.

3.6 Summary

In summary, the steady state HR and VO₂ responses obtained during the SSSAET are reliable, and the criterion validity of the SSSAET for assessing cardiovascular fitness in individuals with SCI is excellent. With further testing, the SSSAET can be implemented as a clinical tool to assess baseline and changes in cardiovascular fitness in individuals with SCI.
Chapter 4: General Discussion

4.1 Overview

With a high incidence of cardiovascular diseases in individuals with spinal cord injury (SCI), it is important to have an accurate and reliable measurement tool to assess cardiovascular fitness level (VO₂peak) to aid in risk assessment of cardiovascular diseases. The work of this thesis has identified the strengths and weaknesses of existing submaximal exercise tests for individuals with SCI. As well, a new submaximal single-stage arm ergometer test (SSSAET) has been presented, and its reliability and validity evaluated in individuals with SCI.

4.2 Evaluation of the SSSEAT

Several submaximal tests for evaluating cardiovascular fitness in individuals with SCI have been described in the literature. Through a systematic review, a variety of predictive and performance based submaximal arm exercise tests were identified and evaluated for their feasibility, reliability, validity and responsiveness. The review identified a number of submaximal tests, and although some initially appeared to be useful for the assessment of cardiovascular fitness in individuals with SCI, all had methodological and/or validation limitations. Thus, it was concluded that the need remained for a submaximal arm exercise test that could be used to predict cardiovascular fitness in individuals with SCI.
Accordingly, the SSSAET was designed to assess cardiovascular fitness in individuals with SCI using a single stage of arm cycle ergometry at a submaximal power output (PO). The SSSAET was found to be both reliable and valid in a group of 30 individuals with SCI. All individuals were able to complete the test without incident, indicating the test is feasible. The excellent one week test-retest reliability for submaximal VO₂ and HR was not surprising, as these variables have fairly consistent responses to steady state submaximal exercise. Criterion validity, as measured by the relationship between submaximal VO₂ and VO₂peak, was also excellent. This is the first submaximal exercise test for individuals with SCI that has shown to be reliable, valid and feasible.

The subject sample used in this study was more heterogenous compared to samples used to evaluate other submaximal tests in individuals with SCI. Those with complete and incomplete spinal lesions, those who use manual and power wheelchairs, and those with a wide range of physical activity level (sedentary, recreationally active and elite athletes), all participated in this study. The range of both impairment and activity level of subjects in this study increases the generalizability of the results and demonstrates the feasibility of using this test in many individuals with SCI. It is possible; however, that the wide range of responses to the SSSAET may have inflated the intraclass correlation coefficients that described the reliability of the test.

The information gained from exercise tests such as the SSSAET can be valuable for activity counselling, exercise prescription, cardiovascular disease risk assessment, and as
positive motivational feedback for individuals already taking part in an exercise program to increase cardiovascular fitness.

4.3 Clinical implications

As the SSSAET has been shown reliable and valid, its limitations as a clinical exercise test must be discussed. In its current form, the SSSAET does not provide specific information about an individuals’ cardiovascular fitness level. It simply measures an individuals’ HR response to arm cycling at a steady-state submaximal PO. The HR response is reliable, so a change in the HR response to arm cycling at the same PO at a later date may be indicative of a change in cardiovascular fitness. An increase in HR while arm cycling at the same PO may indicate a decrease in cardiovascular fitness, while a decrease in HR may signify an increase in cardiovascular fitness. The ability of the SSSAET to detect change has not yet been evaluated. Similar to the SSSAET, the 3-stage arm ergometer test designed by Kofsky et al. (1983) uses the linear relationship between HR and VO\(_2\) to assess cardiovascular fitness. Hicks et al. (2003) found the Kofsky test to be responsive to a change in cardiovascular fitness, so it is anticipated that the SSSAET will also be able to detect change. Based on the evaluation of previous literature, recommendations were made in Chapter 2 to use the Kofsky (1983) test to assess cardiovascular fitness in individuals with paraplegia, and the wheeling test (Rhodes et al. 1981) for individuals with tetraplegia. With further testing of the SSSAET, it is anticipated that it will become the optimal submaximal test for evaluating cardiovascular fitness in all individuals with SCI.
Instructions to a clinician wishing to use the SSSAET may be as follows:

- Use the algorithms provided in Figures 3.8 and 3.9 to determine an appropriate PO for the SSSAET.
- Monitor the individual with SCI as they complete 6 minutes of arm cycling at the appropriate PO. During the final 30 seconds of the test, HR should be recorded. At the 6 minute mark, a rating of perceived exertion (RPE) should be taken.
- Prescribe an intervention with the goal of increasing cardiovascular fitness.
- Re-administer the SSSAET after the intervention has been completed.
- A decrease in HR and/or RPE may indicate an improvement in VO$_2$peak, while an increase may indicate a decrease in VO$_2$peak.

With a tool to measure an individuals' progression through a cardiovascular fitness training program, clinicians will be better equipped to set exercise goals for individuals with SCI and monitor their progress as they work to attain these goals.

4.3.1 Limitations

As this test uses the assumption that HR and VO$_2$ have a linear relationship, attempts were made to minimize and/or eliminate factors that influence this relationship. Subjects were asked to refrain from drinking caffeinated and alcoholic beverages and eating food prior to testing, and scheduling was done with the goal of having all visits that a subject made to the lab (2 or 3 visits) be at the same time of day. Food and fluid intake were not specifically
monitored; therefore changes in hydration status between the two reliability tests may have affected the reliability values.

Subjects for this study were recruited by rehabilitation therapists, through a mail-out to past patients from the local rehabilitation centre, and via advertisements posted in the rehabilitation centre and a SCI newsletter. These individuals were not randomly selected. They were primarily individuals who were already physically active or those who were interested in becoming physically active. Consequently, although individuals with a wide range of activity levels were included in this study, the sample may not have been representative of all individuals with SCI.

The COSMED K4b² gas analysis system was used to measure respiratory variables. Several studies have examined the reliability and validity of this system (Dufffield et al. 2004; Crandall et al 1994; Lucia et al. 1993; McLaughlin et al. 2001). McLaughlin et al. (2001) found a small, significantly higher (<0.1L/min) difference between the VO₂ measured by the COSMED K4b² system and the Douglas bag method, but concluded that despite this small discrepancy the COSMED K4b² was acceptable for measuring VO₂ across a wide range of PO's. On the other hand, Duffield et al. (2004) found the COSMED K4b² system to consistently overestimate both VO₂ and VCO₂. This overestimation may have introduced a systematic bias within the results of this study, but because the same gas analysis system was used for all tests, reliability of VO₂ values during the SSSAET would not have been affected.
4.4 Suggested future work

This thesis has only begun to evaluate the SSSAET. A number of further studies are recommended:

- In a clinical trial aimed to improve cardiovascular fitness in individuals with SCI, the SSSAET should be used to evaluate cardiovascular fitness along with the gold-standard VO$_2$peak test. This study would be designed to assess the responsiveness of the SSSAET by comparing its ability to detect a change in cardiovascular fitness with the VO$_2$peak test. With the high prevalence of cardiovascular disease in individuals with SCI, it is crucial that research focus on interventions aimed at maximizing the cardiovascular fitness of these individuals.

- A large (>50 subjects) cross-sectional study could be done to determine if a regression equation for the prediction of VO$_2$peak could be developed using demographic variables (e.g. age, ASIA motor score) and SSSAET variables (PO, HR). This may allow cardiovascular fitness to be more precisely predicted.

- A cross-sectional study could also be used to assess the reliability and validity of the SSSAET in individuals with other lower limb disabilities. These studies may include individuals with lower limb amputation, post-polio syndrome, cerebral palsy, and individuals with a non-traumatic SCI, and would further increase the generalizability of the SSSAET.
4.5 Summary

This thesis began by identifying submaximal exercise tests for individuals with SCI, and noted that no test has demonstrated reliability, validity, feasibility and responsiveness. The SSSAET was then presented as an alternative submaximal exercise test, and testing has shown this test to be reliable, valid and feasible for testing cardiovascular fitness in individuals with SCI. Although further research is necessary to assess its responsiveness, it is anticipated that the SSSAET will be a useful clinical tool to assess baseline cardiovascular fitness in individuals with SCI, and to monitor any changes that occur in their cardiovascular fitness.
REFERENCES


70. Pare G, Noreau L, Simard C. Prediction of maximal aerobic power from a submaximal exercise test performed by paraplegics on a wheelchair ergometer. Paraplegia 1993; 31(9): 584-592.


APPENDIX A: Systematic review search strategy

(MEDLINE)

1. exp PARAPLEGIA/
2. exp QUADRIPLEGIA/
3. parapl$.mp.
4. quadrip$.mp.
5. tetrapl$.mp.
6. exp Spinal Cord Injuries/
7. SCLmp.
8. or/1-7
9. ((exercise or aerobic or fitness or cardio$) adj5 (test or evaluat$ or measure$)).mp.
10. exp Exercise Test/
11. exp Physical Fitness/
12. exp Physical Endurance/
13. exp EXERCISE/ or exp EXERCISE TEST, CARDIOPULMONARY/
14. or/9-13
15. (submax$ or field or predict$).mp.
16. 8 and 14 and 15
APPENDIX B: Recruitment advertisements

***RESEARCH STUDY***

Exercise Testing for Individuals with Spinal Cord Injury

Persons with spinal cord injury are invited to take part in a study undertaken by the School of Rehabilitation Sciences, University of British Columbia, in conjunction with the GF Strong Rehab Centre. This study will evaluate if a simple arm crank cycling test can be used to predict cardiovascular fitness levels in adults with a spinal cord injury. You will be required to complete a simple arm crank cycling test on two occasions, and undergo a cardiovascular stress test. In addition, you will be required to fill out questionnaires so that we can determine if you have any other health-related problems, how often and for how long you use your wheelchair and your involvement in sporting activities. Every subject will be asked to attend 3 testing sessions, each lasting 1 hour, over a 1-month period. You will receive a short summary about your cardiovascular fitness status after the study has been completed.

There are no direct benefits to you; however, you will receive an honorarium to help defray the cost of transportation to and from the testing sessions.

You are eligible to participate in this study if you meet the following criteria:

- Had a traumatic spinal cord injury at least 6 months ago
- Are between the ages of 18-50
- Use a manual wheelchair for your daily activities
- Are able to independently cycle with your arms
- Are medically stable (i.e. no unstable cardiovascular disease)

For more information or to participate in this study, contact Adrienne Hol at the GF Strong Rehab Centre at:
Spinal Cord Injury Research Study

Persons who have had a spinal cord injury more than 6 months ago are invited to take part in a research study to evaluate physical fitness and wheelchair use. If you use a manual wheelchair and are at least 18 years of age, you may be eligible to participate in this study.

An honorarium will be provided.

Contact the Rehab Research Lab at the GF Strong Rehab Centre at 6.F. STRONG REHAB CENTRE.

G.F. Strong Rehab Centre
A part of the Vancouver Coastal Health Authority
APPENDIX C: Physical Activity Readiness Questionnaire

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES  NO

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions:

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

If you answered NO to all questions:

If you have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

SIGNATURE: ___________________________ DATE: ___________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.
Who is conducting this study:
Dr. Janice Eng and Adrienne Hoi are conducting this study in conjunction with the University of British Columbia, School of Rehabilitation Sciences. The study will take place at the GF Strong Rehab Centre in Vancouver, British Columbia. Funding for this study has been provided by the British Columbia Neurotrauma Fund.

Background:
Heart disease is currently the leading cause of death in individuals with spinal cord injury. One of the most significant risk factors for heart disease is low fitness levels, a condition that is common among those with spinal cord injury. Fitness testing is important to help identify heart disease risk, but standard fitness tests (for example, measuring oxygen intake during arm cycling exercise) require expensive equipment and a physician to be present. We hope to develop a fitness test that can be completed with minimal equipment and that accurately predicts fitness levels. Such a test would be beneficial to both individuals with spinal cord injury and clinicians.

What is the purpose of this study?
The purpose of this study is to evaluate a simple arm crank exercise test in individuals with spinal cord injury. This fitness test will be compared to a standard fitness test to determine how accurate it is.

Who can participate in this study?
If you meet the following criteria you are eligible to participate in this study:
- Had a traumatic spinal cord injury (at least 6 months ago)
- Are between the ages of 18-50
- Use a manual wheelchair for your daily activities
- Able to push an arm crank cycle

In order to ensure that you will be able to understand and follow all of the instructions that will be given during the research study, you will initially be given the Cognitive Capacity Screening Evaluation. You will also be asked several general questions about your current health status to help to decide whether you are safe to participate in this study.

Who should not participate in this study?
If you have any of the following conditions you are not eligible to participate in this study:
- Have a known history of cardiovascular disease (irregular heart beat, chest pains, etc)
- Have respiratory disease, uncontrolled high blood pressure or injuries to muscles, bones, ligaments, tendons or joints
- Have increased pain with arm activities
- Have a brain injury which stops you from understanding the instructions that will be given during the research study

What does the study involve?
This study will take place at the Rehab Research Laboratory at GF Strong Rehab Centre. Sixty persons with spinal cord injury will be recruited for this study.
Medical Information:
If you received treatment for your spinal cord injury at GF Strong Rehab Centre (the provincial spinal cord injury rehabilitation centre) your medical records will be looked at, and the following information taken from them: lesion level, date of injury, and type of injury. If you did not receive treatment at GF Strong Rehab Centre, a form will be sent to your family physician to obtain that information. To determine some more information about your spinal cord injury, you will be asked to try to move different parts of your body, and well, using a safety pin and cotton-tip swab, different areas of skin on your body will be lightly touched, and you will be asked to report any sensation.

Time Commitment for the Study:
You will attend three testing sessions over a one month period. Each will take approximately one hour. During one session, you will have a cardiovascular stress test, and during the other two sessions, you will complete the arm crank cycle test. In total, three hours of your time is required for the testing.

Cardiovascular Stress Test:
The stress test, which also measures your cardiovascular function, will be a test performed on an arm crank cycle in the presence of a physician and kinesiologist. You will begin to cycle with your arms at a very light intensity, and as the test progresses, the intensity will gradually increase until your arms are tired. The intensity refers to how challenging the arm cycling will be; it will be very easy when you begin and gradually become more difficult. You will have 12 electrodes attached to your chest (they stick to your skin similar to a band-aid, and are painless when on your skin) to measure how well your heart and lungs are handling the exercise. You will also be fitted with a face mask to measure the amount of oxygen that you are breathing in. Before you start wheeling, and at the end of the stress test, your finger will be pricked, and one drop of blood taken to measure your lactate levels (a chemical that builds up in your blood during exercise). The test will be stopped if any abnormal signals arise from the electrodes monitoring your heart, or if you feel chest discomfort, if you feel dizzy or lightheaded, or if your blood pressure gets too high.

Arm Cycle Testing:
You will be asked to complete an exercise test using an arm crank cycle. The cycling will begin at a very low intensity, and for two minutes, the intensity will gradually increase until your arms are working somewhat-hard. You will continue to arm cycle at this somewhat-hard intensity for 5 minutes. During the arm cycling, you will wear a heart rate monitor, and will be fitted with a face mask to measure the amount of oxygen that you are breathing in. Before you start arm cycling and at the end of the 7 minutes, your finger will be pricked, and one drop of blood taken to measure your lactate levels. As well, you will be asked to describe any sporting activities that you are currently involved with.

What are the possible harms and side effects of participating?
There is a slight chance that you may feel tired or experience some muscle soreness after the testing sessions. During and immediate following the cardiovascular stress test, you may experience some discomfort (i.e. dry mouth, dizziness from breathing too heavily, muscle soreness). These symptoms can be minimized by drinking 2 cups of water prior to testing,
and deep breathing and stretching following the test. In addition, there is a slight chance that the electrodes used to monitor your heart and lung function during the stress test may cause skin irritation. During any activities which involve exercise, there is a low risk that you may experience a cardiac event. Some of the questions you will be asked before the study begins will determine if you are more likely to experience a cardiac event, and if you are, you will not be able to participate in the study. The stress testing will be done with a physician present.

What are the benefits of participating in this study?
There are no direct benefits to you, other than determining the current status of your cardiovascular fitness.

If you withdraw your consent to participate:
- Your participation in this study is entirely voluntary. You may withdraw at any time. If you decide to enter the study and to withdraw at any time in the future, there will be no penalty or loss of benefits to which you are otherwise entitled, and your future medical care will not be affected.
- The study investigators may decide to discontinue the study at any time, or withdraw you from the study at any time, if they feel that it is in your best interest.
- If you choose to enter the study and then decide to withdraw at a later time, all data collected about you during your enrollment in the study will be retained for analysis. By law, this data cannot be destroyed.

If something goes wrong:
You do not waive any of your legal rights to compensation by signing this consent form. In case of a serious medical event, please report to an emergency room and inform them that you are participating in a research study and the following person can then be contacted for further information: Adrienne Hol at telephone number 604-(number will be activated by Telus).

After the study is completed:
Once the study is completed and all of the data is analyzed, you will receive a short summary of the status of your cardiovascular fitness.

Your cost to participate:
You may incur personal travel expenses by participating in this study. In order to defray the costs of transportation and to compensate you for your time, you will receive $50 after each session, for a total of $150.

Confidentiality:
Your confidentiality will be respected. No information that discloses your identity will be released or published without your specific consent to the disclosure. However, research records and medical records identifying you may be inspected in the presence of the Investigator or his or her designate by representatives of Health Canada, and the UBC Research Ethics Board for the purpose of monitoring the research. However, no records which identify you by name or initials will be allowed to leave the Investigators' offices.
Contact Information:
If you have any questions or desire further information with respect to this study or experience any harmful side effects during participation, you can contact Dr. Janice Eng or one of her associates. If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, contact the ‘Research Subject Information Line in the University of British Columbia Office Research Services’
Consent to Participate:
This is not a contract and I understand that I do not give up any legal rights by signing it. By signing the form I am indicating that:

- I have read and understood the subject information and consent form.
- I have had sufficient time to consider the information provided and to ask for advice if necessary.
- I have had the opportunity to ask questions and have had satisfactory responses to my questions.
- I understand that all the information collected will be kept confidential and that the results will only be used for scientific objectives.
- I understand that my participation in this study is voluntary and I am completely free to refuse to participate or to withdraw from this study at any time without changing in any way the quality of care that I receive.
- I understand that I am not waiving any legal rights as a result of signing this consent form.
- I have read this form and I freely consent to participate in this study.
- I have been told that I will receive a dated and signed copy of this form.

<table>
<thead>
<tr>
<th>Printed name of subject</th>
<th>Subject signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printed name of witness</td>
<td>Witness signature</td>
<td>Date</td>
</tr>
<tr>
<td>Printed name of principal investigator/designated representative</td>
<td>Signature of principal investigator/designated representative</td>
<td>Date</td>
</tr>
</tbody>
</table>
# APPENDIX E: Sample size calculation

<table>
<thead>
<tr>
<th>Power</th>
<th>0.10</th>
<th>0.20</th>
<th>0.30</th>
<th>0.40</th>
<th>0.50</th>
<th>0.60</th>
<th>0.70</th>
<th>0.80</th>
<th>0.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_1 = 0.05 )</td>
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<tr>
<td>0.70</td>
<td>470</td>
<td>117</td>
<td>52</td>
<td>28</td>
<td>18</td>
<td>12</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>0.80</td>
<td>617</td>
<td>153</td>
<td>68</td>
<td>37</td>
<td>22</td>
<td>15</td>
<td>10</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>0.90</td>
<td>854</td>
<td>211</td>
<td>92</td>
<td>50</td>
<td>31</td>
<td>20</td>
<td>13</td>
<td>9</td>
<td>6</td>
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<tr>
<td>( \alpha_2 = 0.05 )</td>
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<td>0.70</td>
<td>616</td>
<td>153</td>
<td>67</td>
<td>37</td>
<td>23</td>
<td>15</td>
<td>10</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>0.80</td>
<td>783</td>
<td>194</td>
<td>85</td>
<td>46</td>
<td>28</td>
<td>18</td>
<td>12</td>
<td>9</td>
<td>6</td>
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<tr>
<td>0.90</td>
<td>1047</td>
<td>259</td>
<td>113</td>
<td>62</td>
<td>37</td>
<td>24</td>
<td>16</td>
<td>11</td>
<td>7</td>
</tr>
</tbody>
</table>

Adapted from Table 3.4.1 in Cohen (1988)
**APPENDIX F: Cognitive Capacity Screening Evaluation**

*Instructions:* Check items answered correctly. Write incorrect or unusual answers in space provided. If necessary urge subject to complete task.

*Introduction to subject:* “I would like to ask you a few questions. Some you will find very easy and others may be very hard. Just do your best.”

<table>
<thead>
<tr>
<th>Questions</th>
<th>Correct</th>
<th>Incorrect / unusual answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What day of the week is this?</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>2. What month?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. What day of month?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. What year?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. What place is this?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Repeat the numbers 8 7 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Say them backwards.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Repeat the numbers 6 3 7 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Remember these numbers 6 9 4 Count 1 through 10 out loud, then repeat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the numbers (6 9 4). If help needed use numbers 5 7 3</td>
<td></td>
<td></td>
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<td>---</td>
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<tr>
<td><strong>10. Remember these numbers 8 1 4 3. Count 1 through 10 out loud, then repeat the numbers (8 1 4 3).</strong></td>
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<tr>
<td><strong>11. Beginning with Sunday, say the days of the week backwards.</strong></td>
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<tr>
<td><strong>12. 9 + 3 is:</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>13. Add 6 (to the previous answer or “to 12”)</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>14. Take away 5 (“from 18”)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repeat these words after me and remember them. I will ask for them later: HAT, CAR, TREE, TWENTY-SIX</td>
<td></td>
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</tr>
<tr>
<td><strong>15. The opposite of fast is slow. The opposite of up is:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>16. The opposite of large is:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>17. The opposite of hard is:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>18. An orange and a banana are both:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red and blue are both:</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>19. A penny and a dime are both:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>20. What were those words I asked you to remember?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(HAT)</td>
<td></td>
<td></td>
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<tr>
<td><strong>21. (CAR)</strong></td>
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<td>---</td>
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<td></td>
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<tr>
<td>22. (TREE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. (TWENTY-SIX)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24. Take away 7 from 100, then take away 7 from what is left and keep going:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-7 is (93)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25. Minus 7 (86)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. Minus 7 (79)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27. Minus 7 (72)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28. Minus 7 (65)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29. Minus 7 (58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30. Minus 7 (51)</td>
<td></td>
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</tr>
</tbody>
</table>

**TOTAL CORRECT** / 30
ASIA IMPAIRMENT SCALE

- **A** = Complete: No motor or sensory function is preserved in the sacral segments S4-S5.
- **B** = Incomplete: Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.
- **C** = Incomplete: Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.
- **D** = Incomplete: Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.
- **E** = Normal: motor and sensory function are normal.

CLINICAL SYNDROMES

- Central Cord
- Brown-Sequard
- Anterior Cord
- Conus Medullaris
- Cauda Equina
STANDARD NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

**MOTOR**

**KEY MUSCLES**

- C2: Elbow flexors
- C3: Wrist extensors
- C4: Elbow extensors
- C5: Finger flexors (distal phalanx of middle finger)
- C6: Finger abductors (little finger)
- C7: Hip flexors
- T1: Knee extensors
- T2: Ankle dorsiflexors
- T3: Long toe extensors
- T4: Ankle plantar flexors
- T5: Voluntary anal contraction

**LUMBAR**

- S1: Any anal sensation

**SENSORY**

**KEY SENSORY POINTS**

- C2: Voluntary anal contraction (Yes/No)
- C3: Any anal sensation (Yes/No)
- T1: Pin prick score (max: 112)
- T2: Light touch score (max: 112)

**COMPLETE OR INCOMPLETE?**

- Complete: Any sensory or motor function in S4-S5
- Incomplete: Any sensory or motor function in S4-S5

**ASIA IMPAIRMENT SCALE**

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APPENDIX H: Physical Activity Scale for Individuals with Physical Disabilities

Leisure Time Activity

1. During the past 7 days how often did you engage in stationary activities such as reading, watching TV, computer games, or doing handcrafts?
   a) never (go to question #2)
   b) seldom (1 ~ 2 days)
   c) sometimes (3 ~ 4 days)
   d) often (5 ~ 7 days)

   What were these activities? ________________________________

   On average, how many hours per day did you spend in these stationary activities?
   a) less than 1 hour
   b) 1 but less than 2 hours
   c) 2 ~ 4 hours
   d) more than 4 hours

2. During the past 7 days, how often did you walk, wheel, push outside your home other than specifically for exercise. For example, getting to work or class, walking the dog, shopping, or other errands?
   a) never (go to question #3)
   b) seldom (1 ~ 2 days)
   c) sometimes (3 ~ 4 days)
   d) often (5 ~ 7 days)

   On average, how many hours per day did you spend walking, wheeling or pushing outside your home?
   a) less than 1 hour
   b) 1 but less then 2 hours
   c) 2 to 4 hours
   d) more than 4 hours

3. During the past 7 days, how often did you engage in light sport or recreational activities such as bowling, golf with a cart, hunting or fishing, darts, billiards or pool, therapeutic exercise (physical or occupational therapy, stretching, use of a standing frame) or other similar activities?
   a) never (go to question #4)
   b) seldom (1 ~ 2 days)
   c) sometimes (3 ~ 4 days)
   d) often (5 ~ 7 days)

   What were these activities? ________________________________
On average, how many hours per day did you spend in these *light sport or recreational activities*?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

4. During the past 7 days, how often did you engage in *moderate sport and recreational activities* such as double tennis, softball, golf without a cart, ballroom dancing, wheeling or pushing for pleasure or other similar activities?

a) never (go to question #5)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)

What were these activities? __________________________________________________________

On average, how many hours per day did you spend in these *moderate sport and recreational activities*?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

5. During the past 7 days, how often did you engage in *strenuous sport and recreational activities* such as jogging, wheelchair racing (training), off-road pushing, swimming, aerobic dance, arm cranking, cycling (hand or leg), singles tennis, rugby, basketball, walking with crutches and braces, or other similar activities?

a) never (go to question #6)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)

What were these activities? __________________________________________________________

On average, how many hours per day did you spend in these *strenuous sport or recreational activities*?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours
6. During the past 7 days, how often did you do any exercise specifically to increase muscle strength and endurance such as lifting weights, push-ups, pull-ups, dips, or wheelchair push-ups, etc?
   a) never (go to question #7)
   b) seldom (1 ~ 2 days)
   c) sometimes (3 ~ 4 days)
   d) often (5 ~ 7 days)

   What were these activities? ________________________________

   On average, how many hours per day did you spend in these exercises to increase muscle strength and endurance?
   a) less than 1 hour
   b) 1 but less than 2 hours
   c) 2 ~ 4 hours
   d) more than 4 hours

Household Activity

7. During the past 7 days, how often have you done any light housework, such as dusting, sweeping floors or washing dishes?
   a) never (go to question #8)
   b) seldom (1 ~ 2 days)
   c) sometimes (3 ~ 4 days)
   d) often (5 ~ 7 days)

   On average, how many hours per day did you spend doing light housework?
   a) less than 1 hour
   b) 1 but less than 2 hours
   c) 2 ~ 4 hours
   d) more than 4 hours

8. During the past 7 days, how often have you done any heavy housework or chores such as vacuuming, scrubbing floors, washing windows, or walls, etc?
   a) never (go to question #9)
   b) seldom (1 ~ 2 days)
   c) sometimes (3 ~ 4 days)
   d) often (5 ~ 7 days)
On average, how many hours per day did you spend doing *heavy housework or chores*?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

9. During the past 7 days, how often have you done *home repairs* like carpentry, painting, furniture refinishing, electrical work, etc?

a) never (go to question #10)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)

On average, how many hours per day did you spend doing *home repairs*?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

10. During the past 7 days, how often have you done *lawn work or yard care* including mowing, leaf or snow removal, tree or bush trimming, or wood chopping, etc?

a) never (go to question #11)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)

On average, how many hours per day did you spend doing *lawn work*?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

11. During the past 7 days, how often have you *outdoor gardening*?

a) never (go to question #12)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)
On average, how many hours per day did you spend doing outdoor gardening?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

12. During the past 7 days, how often have you care for another person, such as children, a dependent spouse, or another adult?

a) never (go to question #13)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)

On average, how many hours per day did you spend caring for another person?

a) less than 1 hour  
b) 1 but less than 2 hours  
c) 2 ~ 4 hours  
d) more than 4 hours

Work-Related Activity

13. During the past 7 days, how often have you work for pay or as a volunteer? Exclude work that mainly involved sitting with slight arm movement such as light office work, computer work, light assembly line work, driving bus or van, etc.

a) never (go to END)  
b) seldom (1 ~ 2 days)  
c) sometimes (3 ~ 4 days)  
d) often (5 ~ 7 days)

On average, how many hours per day did you spend working for pay or as a volunteer?

a) less than 1 hour  
b) 1 but less than 4 hours  
c) 5 but less than 8 hours  
d) 8 hours or more
APPENDIX I: Strength testing – positioning and data collection

Elbow Flexors: Shoulder 0° abduction, elbow 90° flexion
(R): 1) ________________ (L): 1) ________________
     2) ________________                     2) ________________
     3) ________________                     3) ________________

Elbow Extensors: Shoulder 0° abduction, 45° flexion, elbow 90° flexion
(R): 1) ________________ (L): 1) ________________
     2) ________________                     2) ________________
     3) ________________                     3) ________________

Shoulder Flexors: Shoulder 0° abduction, elbow 0° extension
(R): 1) ________________ (L): 1) ________________
     2) ________________                     2) ________________
     3) ________________                     3) ________________

Shoulder Extensors: Shoulder 0° abduction, elbow 0° extension
(R): 1) ________________ (L): 1) ________________
     2) ________________                     2) ________________
     3) ________________                     3) ________________

Wrist Flexors: Forearm on table, elbow extended, wrist neutral, palm up
(R): 1) ________________ (L): 1) ________________
     2) ________________                     2) ________________
     3) ________________                     3) ________________

Wrist Extensors: Forearm on table, elbow extended, wrist neutral, palm down
(R): 1) ________________ (L): 1) ________________
     2) ________________                     2) ________________
     3) ________________                     3) ________________
Appendix J: Borg’s Rating of Perceived Exertion Scale

(Borg 1970)

6

7 very, very light

8

9 very light

10

11 fairly light

12

13 moderately hard

14

15 hard

16

17 very hard

18

19 very, very hard

20
APPENDIX K: Blood lactate measurement protocol


1. Peel a Test Strip packet to the line indicated and insert it into the Strip Inlet of the Test Meter as shown.

2. A beep will be heard, and "88.8" will appear in the display.

3. Disinfect the finger you will draw blood from by using a gauze and alcohol and dry it thoroughly.

4. Use the lancing device on your finger and press the finger until a drop of blood forms. Use a new lancet every time.

5. Apply pressure to the surrounding site to obtain a drop of blood. The required amount of blood is 5mmol/l.

6. Especially, sweat affects test result. Wipe the blood with a gauze and alcohol since the first drop of blood contains sweat.

7. Apply pressure to the surrounding site again to obtain a drop of blood.

8. The blood is aspirated automatically.

9. In 60 seconds, the test result of blood lactate level will appear in the display.

10. Using the original foil packet, grasp the use Test Strip as shown above.

**Note:**
Examination gloves were worn during the protocol.
Used lancets were disposed of into a bio-hazardous materials container.
APPENDIX L: Electrode placement for ECG leads

Electrode Placement for Limb and Augmented Leads (I, II, III, AVF, AVR, AVL)
RL: Right Leg - (Ground wire) put on the right acromion process
RA: Right Arm - put just inferior the right clavicle
LL: Left Leg - put just superior to the left ASIA
LA: Left Arm - put just inferior to the left clavicle

Electrode Placement for Precordial Leads (V1, V2, V3, V4, V5, V6)
V1 4th intercostal space, right of sternum
V2 4th intercostal space, left of sternum
V3 midway between V2 and V4
V4 5th intercostal space, in the midclavicular line
V5 same level as V4, at anterior axillary line (between V4 and V6)
V6 in 5th intercostal space, in the midaxillary line

ECG Electrode Skin Preparation
1. Shave the skin so it is free of hair.
2. Rub the spot with alcohol until it is red.
APPENDIX M: VO₂peak Protocol

**Equipment calibration:** The Cosmed K4b² was used to for metabolic measurement. The equipment consists of a soft mask to sample exhaled air, a sensor system to measure ventilation, and oxygen and carbon dioxide analyzers. Respiratory flow was measured by a turbine fixed to the face mask, and expired gas concentrations were measured using a polarographic electrode for the oxygen fraction and an infrared electrode for the carbon dioxide fraction. The Cosmed K4b² system was calibrated before each test according to the manufacturer’s recommended procedures (operator’s manual of K4b² system). Calibrations included a gas calibration using gas of a known concentration (16% oxygen, 5% carbon dioxide), a delay calibration to determine the time delay between expiration and inspiration, and a turbine calibration using a known volume of air.

**Positioning:** All subjects remained seated in their wheelchair (brakes on) for the VO₂peak test. Adjustments were made so that the centre of the crank was level with their shoulder (in either the height of the ergometer, or the height of the wheelchair). Subjects were positioned so that during the arm cycling their elbows did not reach full extension.

**Instructions:** All subjects were given verbal instructions prior to beginning the test. First they were informed of a short (1-2 minute) warm-up period, where they were able to cycle against zero resistance to get used to the motion of the arm ergometer. Subjects were then told:

“During the test, the resistance, or difficulty of the cycling will start out pretty light. At the end of each minute, it will get a little bit harder. We want you to keep cycling at the same cadence (speed) for the whole test. Towards the end when it starts to get quite a bit harder, we’ll give you some encouragement to keep you cycling for as long as you can. If you feel any chest pain, lightheadedness, dizziness or feel sick to your stomach, please stop the test right away and tell us how you are feeling.”

**Protocol:** For subjects with paraplegia, the PO increased at 10W/min. For subjects with tetraplegia, PO increased at 5W/min.
**VO₂max Test – data collection sheet**

**Subject code:** ____________

**Height:** ____________  
**Weight:** ____________

**Gender:** ____________  
**Mask Size:** S M L

**Date of Birth:** ____________

**Age:** ____________

**Protocol:** ____________

**Start:**  
**HR:** ____________  
**BP:** ____________

  **Lactate:** ____________

**End:**  
**HR:** ____________  
**BP:** ____________

  **Lactate:** ____________  
  **RPE:** ____________

  **Peak WR:** ____________

**Recovery:**

<table>
<thead>
<tr>
<th>Recovery</th>
<th>BP</th>
<th>HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome Measure</td>
<td>Reliability</td>
<td>Validity</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
<td>----------</td>
</tr>
<tr>
<td>American Spinal Injury Association (ASIA) Impairment Scale</td>
<td>Motor Score: Intra-rater reliability, intraclass correlation coefficient (ICC)=0.99, inter-rater reliability ICC=0.98 Pin Prick Score: Intra-rater reliability ICC=0.98, inter-rater reliability ICC=0.96 Light Touch Score: Intra-rater reliability ICC=0.99, inter-rater reliability ICC=0.96 Impairment Scale: Intra-rater reliability Kappa=0.84, inter-rater reliability Kappa=0.72 (Cohen and Bartko 1994)</td>
<td>Motor Score: Criterion validity with cumulative motor score, r=0.988 (El Masry et al. 1996)</td>
</tr>
<tr>
<td>Blood Lactate</td>
<td>Inter-rater reliability: The correlation between two Lactate Pro analysers on the same sample was r=0.99 (Pyne et al. 2000)</td>
<td>Concurrent Validity: Correlations between lactate measurements using the Lactate Pro and the ABL 700 Series Acid-Base analyser, the YSI 2300 Stat lactate analyser and the Accusport Lactate Meter were r=0.98, r=0.99 and r=0.97, respectively (Pyne et al. 2000)</td>
</tr>
<tr>
<td>Cognitive Capacity Screening Evaluation (CCSE)</td>
<td>Reliability results not found in the literature.</td>
<td>Concurrent Validity: Agreement of CCSE scores indicating the presence of a cognitive deficit (&lt;20) with complete neurological evaluation in: Of 59 cases, 24 true-positive, 2 false-negative, 18 true-negative, 9 false-negative (Kaufman et al. 1979)</td>
</tr>
<tr>
<td>Physical Activity Scale for Individuals with Physical Disabilities (PASIPD)</td>
<td>Internal consistency: Cronbach’s $\alpha = 0.37-0.65$ (in individuals with various orthopaedic and neuromuscular diagnoses including SCI) (Washburn et al. 2002)</td>
<td>Construct validity: Correlations between each survey item &amp; total PASIPD score were all $\geq 0.20$ (0.20-0.67) and significant Factor analysis revealed 5 factors (in individuals with various orthopaedic and neuromuscular diagnoses including SCI) (Washburn et al. 2002)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Isometric strength – hand held dynamometer</strong></td>
<td>Intra-rater reliability: Test-retest Pearson product-moment correlations (in individuals with various orthopaedic or neuromuscular diagnoses): $0.69 \leq r \leq 0.90$ ($p \leq 0.05$) (Wadsworth et al. 1987) Inter-rater reliability: Pearson product-moment correlation between raters (in individuals with various orthopaedic or neuromuscular diagnoses including SCI): $0.84 \leq r \leq 0.94$ ($p \leq 0.001$) (Bohannon and Andrews 1987)</td>
<td>Concurrent Validity: Correlations between strength scores obtained by handheld dynamometry and isokinetic dynamometry (in individuals with SCI): $0.75 \leq r \leq 0.96$ ($p \leq 0.001$) (Noreau and Vachon 1998) Correlations between manual muscle testing and handheld dynamometry (in individuals with SCI): $0.59 \leq r \leq 0.94$ ($p \leq 0.001$) (Schwartz et al. 1992)</td>
</tr>
</tbody>
</table>
APPENDIX O: Selected results – with subjects presented as two groups (paraplegia/tetraplegia)

Subject characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subjects with Paraplegia (n=13)</th>
<th>Subjects with Tetraplegia (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>Sex (M/F), N</td>
<td>8/5</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>34.3 (10.2)</td>
<td>19-49</td>
</tr>
<tr>
<td>Time since injury (years)</td>
<td>6.0 (6.5)</td>
<td>1-24</td>
</tr>
<tr>
<td>ASIA Grade (A/B/C/D), N</td>
<td>10/2/0/1</td>
<td></td>
</tr>
<tr>
<td>ASIA Motor Score (0-100)</td>
<td>57.4 (9.8)</td>
<td>50-75</td>
</tr>
<tr>
<td>PASIPD score</td>
<td>18.6 (10.8)</td>
<td>4.8-38.7</td>
</tr>
<tr>
<td>Wheeled mobility category (1/3/4/5/6), N</td>
<td>0/0/2/10/1</td>
<td></td>
</tr>
</tbody>
</table>

Values during the VO$_2$peak test

<table>
<thead>
<tr>
<th></th>
<th>Subjects with Paraplegia (n=13)</th>
<th>Subjects with Tetraplegia (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>Peak work rate (W)</td>
<td>91.5 (31.3)</td>
<td>50-160</td>
</tr>
<tr>
<td>Peak HR (beats/min)</td>
<td>154.6 (22.3)</td>
<td>109-183</td>
</tr>
<tr>
<td>Percent HR maximum$^1$</td>
<td>83.0 (9.5)</td>
<td>63.0-97.3</td>
</tr>
<tr>
<td>VO$_2$peak (mL/kg/min)</td>
<td>24.7 (9.0)</td>
<td>10.8-38.1</td>
</tr>
<tr>
<td>VO$_2$peak (L/min)</td>
<td>1.70 (0.56)</td>
<td>0.97-2.81</td>
</tr>
<tr>
<td>Blood lactate (mmol/L)$^2$</td>
<td>8.9 (2.5)</td>
<td>5.7-15.1</td>
</tr>
</tbody>
</table>

$^1$ Based on 220-age prediction equation  
$^2$ Only 27 of 30 subjects had their blood lactate tested
### Steady state values during the SSSAET

<table>
<thead>
<tr>
<th>Variables</th>
<th>Subjects with Paraplegia (n=13)</th>
<th>Subjects with Tetraplegia (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>SSSAET work rate (W)</td>
<td>43.1 (12.0)</td>
<td>20-60</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>117.9 (16.8)</td>
<td>88-142</td>
</tr>
<tr>
<td>Percent HR maximum(^1)</td>
<td>63.4 (7.5)</td>
<td>51.5-75.7</td>
</tr>
<tr>
<td>VO(_2) (mL/kg/min)</td>
<td>15.9 (3.9)</td>
<td>10.2-22.9</td>
</tr>
<tr>
<td>VO(_2) (L/min)</td>
<td>1.11 (0.26)</td>
<td>0.65-1.61</td>
</tr>
<tr>
<td>Percent VO(_2)peak</td>
<td>67.9 (12.5)</td>
<td>51.0-94.3</td>
</tr>
<tr>
<td>Blood lactate (mmol/L)(^2)</td>
<td>3.5 (1.38)</td>
<td>1.0-6.0</td>
</tr>
</tbody>
</table>

\(^1\) Based on 220-age prediction equation  
\(^2\) Only 28 of 30 subjects had their blood lactate tested
Scatterplots and values of test-retest reliability of HR

Scatter-plot comparing HR during SSSAET test 1 and test 2 for subjects with **tetraplegia** (n=12)

- ICC\(_{2,1}\)=0.82
- SEM=7.89
- 95% CI=0.48-0.94

Scatter-plot comparing HR during SSSAET test 1 and test 2 for subjects with **paraplegia** (n=8)

- ICC\(_{2,1}\)=0.82
- SEM=6.58
- 95% CI=0.34-0.96
Scatterplots and values of test-retest reliability of VO₂

Scatter-plot comparing VO₂ during SSSAET test 1 and test 2 for subjects with tetraplegia (n=12)
ICC₂,₁=0.70
SEM=1.78
95% CI=0.25-0.90

Scatter-plot comparing VO₂ during SSSAET test 1 and test 2 for subjects with paraplegia (n=8)
ICC₂,₁=0.80
SEM=1.52
95% CI=0.29-0.96
Scatterplots and correlations between SSSAET PO and VO$_2$peak

Scatter-plot comparing PO during the SSSAET and VO$_2$peak for subjects with tetraplegia (n=17)
\[ r=0.40 \quad (p=0.112) \]

Scatter-plot comparing PO during the SSSAET and VO$_2$peak for subjects with paraplegia (n=13)
\[ r=0.54 \quad (p=0.066) \]
Scatterplots and correlations between SSSAET VO₂ and VO₂peak

Scatter-plot comparing VO₂ during the SSSAET and VO₂peak for subjects with **tetraplegia** (n=17)

\( r=0.852 \) (p<0.001)

Scatter-plot comparing VO₂ during the SSSAET and VO₂peak for subjects with **paraplegia** (n=13)

\( r=0.933 \) (p<0.001)
Scatterplots and correlations between SSSAET HR and VO$_2$peak

Scatter-plot comparing HR during the SSSAET and VO$_2$peak for subjects with tetraplegia (n=17)
r=0.343 (p=0.178)

Scatter-plot comparing HR during the SSSAET and VO$_2$peak for subjects with paraplegia (n=13)
r=0.446 (p=0.127)