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Aerobic Fitness Benefits of a Community-Based Activity Program that Promotes Functional Outcomes for People with Spinal Cord Injury

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Supervisor Statement

As supervisor of David O'Brian's work, I certify that I consider his thesis **"Aerobic Fitness Benefits of a Community-Based Activity Program that Promotes Functional Outcomes for People with Spinal Cord Injury",** in fulfilment of the requirements for the degree of Master of Applied Science, is in a form suitable for examination.

Signed 

Date 04/08/14

Professor Glen Davis

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ABSTRACT

The aim of the work presented in this thesis was to classify physical activities performed as part of a community-embedded, activity-based restorative therapy (ABRT) program for people with a spinal cord injury (SCI). This thesis also aimed to determine whether the intensity and duration of activity performed by participants during their regular ABRT were sufficient to meet current American College of Sports Medicine (ACSM) physical activity (PA) guidelines for developing and maintaining cardiorespiratory fitness and general health.

Twenty-one regular clients of an Australian ABRT program (Walk On®) had their heart rate (HR) recorded and an observational time-and-motion analysis conducted during their regular therapy sessions over two successive one-week periods. The time and motion analysis included classification of each movement (1-9 schema), and ratings of perceived exertion (RPE) given by both the client and an independent observer for each exercise movement performed during a session of approximately two hours. Clients also completed a multi-stage, sub-maximal assessment on an arm crank ergometer followed by progressive, incremental exercise to volitional fatigue to determine submaximal and peak oxygen consumptions (VO_2). The HR and VO_2 relationship during arm cranking was then used to estimate VO_2 values from HR recorded during ABRT sessions. The average intensity and total duration of ABRT exercises that clients performed as part of their regular therapy was compared with The ACSM PA guidelines for improving cardiorespiratory fitness and general health. The weekly average intensity x total duration of therapy sessions were statistically contrasted with

'cut-points' for "moderate" and "vigorous" exercise using percentage of HR maximum (%HRmax), percentage of heart rate reserve (%HRR), percentage of VO_2 reserve (%VO_2R) and self-reported RPE.

For individuals with paraplegia (n=5) and tetraplegia (n=16) combined, arm cranking VO_2peak was 13.2 ± 4.2 ml·kg^{-1}·min^{-1} achieved at 38.4 ± 11.8 W power output, and there was no significant difference between the two groups. When comparing total volume (intensity x duration x frequency) of physical activities comprising ABRT, there were four results that indicated that participant activity was significantly below the guidelines for improving and maintaining health (i.e. *moderate* and *vigorous* absolute %HRmax and *moderate* and *vigorous* %HRR were below ACSM 'cut points'). By contrast there was one intensity measure that significantly exceeded ACSM guidelines (*moderate* RPE was above RPE 'cut points'). Finally, there were three variables (*moderate* and *vigorous* %VO_2R and *vigorous* RPE) for which no definitive conclusion could be drawn as to whether average weekly ABRT was of sufficient intensity and duration to meet the current guidelines. Twelve of the 21 participants achieved > 500 MET·min^{-1} of activity over the two, one-week periods that were measured (mean: 482 ± 247 MET·min^{-1} per week), but this result was not statistically significant ($p = 0.76$). There was poor correlation between HR and either participant RPE ($R^2 = 0.08$, $p < 0.01$) or observer RPE ($R^2 = 0.12$, $p < 0.01$). This was consistent across each individual exercise classified with an activity code.

This study demonstrated that ABRT was generally unlikely to be of sufficient intensity and duration to satisfy current ACSM physical activity guidelines for developing and maintaining cardiorespiratory fitness and general health in

individuals with SCI, however these results were not consistent across all clients in the study. The different activities used as part of ABRT were classified and mean values were determined for their intensity and duration. These data suggest that, based on sufficient intensity and duration of weekly exercise, a community-based ABRT program may not meet current guidelines for health. Results highlighted the need for additional 'dose-potent' physical activity either within current ABRT programs or gained via supplementary methods.

STATEMENT OF THE AUTHOR

I, **David O'Brian**, hereby declare that the work contained within this thesis is entirely my own and has not been submitted to any other university or institution as a part or a whole requirement for any higher degree.

In addition, ethical approval from the University of Sydney Human Ethics Committee was granted for the study presented in this thesis. Participants were required to read a participant information statement and informed consent was gained prior to data collection.

Signed 

Date 18/02/15

David O'Brian

CONFERENCE PRESENTATIONS

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 Spinal Cord Injury

The spinal cord is a thick bundle of nerve fibres, which is not only vitally important, but also a relatively fragile part of the human body. It relays motor and sensory information between the brain and the rest of the body making it essential for movement and sensation. The spinal cord is contained within a protective casing of bone known as the vertebral column, which is made up of 33 bony vertebrae – 7 cervical, 12 thoracic, 5 lumbar, 5 fused sacral and 4 fused coccygeal – joined together by muscle and connective tissue. Segmental nerve roots branch out from each level of the vertebral column. These nerve roots are numbered and named after the vertebral foramina from which they exit or enter the vertebral column and are responsible for carrying and receiving information out to and in from the periphery of the body.

A spinal cord injury (SCI) is a debilitating condition affecting just over 10,000 people in Australia (O'Connor, 2005). It occurs when the spinal cord is damaged in some way, most frequently as a result of trauma from transport accidents or falls (Access Economics Pty Ltd, 2009). In the majority of cases, a SCI leads to numerous disruptions in motor and sensory information traversing the brain and the rest of the body. People who suffer from SCI will have different levels of ability depending on the location of their injury and whether the injury is complete or incomplete. The level is described by which spinal nerve roots have incurred damage, for example the 5th cervical nerve root - C5 - or the 10th and 11th thoracic nerve roots - T10/11 - injury. The completeness of an injury refers to the degree

of damage in the spinal cord. People with no movement or sensation below the level of injury are known as 'complete' and people with even the slightest movement or sensation below the level of injury are classed as 'incomplete'. Generally speaking, the more incomplete the injury, the more likely the chance a person may regain their function. Tetraplegia (also known as quadriplegia) is a result of damage to the area of the cervical vertebrae and results in the loss of function or sensory information in the arms, legs and trunk. Paraplegia is a result of damage to the thoracic, lumbar or sacral segments of the spinal cord leading to motor and sensory loss in the trunk and lower limbs. While there is currently no 'cure' for spinal cord injuries, there are a number of different therapies available to rehabilitate and improve the function of people with this condition.

1.1.2 Spinal cord injury rehabilitation

Physical rehabilitation for SCI is a long and arduous process. It can take anywhere from 3 months to over a year until a patient is discharged from hospital post-injury (Tooth, McKenna, & Geraghty, 2003). In Australia, SCI rehabilitation begins once a patient's injuries have been stabilised and is usually undertaken as an inpatient in a specialised hospital. Traditionally, the focus of this rehabilitation is on increasing function through compensatory techniques. This form of therapy is used to help people develop the skills needed to re-integrate into their social and work roles and assist them with independent living. This type of rehabilitation includes teaching patients how to safely and effectively use a wheelchair, transfer, turn over in bed and other self-care activities.

Therapy for SCI has more recently become focussed on central nervous system (CNS) remodelling through intense 'task-specific training' in an attempt to aid

recovery rather than teaching compensatory techniques for lost motor patterns (Behrman, Bowden, & Nair, 2006). This method of rehabilitation has come to be known as 'activity-based restorative therapy' (ABRT) or 'activity-based rehabilitation'. ABRT is based on the principle of neuroplasticity which employs intense activities (performed both above and below the level of injury), individualised for the patient, to promote neural remodelling (Fritz et al., 2011). ABRT has become more popular as a method of ongoing rehabilitation post-hospital treatment (Sadowsky & McDonald, 2009) and has also been integrated into some hospital rehabilitation programs. As this method of rehabilitation is a relatively new development, it currently has limited evidence to support its efficacy over other forms of therapy. As a result, ABRT is not common practice in hospital-based programs and to take part in structured ABRT, a patient must seek out private means of undertaking this therapy.

Most patients hold onto the hope that their condition is not permanent and as a result, will seek further rehabilitation (finances permitting) outside of the public system once they have been discharged from hospital (Whiteneck et al., 2011). Whiteneck et al. (2011) also found that in the first year after an injury occurs, 44% of a patient's total hours spent on rehabilitation occur once they have been discharged from inpatient rehabilitation. For patients intending to do this though, their options for specialised treatment are fairly limited. In Australia, further therapy is limited to finding a private physiotherapist specialising in the area or starting therapy with Spinal Cord Injuries Australia's (SCIA) Walk On (WO) program – an example of structured, community-based ABRT.

1.1.3 Spinal cord injury physical activity and health

For most people with SCI, decreased motor capabilities can lead to an increase in sedentary behaviour (Buchholz, McGillivray, & Pencharz, 2003). A lack of physical activity (PA) has been linked to a number of chronic conditions, and this relationship is even more pronounced in people with SCI due to their elevated levels of sedentary behaviour. Incidences of cardiovascular disease (CVD), diabetes mellitus and visceral obesity are all much higher in this population than their able-bodied counterparts, (Bauman, Adkins, Spungen, & Waters, 1999; Edwards, Bugaresti, & Buchholz, 2008; Yekutiel, Brooks, Ohry, Yarom, & Carel, 1989). Prevalence of symptomatic CVD in SCI populations ranges from 30-50% compared to 5-10% in able-bodied persons of similar age (Myers, Lee & Kiralti, 2007). Injury level was also found to have a significant impact on the risk of all CVD with higher lesion levels leading to greater risk of CVD. Another study by Yekutiel et al. (1989) observed that approximately 34% of people with SCI suffer from hypertension, ischaemic heart disease or diabetes mellitus compared with 19% of able-bodied controls.

Physical activity has been shown to have a positive effect on a number of health-related outcomes in people with SCI including an increase in insulin sensitivity, reduced risk of cardiovascular (CV) events and improved body composition (Warburton, Eng, Krassioukov, & Sproule, 2007). Due to this relationship, and to the high prevalence of chronic disease in people with SCI, it is very important to have people with SCI engage in regular physical activity. This activity should be at an intensity and duration high enough to stimulate improvements in their cardiovascular health. The volume (intensity x duration) of exercise required to

gain these benefits can be quantified as a 'dose' of PA (Lamonte & Ainsworth, 2001) and in doing so, allows for comparison with physical activity guidelines in epidemiological research.

For people with SCI, there can be a number of different barriers to taking part in regular physical activity. These can include things such as a "loss of an able identity", "societal attitudes" towards people with a disability and the "material environment" which can be unsuitable for exercise for people in a wheelchair (Levins et al., 2004). Because of these barriers, programs that could potentially improve cardiovascular health in people with SCI should be made as accessible as possible. This could be achieved by incorporating such activity into well-established rehabilitation programs that already exist. However, it has not yet been determined whether current programs do or do not already satisfy physical activity guidelines for health. It is important to establish this so that we know whether and how to modify these programs.

1.2 RATIONALE

As people with SCI are at such a high risk of chronic disease due to decreased levels of physical activity, it becomes vital to have them engage in regular physical activity of an intensity and duration to elicit improvements in their CV health. However, people with SCI will rarely choose a program aimed at improving CV health over an ABRT program designed to promote neural recovery – such as the Walk On program – which, in theory, may increase their likelihood of walking again (Harkema et al., 2012). If such a program aimed at motor recovery was also

proven to be beneficial for a client's CV health, then this would effectively be 'killing two birds with one stone' – satisfying the patient's desire for a therapy to improve their function (and possibly walking ability) while simultaneously attending to the need for a program which was of a sufficient intensity and duration to improve CV health.

Conversely, if it was determined that the program intensity and duration were far below physical activity recommendations for improving CV health in people with SCI, then the CV health of patients would need to be addressed by other means. It may be that particular components of therapy could be further emphasized if found to be of a higher intensity or perhaps patients would need to seek out supplementary therapies to further address the need to improve their CV health.

1.3 PURPOSE

Considering the importance of physical activity for health and the availability of an already-established, community-based program for people with SCI, the purpose of this thesis was twofold: firstly, to classify the activity performed as part of patients' regular therapy in terms of intensity and duration and secondly, to use this data to compare the activity that patients were performing as part of a community-based ABRT program with current ACSM physical activity guidelines for health.

1.4 OBJECTIVES

The previous rationale and purpose led to four main objectives being developed for this thesis. These were to:

- Determine whether activities undertaken as part of a popular Australian ABRT program – The Walk On Program – are of sufficient intensity and duration to meet current American College of Sports Medicine (ACSM) PA guidelines for health in SCI.
- Discover whether an individual's ability to meet ACSM PA guidelines during ABRT is related to other health or demographic measures.
- Compare activities included in ABRT to determine which are the most intense, and hence the most beneficial, in helping to meet current ACSM guidelines.
- Determine whether there is a relationship between heart rate (HR) and rating of perceived exertion (RPE) across multiple intensities and activities during ABRT.

1.5 HYPOTHESES

Based on the objectives of this study, the following hypotheses were proposed:

- The intensity and duration of activity in the Walk On program will not be sufficient to satisfy the ACSM guidelines for health.
- Meeting the ACSM guidelines for health will be dependent upon patients' frequency of attendance at the program.
- There will be a relationship between activity intensity and injury level but not between activity intensity and age.
- There will be no direct relationship between HR and the RPE when measured by the patient or a person observing the activity.

1.6 DEFINITION OF KEY TERMS

The following recurring key terms that were used in this thesis have been defined herein as:

Activity-Based Restorative Therapy – A rehabilitation strategy designed to maximise the neuromuscular system, through exercise such as standing and locomotion or training on a functional electrical stimulation therapy device (Dromerick, Lum, & Hidler, 2006). Sometimes also referred to as "activity-based therapy" (ABT) or "activity-based rehabilitation"

Community-Based Therapy – Rehabilitative therapy that is conducted in a community setting, and not while a patient is in a hospital.

Clinical Significance – The practical importance of a treatment effect whether or not a result is of statistical significance.

Exercise – A series of physical activities which are structured, planned and repetitive (Caspersen, Powell, & Christenson, 1985).

Physical Activity (Exercise) Dose – A "dose" of physical activity refers to a bout that is quantified in both intensity and duration (Lamonte & Ainsworth, 2001).

Intensity of Activity – Refers to the rate at which the activity is performed or the magnitude of the effort required to perform an activity or exercise (WHO, 2014).

Physical Activity – Any bodily movement produced by skeletal muscles that results in a reasonable amount of energy expenditure (Caspersen et al., 1985).

Spinal cord injury – A trauma to the spinal cord resulting in a change, temporary or permanent, in its motor, sensory and autonomic function (American Spinal Injury Association, 2000).

Statistical Trend – When a result has a probability of a significant finding between 0.05 and 0.10.

Volume (of Exercise) – A function of the intensity, duration and frequency of exercise.

1.7 ABBREVIATIONS

The following is a list of abbreviations that were used frequently throughout this thesis:

ABRT – Activity-Based Restorative Therapy

ACSM – American College of Sports Medicine

AIS – American Spinal Injury Association Impairment Scale

ASIA – American Spinal Injury Association

BMI – Body Mass Index

$b \cdot min^{-1}$ – beats per minute

CNS – Central Nervous System

CSA – Cross-Sectional Area

CV – Cardiovascular

CVD – Cardiovascular Disease

DALY – Disability-Adjusted Life Years

EE – Energy Expenditure

FES – Functional Electrical Stimulation

HDL – High-Density Lipoprotein

HR – Heart Rate

HRR – Heart Rate Reserve

HRV – Heart Rate Variability

LDL – Low-Density Lipoprotein

MET – Metabolic equivalent

min – Minute

PA – Physical Activity

PCF – Participant Consent Form

PIS – Participant Information Statement

PO – Power Output

QoL – Quality of Life

RPE – Rating of Perceived Exertion

SCI – Spinal Cord Injury

SCIA – Spinal Cord Injuries Australia

VCO_2 – Carbon Dioxide Production

VO_2 – Oxygen Consumption

W – Watt

WO – Walk On

CHAPTER 2

LITERATURE REVIEW

2.1 SPINAL CORD INJURY AND DISABILITY

Spinal cord injury refers to the occurrence of an acute, traumatic lesion of neural elements in the spinal canal resulting in temporary or permanent sensory deficit, motor deficit or bladder/bowel dysfunction (Cripps, 2008). A SCI has a profound effect on a person's motor and sensory capabilities. It also has a life-changing impact on the person's physical, psychological and social well-being.

2.1.1 Spinal cord injury epidemiology

SCI is not one of the most frequently occurring chronic conditions affecting people around the world, however, given the severity of disability that most sufferers experience, it is vitally important to understand in depth. For the year 2008, there were 137 new cases of paraplegia and 136 new cases of tetraplegia in Australia (Cripps, 2008) and it is estimated that there are now over 10, 000 people with a SCI living in Australia (O'Connor, 2005).

The majority of people with SCI are male, aged between 15 – 25 years with only 15% of SCI affecting females and only 18% of affected people being over 45 years (Harvey, 2008). SCI is most commonly caused by motor-vehicle and motor-bike accidents (34%) followed closely by falls (33%) (Access Economics Pty Ltd, 2009). Other causes include sport and water-based activities, as well as violence-related injuries. A SCI can also be the consequence of a disease, infection or congenital defect (Harvey, 2008).

'Burden of disease' is a measure used to assess and compare the relative impact of different diseases and injuries on populations. In Australia, the burden of disease representing SCI is growing from 9.6% of the total healthcare burden in

1993, to 11.9% in 2003 and projected to be at 16.4% by 2023 (Begg, Vos, Barker, Stanley, & Lopez, 2008). The burden of disease is measured in terms of disability adjusted life years (DALY) which is expressed as the number of years lost due to ill-health, disability or early death. In Australia, for SCI, this figure was 5,090 years in 2008 with 2,032 years attributed to paraplegia and 3,058 attributed to tetraplegia (Access Economics Pty Ltd, 2009). The total cost of spinal cord injury in Australia was reported to be $2.0 billion with the lifetime cost per incident case of paraplegia $5.0 million and tetraplegia $9.5 million (Access Economics Pty Ltd, 2009).

2.1.2 Spinal cord injury classification

Spinal cord injuries may be defined generally as one of the following: (Kirshblum et al., 2011):

- Tetraplegia (or quadriplegia) – the impairment or loss of motor and/or sensory function in the cervical, vertebral segments of the spinal cord (C1 – C7) typically resulting in impairment of function of the arms as well as the trunk, legs and pelvic organs.
- Paraplegia – the impairment or loss of motor and/or sensory function in the thoracic, lumbar or sacral vertebral segments of the spinal cord (T1 – S5). Arm function is spared but, depending on the level of injury, the trunk, legs and pelvic organs may be involved.

Injuries may also be described based on their completeness. These classifications are either (Kirshblum et al., 2011):

- Incomplete injury – there is preservation of any sensory and/or motor function below the neurological level of injury including 'sacral sparing' – sensation preservation in the lowest sacral segments (S4-S5) or
- Complete injury – there is a complete absence of sensory and motor function below the level of lesion including in the lowest sacral segment (S4-S5)

These two classifications are combined as part of The American Spinal Injury Association impairment scale (Kirshblum et al., 2011) which is one of the preferred tools used by clinicians to classify spinal cord injuries. These classifications divide spinal cord injuries into 5 categories and are as follows:

- A – complete sensorimotor loss
- B – incomplete: Sensory but no 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 strength
- 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 strength
- E – normal

2.1.3 Spinal cord injury impact on physical capacity

A person's physical capacity is the ability to perform physical work and is the combination of cardiovascular, pulmonary and neural function along with the action of exercising muscles (Goldstein, 1990). As a result, some of the most important determinants of physical capacity in people with SCI are aerobic fitness, muscle strength and physical activity levels (Janssen, Dallmeijer, Veeger, & van der Woude, 2002) which are in turn affected by the neurological level of injury.

Aerobic fitness in people with SCI is very limited. This can be attributed to a disruption of the motor pathways leading to paralysis or paresis in the innervated muscles, impaired parasympathetic and/or sympathetic control and a resulting sedentary lifestyle (Phillips et al., 1998). Aerobic fitness in people with SCI is significantly reduced compared with able-bodied individuals (Jacobs & Nash, 2004). VO_2peak during arm cranking has been shown to be significantly less in athletes with paraplegia when compared with able-bodied athletes (2.04 $L.min^{-1}$ vs 3.45 $L.min^{-1}$) (Price, 2003). In the same study, athletes with tetraplegia demonstrated a reduced VO_2peak (1.26 $L.min^{-1}$) when compared with athletes with high level paraplegia (1.70 $L.min^{-1}$) and low level paraplegia (2.15 $L.min^{-1}$). This demonstrates that the neurological level of an injury also has a significant impact on aerobic fitness and those with high-level injuries have lower physical capacity than those with low-level injuries (Coutts, Rhodes, & McKenzie, 1983; Eriksson, Lofstrom, & Ekblom, 1988). One aspect of SCI pathophysiology that relates to a reduced physical capacity is the altered cardiovascular response to exercise. The autonomic nervous system plays an important role in

cardiovascular regulation at rest and during exercise. Efferent fibres which innervate the heart, among other regions, originate from the spinal cord between T1 and T4. An injury to this level of the spinal cord or above will have a marked impact on autonomic function, especially in the parasympathetic system, affecting the normal cardiovascular response to exercise (Krassioukov et al., 2007). Because of this, people with higher spinal cord lesions – at the level of T4 and above – may have blunted HR responses to exercise due, in part, to a deprivation of supraspinal sympathoadrenal control and individuals with tetraplegia may only display a peak HR of around 110 - 130bpm (Dela et al., 2003; Takahashi et al., 2004). This further explains the impact that lesion level has on the physical capacity of people with SCI as people with higher-level injuries may have a distinctly reduced ability to supply working muscles with oxygen.

Muscle strength impairments also have a significant impact on physical capacity in people with SCI (Shields, 2002). The primary reason for the reduction in strength is the reduction in neurological activation in the muscles after SCI (or the strength of the signals that tell the muscle to contract). Lesions to the spinal nerves have a direct impact on the innervations to a muscle and severance of these connections leads to a reduced capacity for voluntary contraction. Secondary to this, there are physiological adaptations in the muscle below the level of lesion including atrophy, muscle fibre type changes, available cross-bridging and responses to training which all lead to a reduction in strength (Stein et al., 1992).

The level and severity of the lesion has a significant effect in determining the physical capacity of individuals with SCI resulting in a wide range of exercise

impairments in individuals with SCI. It has also been shown that wheelchair users with SCI who maintain a more active lifestyle by regular participation in exercise and sport programs can increase their muscle strength, aerobic fitness and overall physical capacity to levels well above those of their sedentary counterparts (Davis & Shephard, 1988; Eriksson et al., 1988). This emphasizes the importance of increasing physical activity levels for people with SCI as a fundamental method of maintaining their physical capacity.

2.2 SPINAL CORD INJURY AND CHRONIC DISEASE

People with SCI have been classified as extremely sedentary and one of the most physically inactive groups in society (Buchholz, McGillivray, & Pencharz, 2003; Dearwater, LaPorte, Cauley, & Brenes, 1985). One study (Dearwater et al., 1985) found a 30-fold difference in activity between people with SCI (4 activity counts per hour) and an age matched group of college students (126.7 activity counts per hour).

However, it is possible to encourage this group to do more exercise. A study by van den Berg-Emons and colleagues (2008) showed that during their time as inpatients in a rehabilitation hospital, patient activity levels increased. In this study, at the start of inpatient rehabilitation, the mean duration of dynamic activity performed was measured as 3.4 ± 2.2% of total time over a 24-hour period, while after three months of inpatient rehabilitation it had increased to a mean of 5.0 ± 2.3%. After discharge, however, the mean activity level (3.4 ± 2.2%) dropped again to below what it had been on first admission post-injury.

There are a number of reasons why people with SCI may not involve themselves in regular exercise – some of these may be to do with physical limitations while others may be due to real or perceived barriers. Reasons can include such things as loss of an identity of themselves as able-bodied people, physical inaccessibility and access to information resources, and general attitudes of society as a whole (Levins et al., 2004).

It is critically important for the health and well-being of the SCI population to increase PA levels generally. To do this, it is obviously important to find ways to address any issues that are preventing them from undertaking routine exercise. One way to address identified barriers could be to provide access to more community-based exercise programs developed specifically for this group. Such programs could be tailored specifically to their physical limitations, provide a genuine support network, as well as general education and information. If found to be effective, they could provide an accessible means to increase PA levels in this population.

2.2.1 Physical activity and health

Because of their heightened levels of inactivity, people with SCI are at a much greater risk of a number of chronic diseases (Cowan & Nash, 2010). The relationship between physical activity and health is well established in able-bodied populations and there is also a clear association between activity and disease risk in people with SCI (Fernhall, Heffernan, Jae, & Hedrick, 2008). Regular physical activity has been shown to be very important in reducing the

risk of a number of different chronic conditions including coronary artery disease, stroke, hypertension, colon cancer, breast cancer, type 2 diabetes and osteoporosis (Brown et al., 2003; Cowan & Nash, 2010; Warburton et al., 2007). Buchholz et al. (2009) found that greater daily leisure-time physical activity was associated with lower levels of selected cardiovascular disease and type 2 diabetes risk factors in individuals living with SCI (body mass index (BMI) – 27.3 ± 5.4 vs 23.0 ± 5.7, %fat mass – 30.8 ± 8.2 vs 25.8 ± 9.2 and fasting glucose – 5.55 ± 1.42mmol.L^{-1} vs 5.17 ± 0.84mmol.L^{-1}) .

PA in SCI has also been found to have a strong positive association with quality of life (QoL) ($r = 0.75$; $P < 0.05$) (Stevens, Caputo, Fuller, & Morgan, 2008). Multiple regression analysis also showed that when level of physical activity, anatomical location of the injury, completeness of injury and time since injury were used as explanatory variables, level of physical activity was the only significant predictor of QoL (Stevens et al., 2008).

Improving or maintaining aerobic fitness for people with SCI is crucial. Not only is there a significant correlation between improved aerobic fitness and lowered disease risk (Jacobs & Nash, 2004; Lee & Skerrett, 2001; Oja, 2001), but some activities of daily living (ADL's) require a baseline level of fitness to complete (Collins et al., 2010). Normative peak oxygen uptake values for people with tetraplegia were measured as 900 ± 410 mL.min^{-1} and 1680 ± 450 mL.min^{-1} in high-level individuals with paraplegia (Janssen et al., 2002). Collins et al. (2010) determined that dressing/undressing and grocery shopping required an oxygen uptake of 751.0 ± 280.0 mL.min^{-1} and 524.1 ± 62.7 mL.min^{-1} respectively. These values are 83% and 53% of the peak oxygen uptake in individuals with

tetraplegia which could be considered as quite high intensity activity. Therefore, aerobic fitness is also an important factor for people with SCI in maintaining their independence. Hetz, Latimer, & Martin Ginis (2009) found a positive relationship between aerobic fitness and time spent participating in more strenuous ADL's ($R > 0.32$, $p < 0.01$). The authors stated though that further research would be needed to confirm whether increased fitness levels allowed people with SCI to engage in more strenuous ADL's for a longer duration.

2.3 REHABILITATION AFER SPINAL CORD INJURY

Until fairly recently, it was believed that the central nervous system (CNS) was hard-wired, non-malleable and incapable of repairing itself. In the past, this led rehabilitation to be primarily focussed on increasing function through compensatory techniques known as compensatory therapy (Somers, 2001; Dromerick et al., 2006). During the acute phase, while patients are bed-ridden, the key impairments that are addressed with physical therapy include pain, poor respiratory function, loss of joint mobility and weakness (Harvey, 2008).

Compensatory therapy is still used to help people develop the skills needed to re-integrate into their social and work roles and assist them with independent living. However, in the past 20 years, the lack of satisfaction with the conventional method has led to alternative strategies being trialled which aim to promote recovery below the level of the SCI (Dromerick et al., 2006).

2.3.1 Activity-Based Restorative Therapy

Activity-based restorative therapy (ABRT) or activity-based rehabilitation are terms that have been coined in the past 15 years to describe a method of treating the neurological deficits afflicting people with SCI. The goal of this type of rehabilitation is to trigger activation of neurological levels both above and below the lesion by using whole-body rehabilitative activities (Sadowsky & McDonald, 2009). There is currently not enough evidence to make a definitive claim regarding the efficacy of ABRT for improving function in SCI, however, preliminary studies have demonstrated positive results (Jones et al., 2012) and anecdotal evidence regarding its benefits is common among therapists and patients. The specific means by which activity-based therapy reportedly improves function is currently unknown; however, it is theorised that it could be due to a number of different mechanisms. Neuroplasticity is one such mechanism which could account for improvements. The spinal cord is thought to exhibit neuroplasticity through neuro-regeneration, neuro-facilitation and neuro-protection and there is a reasonable body of animal evidence to support this assumption (Konya et al., 2008; Petrosyan et al., 2013).

Other mechanisms that may be responsible for functional improvement include motor control re-learning, in which the motor cortex of the brain is "reorganised" (Krakauer, 2006), and overload adaptation in which the residual neuromusculature simply becomes stronger in response to physical strain (Shields & Dudley-Javoroski, 2007).

The tools which form the basis of ABRT include (Sadowsky & McDonald, 2009):

- Patterned motor activation – locomotor training, functional electrical stimulation (FES) training
- Non-patterned motor activation – recruitment and strengthening, task specific training
- Sensory stimulation – sensorimotor training

2.3.2 Reported benefits of Activity-Based Restorative Therapy

There is increasing evidence of the benefits of ABRT for improving health and function (Harkema et al., 2012). It is still unknown whether the reported gains in function after undertaking ABRT come from the therapy itself or whether people with SCI recover naturally on their own. Most research in the past that has looked at ABRT as a whole investigates its effect on function and improvements in neurological regeneration. Health benefits have been reported for the different aspects of ABRT such as FES training (Hamzaid & Davis, 2009) and locomotor training (de Carvalho, Martins, Cardoso, & Cliquet, 2006; Ditor et al., 2005), however the health benefits of ABRT in its entirety are not well-documented.

Locomotor training is the primary focus of ABRT, and it is hypothesized that its functional benefits are achieved by providing the damaged nervous system with sensory input which stimulates the remaining spinal cord networks to adapt and induce permanent modifications in the system (Harkema et al., 2012). Locomotor training has demonstrated that recovery of walking and balance can occur in individuals months or even years after the injury has occurred (Harkema et al.,

2012). Locomotor training has also been shown to be more effective than conventional physiotherapy for improving spatial-temporal and gait parameters among patients with incomplete SCI (Lucareli et al., 2011). Results from previous research have however been variable and there is currently inconclusive evidence to suggest that locomotor training may affect walking function any more than other types of physical rehabilitation (Mehrholz, Kugler, & Pohl, 2008). It is agreed though, that the intensity of treatment is a critical determinant in recovery (Fritz et al., 2011; Harness & Astorino, 2011).

There is some evidence to suggest that locomotor training is also beneficial for improving health, however the majority of research so far has been directed at functional improvements including improved gait, balance and body kinematics. Ditor et al., (2005) found that locomotor training caused a significant increase in femoral artery compliance (0.061 vs 0.11 $mm^2 \cdot mmHg^{-1}$) and modest improvements in HR variability (HRV) and blood-pressure variability. This led them to suggest that body-weight supported treadmill training should be encouraged as a means of improving CV health in people with SCI. As a result of being seen mainly as a means of improving functional outcomes, locomotor training has had no research looking at it in terms of its exercise intensity and its contribution to ABRT as a whole.

FES has been used as a method for contracting paralysed muscle in an attempt to recreate the neuromuscular benefits of cycling and walking (Kralj & Badj, 1989). It is theorised that this repetitive type of training stimulates the central pattern generators (CPG) which produce rhythmic patterned outputs without sensory feedback. FES in SCI has been shown to have numerous positive health benefits

including improved cardiorespiratory fitness, reversal of muscle atrophy and increased muscle cross-sectional area (CSA), enhanced functional exercise capacity and to a lesser degree, bone mineral density (Davis, Hamzaid, & Fornusek, 2008; Hamzaid & Davis, 2009).

2.3.3 Exercise and the Dose-Response Relationship to Health

Dose-response

For improvements to health and function, the "dose" of physical activity that is required is very important. A "dose" of physical activity refers to the amount that is quantified in both intensity and duration and generally speaking, the bigger the dose, the bigger the response within the body (Lamonte & Ainsworth, 2001). It is very important to know the precise amount and type of physical activity required to achieve specific health-related outcomes. This allows epidemiological research to produce an estimate of the strength of association between an amount of physical activity and a specific health outcome.

Improvements in function rely on the dose of exercise and the gains in ASIA motor score have been found to have a correlation with number of exercise hours per week ($r = 0.53$, $P < 0.02$) (Harness, Yozbatiran, & Cramer, 2008). In this study, there was an intense exercise group who participated in an individually designed program focused on attempting to regain voluntary motor function below the level of injury and a control group who were unsupervised and asked to maintain a PA log book. Exercise durations were 5.2 ± 1.3 hours.week^{-1} for the control group and 7.3 ± 0.7 hours.week^{-1} for the intense exercise group which were not

significantly different however the intense exercise group showed significantly greater motor gains than the control group. This suggests that intensity of exercise as well as duration is an important factor in improving functional outcomes.

The dose of physical activity that was found to be effective for an improvement in function for SCI was 120min, 3 days.week^{-1} consisting of mobility, strength, coordination, aerobic resistance and relaxation activities (Durán, Lugo, Ramírez, & Eusse, 2001). There was, however, no indication of the intensity of this activity, only the duration and type. The same study found that this program also had a positive effect on indicators of cardiorespiratory fitness including improved peak arm cranking performance (90 ± 24 W at the beginning of the program and 110 ± 26.1 W at the end), HR 6 minutes after exercise (115 ± 18.9 b.min^{-1} vs 108 ± 18.6 b.min^{-1}), resting HR (83 ± 19.7 b.min^{-1} vs 81 ± 14.6 b.min^{-1}) and weight lifted in a number of different exercises. This demonstrates that physiotherapy programs aimed at improving function may also have the benefit of increasing cardiorespiratory health as well. Jack et al. (2010) found that robotic-assisted treadmill training led to a higher acute bout of cardiopulmonary stress than arm crank training – higher VO_2peak (2.26 ± 0.54 L·min^{-1} vs 1.98 ± 0.37 L·min^{-1}) and respiratory exchange threshold (1.13 ± 0.33 vs 0.81 ± 0.11). This may indicate that locomotor training is more likely to improve aerobic capacity than arm crank training.

Harness & Astorino (2011) found that typical exercises included in ABRT (such as locomotor training, FES training, circuit/resistance training and sensorimotor therapy) ranged from an intensity of 1.89 – 3.24 METs. Activity in this range

would be unlikely to be of a sufficient intensity to elicit significant health or fitness benefits, especially if the majority of activity was performed at the lower end of the spectrum. This outlines the need for more in-depth analysis of ABRT to investigate how long is being spent at different intensities, the dose (duration and intensity) of activity being performed and which activities may be contributing more or less to improvements in health.

A study by Alexeeva et al. (2011) found that walking ability was improved in all subjects regardless of training method as long as intensity and duration were maintained between the different training mediums. This would suggest that the type or mode of activity being performed is irrelevant as long as the total volume of exercise is maintained. There is also some evidence to show that increasing aerobic fitness in people with SCI will improve their function (Brurok, Helgerud, Karlsen, Leivseth, & Hoff, 2011; Noreau, Shephard, Simard, Paré, & Pomerleau, 1993; Tawashy, Eng, Krassioukov, Miller, & Sproule, 2010). This supports the theory that there is a 'dose' of exercise that is required before a benefit in function is acquired and this is independent of the way it is achieved. It also highlights the importance of improving fitness as part of rehabilitative therapy for SCI.

2.4 PHYSICAL ACTIVITY QUANTIFICATION IN SPINAL CORD INJURY

It is difficult to assess intensity and energy expenditure in the SCI population due to a number of different factors affecting their response to exercise (Martin Ginis et al., 2008). There are three main factors that affect the response to exercise in

people with SCI. These are the reliance on arm exercise (when arm function may be inhibited due to interrupted, efferent pathways), lower limb paralysis and loss of supraspinal sympathetic nervous control. Current models that exist to measure activity in the ambulatory population – compendium standards, activity questionnaires, predictive equations and heart rate methods – tend to over-predict energy expenditure in people with SCI (Buchholz & Pencharz, 2004; Cox et al., 1985; Monroe et al., 1998). A number of different methods to measure activity intensity in this population have been used with varying degrees of accuracy.

2.4.1 Indirect Calorimetry

Energy expenditure is frequently calculated using the relationship between VO_2 and carbon dioxide production (VCO_2) (Lamonte & Ainsworth, 2001) and the Weir formulae (Weir, 1949) to calculate metabolic rate. Indirect calorimetry is used frequently to measure exercise intensity in people with SCI and has been shown to be an accurate measure of energy expenditure (Livesey & Elia, 1988). The ratio of resting VO_2 to exercise VO_2 is known as a MET and is another effective measure of exercise intensity and a useful measure to compare the intensity of different activities. However, tools for measuring indirect calorimetry can be bulky and inhibiting and may not always be suitable for use when attempting to reflect free-living conditions.

2.4.2 Heart Rate

In able-bodied people, there is a strong linear relationship between HR and VO_2 during moderate intensity physical activity. This means that HR can be used as a

proxy of exercise intensity and as an estimation for EE (energy expenditure) (Achten & Jeukendrup, 2003). In able-bodied people, HR increases linearly with PA intensity. The ratio of exercise HR to resting HR is similar to the ratio of VO_2 during exercise to resting VO_2 which should be able to accurately estimate MET values of PA.

HR monitoring alone has been shown to overestimate EE in people with SCI by 25% (Hayes et al., 2005), however, HR monitoring with the use of individually calibrated prediction equations has been shown to provide accurate gross estimations of energy expenditure in people with SCI, particularly during higher intensity activities (Hayes et al., 2005; Lee, Zhu, Hedrick, & Fernhall, 2010). Hayes et al. (2005) also found that HR predictions of EE were equally accurate between individuals with paraplegia and tetraplegia. Other studies have found that the HR-oxygen uptake relationship for people with tetraplegia is not as strong as those with paraplegia or able-bodied populations ($r = 0.80$ for injuries C6 and above and $r = 0.90$ for those with C7-T1 injuries – McLean, Jones & Skinner, 1995). This is likely due to a reduced maximum HR in people with tetraplegia compared with able-bodied and paraplegic individuals, however the relationship is still good enough to be acceptable for an accurate estimation of oxygen uptake based on exercise HR (McLean, Jones, & Skinner, 1995). Accurate estimations of EE and other measurements of intensity for people with SCI are valuable in assisting clinicians and researchers to determine whether PA done by people with SCI is meeting current physical activity guidelines for health.

2.4.3 Rating of Perceived Exertion

Rating of Perceived Exertion (RPE) is a widely used and accepted method of estimating exercise intensity in able-bodied people. It has been shown to have a strong correlation with a number of other different measures of intensity including HR, power and lactate accumulation (Borg, 1982a, 1982b). There is currently limited evidence however to suggest that RPE is as accurate in clinical populations, in particular in people with SCI. Lewis et al. (2007) found that, for individuals with tetraplegia, there was inconsistent association between RPE and oxygen consumption (r = 0.52) and minute ventilation (r = 0.40); however they found a significant, positive relationship between HR and RPE (r = 0.78). In individuals with paraplegia, there was no significant correlation between RPE and any of the other measures of intensity. Similar findings were made by Dawes et al. (2005) when they investigated the relationship between RPE and other measures of intensity in various clinical populations. A study by Goosey-Tolfrey et al. (2010) provided contrasting results relating to the use of RPE as an intensity measure in people with SCI. This study showed that RPE may provide a reliable means for regulating exercise intensities at 50% and 70% of VO_2peak. There are very few studies at present though which have investigated the use of the RPE scale in clinical populations and current results are mixed. It is clear that more research is needed to determine whether the validity of the RPE scale in people with SCI is as strong as with able-bodied people.

2.5 PHYSICAL ACTIVITY GUIDELINES FOR HEALTH IN SPINAL CORD INJURY

Physical activity guidelines have been developed around the world for the purpose of providing guidance to health professionals who counsel and prescribe individualised exercise to adults. The most widely accepted and utilised of these is the American College of Sports Medicine's position stand which recommends the following dose of cardiorespiratory exercise training for health (Garber et al., 2011):

- Moderate intensity cardiorespiratory exercise training ≥ 30 min.day^{-1} on ≥ 5 days.week^{-1} totalling ≥ 150 min.week^{-1} or
- Vigorous intensity cardiorespiratory exercise training ≥ 20 min.day^{-1} on ≥ 3 days.week^{-1} totalling ≥ 75 min.week^{-1} or
- A combination of moderate and vigorous intensity exercise to achieve a total energy expenditure of ≥ 500-1000 METmin.week^{-1}

These guidelines were designed to be used for apparently healthy adults; however, ACSM has stated that the same guidelines should apply for people with SCI (ACSM, 2013). The guidelines above have been deemed sufficient to improve and maintain physical fitness and health.

ACSM has classified the different intensities of exercise according to a number of different criteria. These different intensity measures were used in the study reported in this thesis to measure activity that participants were doing as part of their therapy and include the following classifications:

Table 2.1 – Classifications of exercise intensity

Relative and absolute exercise intensities for cardiorespiratory endurance and resistance exercise adapted from (Garber et al., 2011).

	RELATIVE INTENSITY			
Intensity	**%HRR or %VO_2R**	**%HR_{max}**	**%VO_{2max}**	**Perceived Exertion (6-20 Scale)**
Very Light/Sedentary	<30	<57	<37	<Very light (RPE < 9)
Light	30-39	57-63	37-45	Very light – Fairly light (RPE 9-11)
Moderate	40-59	64-76	46-63	Fairly light to somewhat hard (RPE 12-13)
Vigorous	60-89	77-95	64-90	Somewhat hard to very hard (RPE 14-17)
Near-Maximal to Maximal	≥90	≥96	≥91	≥Very hard (RPE ≥ 18)

In the past, people with SCI have been understudied with regard to PA and health epidemiology (Martin-Ginis & Hicks, 2005). To this date, only one group of researchers has created evidence-based guidelines designed specifically for people with SCI. Martin Ginis et al. (2011) used a multi-disciplinary panel including practitioners, service providers and people with SCI to delineate recommended levels of activity that people with a SCI should be engaging in.

These recommendations involved the following dose of cardiorespiratory exercise training:

- 20 min of moderate to vigorous intensity aerobic activity two days.week^{-1}

It is apparent that these SCI-specific guidelines are of a much lower dose than the ACSM guidelines. It was also admitted by the expert panel that, although there is an intuitive link between increased fitness and improvements in health, there was insufficient evidence to justify PA recommendations related to reducing disease risk and these guidelines are limited by the current state of the evidence. However, these guidelines were the first attempt to develop SCI-specific PA guidelines using the internationally accepted consensus approach outlined in the Appraisal of Guidelines, Research and Evaluation II (AGREE II) guideline development protocol and may provide a foundation for future PA guideline development in this population.

As there is still a significant discrepancy between physical activity guidelines for this population, it is clear that further research is needed to determine the true dose of exercise needed to elicit health benefits for people with SCI.

2.6 SUMMARY

People with SCI are at a much higher risk of a number of chronic diseases due to their decreased levels of PA. As a result, it is essential to have them engage in regular, structured exercise to reduce the likelihood of these diseases occurring.

For an increase in a person's health, it is apparent that there is a minimum 'dose' of exercise that is required to obtain these benefits. Research relating to PA guidelines and the 'dose' of exercise to improve health in people with SCI is limited and there are currently no widely accepted, SCI-specific guidelines for use with this population.

Further research is also needed to determine the duration and intensity of activity that people with SCI are currently performing as part of their regular therapy to determine whether these provide a sufficient 'dose' to satisfy guidelines for improving health. The study reported in this thesis was designed to answer these questions.

CHAPTER 3

METHODS

3.1 OVERVIEW

The purpose of this study was to determine whether an activity-based therapy program's intensity and duration were sufficient to meet current ACSM PA guidelines for promoting and maintaining cardiorespiratory fitness and general health in individuals with SCI. Participants were assessed during their regular therapy visits to the Walk On program in Sydney and Melbourne, Australia. Heart rate (HR) was measured and a time-and-motion analysis was completed for each session, which included their rating of perceived exertion (RPE) along with a code and description for each physical activity.

3.2 PARTICIPANTS

3.2.1 Inclusion criteria

Participants needed to meet the following criteria to be included in the study:

- Traumatic or non-traumatic SCI at any level from C2 or below
- Complete or incomplete SCI
- Discharged from their hospital rehabilitation for at least one month
- Over the age of 18 years

3.2.2 Exclusion criteria

Participants were excluded from the study if they met any of the following conditions:

- Other neurological conditions, such as multiple sclerosis, motor neurone disease or traumatic brain injury.
- Unable to breathe on their own
- Unable to perform maximal arm crank testing, or were contraindicated from maximal exertion for medical reasons

Clients of the WO Program were given participant information statements (PIS – see Appendix A) by their regular therapists and were asked to take these home to consider participation before providing informed consent. Written informed consent was obtained from all participants prior to testing (see Appendix A), and all procedures were approved by The University of Sydney Human Research Ethics Committee (see Appendix A).

3.3 PROTOCOL AND PROCEDURES

3.3.1 Pre-screening

Before taking part in any assessment, participants were screened using the Physical Activity Readiness Questionnaire (PAR-Q) (see appendix B) to ensure that there were no obvious, self-reported health risks to undertaking vigorous exercise. The PAR-Q is a questionnaire used as 'best-practice' by exercise allied health professionals (ACSM, 2013) to ensure there are no obvious underlying pathologies present which may present a risk during exercise. The PAR-Q was used in conjunction with physician clearance to ensure that participants were safe to exercise at vigorous intensities. If participants answered 'yes' to any of the questions, they were asked to return to their physician for secondary medical

clearance so that they could undertake maximal exercise testing before joining the study.

3.4 MEASUREMENTS

3.4.1 Aerobic Fitness

Participants' aerobic fitness was measured using a multi-stage, sub-maximal effort test followed by progressive, incremental exercise to volitional fatigue to determine sub-maximal cardiorespiratory responses and maximal aerobic fitness. All participants were tested before their usual therapy sessions. They were requested to refrain from eating, drinking caffeinated beverages or smoking for one hour prior to testing. On arrival, participants were comfortably set up in front of an arm crank ergometer and asked to relax for 5 minutes, so that resting heart rate (HR) and basal metabolic data could be obtained. The values from the last minute of this resting stage were used to obtain pre-exercise data.

During the exercise test, participants' HR was measured and recorded using a HR monitor (Polar Electro Oy RS800CX, Finland). Expired gases were collected during each sub-maximal workload, and until the conclusion of maximal effort through a portable gas analysis system (COSMED K4b2 portable metabolic measurement system). VO_2, VCO_2, expired ventilation and respiratory exchange ratio were calculated for each sub-maximal workload and at maximum effort.

The test commenced with a power output of either 0, 5 or 10 Watts (W) using an arm crank ergometer (ACE) (Monark 881 E Vansbro, Sweden) depending on the

researcher's perceived level of function for each participant. Participants were instructed to begin cranking at 70 rpm and resistance was adjusted accordingly. This acted as both a warm-up and first sub-maximal workload. Researcher judgement was then used to predict two further, sub-maximal stages with a separation of > 5 $b \cdot min^{-1}$. This approach was to derive the participants' HR- VO_2 relationship, as predetermined workloads could not be easily estimated in this diverse population of individuals with paraplegia and tetraplegia.

During the sub-maximal stages, participants were defined as being in "steady state" when there was a difference of < 5 $b \cdot min^{-1}$ between the final two consecutive minutes of exercise. The duration of each workload was 4 to 6 minutes, and participants were permitted to recover for up to 5 minutes between workloads. After the end of the final sub-maximal stage, the power output was increased by 5 W every minute until volitional fatigue to obtain the participants' peak exercise responses.

Steady-state HR and VO_2 data from the last minute of each sub-maximal stage were ensemble-averaged and used to develop a linear regression equation between HR and VO_2. This relationship was then used to estimate the submaximal VO_2 for different activities during therapy sessions (Hooker et al. 1993) from the HR-monitor observed HR. Peak HR and VO_2 were also obtained as an estimate of maximal values, so that a percentage of maximal values could be estimated.

3.4.2 Activity-Based Restorative Therapy (Walk On)

Participants attending the ABRT program were assessed during all of their therapy sessions over a two-week period. The number of sessions that were

measured depended on the frequency that participants regularly attended the ABRT program. In the two-week period, if a client attended the program three times per week, then they were tested six times in total. If a client missed a session due to illness or misadventure, then this was made up by testing the client in an additional session. Measurement duration for each therapy session was approximately two hours for both individuals with tetraplegia and paraplegia, but may have been slightly more or less due to clients arriving late or sessions going over-time. For each participant, the following measurements were made each session.

Heart Rate (HR)

Before participants started each therapy session in which they were measured, they were fitted with a HR monitor (Polar Electro Oy RS800 CX, Fin). This comprised a chest-strap and wrist watch, and was set to record HR at 1 s intervals for the duration of therapy. The monitor was started when each participant commenced their first activity and continued recording for the duration of the therapy session. Recording was ceased when their last activity was finished. Participants were fitted with the same monitors during arm-crank testing which also measured HR at 1 s intervals for consistency of measurement units.

Time-and-Motion Analysis of Physical Activities

To classify the therapy being undertaken, a time-and-motion analysis was conducted during participants' therapy sessions. This analysis also allowed the researcher to record the details of activities done during the session. The time-and-motion analysis involved coding the activities into numerical categories from

1-9 (see Appendix C), recording the time spent doing that activity and recording a rating of perceived exertion (RPE) of that activity from both the participant and the observer (researcher). The time that each activity was performed was also recorded to allow a HR value to be assigned to each activity from the HR monitor.

3.5 DATA ANALYSIS

3.5.1 Heart Rate

For each therapy session, HR data were collected and stored at 1 s intervals. The raw data were downloaded from the HR monitor and presented as a HR vs. time periodogram (see Appendix D). From these data, using the times that were recorded for each activity from the time-and-motion analysis, an average HR for each activity was calculated manually using Polar ProTrainer 5 software. This resulted in an average HR intensity for every activity code being undertaken by participants.

Heart rate reserve (HRR) is a measure of exercise intensity which accounts for the variability in individuals' resting and peak HR. Participant resting HR was obtained prior to arm crank testing by asking participants to relax and sit still for a period of 5 minutes. HR data was averaged over the last minute to obtain a value for resting HR. Peak HR was the highest HR value observed during either arm crank testing or therapy. HRR was calculated using the equation:

$$HRR = HR_{peak} - HR_{rest}$$

A percentage of HRR was able to be calculated from raw HR data obtained during therapy to give a measurement of the intensity of the different exercises which was relative between different participants.

Percentage of absolute HR and HRR were two of the exercise intensity criteria used to delineate the different intensity bands as described in the ACSM position stand (2011). Using a commercial spreadsheet (Microsoft Excel, 2010), the raw HR data from the HR monitors were used to create a frequency histogram of the entire therapy session (see figure 4.4 for example). This grouped each HR measurement into one of a number of frequency 'bins' that had cut-offs organised to be the same as the absolute HR and HRR and classifications of exercise intensity (Table 2.1) used in the ACSM physical activity guidelines position stand (ACSM, 2011). These frequency histograms showed the total time that participants spent in different intensity bands during their therapy session by summing the number of HR counts into each frequency 'bin'.

3.5.2 Rating of Perceived Exertion

For each activity that was performed during participants' therapy sessions, a rating of perceived exertion was recorded by both the participant and an observer (researcher). A scale from 0-10 (Norton, Norton & Sadgrove, 2010) (Table 3.1) was used. As each activity was coded into one of nine categories, an average RPE from participants and observer was obtained for each activity code.

3.5.3 Energy Expenditure

Using the steady-state HR and VO_2 data recorded during arm-crank testing, an individualised regression equation between these two variables was developed for each participant. Using this linear relationship, VO_2 was estimated from HR data collected during therapy sessions (Lee et al. 2010).

Metabolic equivalent (MET) values were also estimated using HR-VO_2 data collected during therapy. Due to the relative physical inactivity of this population, and based on previous reports (Mollinger et al,. 1985; Monroe et al., 1998), standardised estimates of 1 MET as 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ were utilised as well as MET values being calculated using resting VO_2 data from before each individual's arm crank testing. It has been proposed that 2.7 $ml.kg.min^{-1}$ should be the value for 1 MET in people with SCI (Collins et al. 2010), however throughout the thesis the author decided to use each individual participant's resting VO_2 value during sitting in their wheelchair as representative of 1 MET, as this provided the most accurate estimate of resting basal metabolism. This study also compared data using 3.5 $ml.kg.min^{-1}$ as this is the most commonly accepted value of 1 MET for able-bodied people, and has the most research supporting its use (Mollinger et al,. 1985; Monroe et al., 1998). Each activity performed during therapy had a recorded duration and an average HR. A VO_2 was estimated for these activities by using the individualised regression equations and the MET minutes of physical activity were calculated by multiplying the MET intensity of the activity by its duration (Hayes et al. 2005).

3.5.4 Comparison with Physical Activity Guidelines

The ACSM guidelines for physical activity stipulate that people should complete one of the following each week for cardiovascular health (Garber et al., 2011):

- Moderate intensity cardiorespiratory exercise training ≥ 30 min·day^{-1} on ≥ 5 days/week totalling ≥ 150 min·week^{-1},
- Vigorous intensity cardiorespiratory exercise training ≥ 20 min·day^{-1} on ≥ 3 days/week totalling ≥ 75 min·week^{-1} or
- A combination of moderate and vigorous intensity exercise to achieve a total energy expenditure of ≥ 500-1000 MET-min·week^{-1}

To define the different intensities of exercise, this study used the cut-off criteria mentioned previously in Table 2.1.

Since ACSM RPE measurements for exercise guidelines range on a category scale from 6-20, this study utilised a category-ratio scale from 0-10. The 6-20 RPE scale was transformed to 0-10 using the conversion table shown below:

Table 3.1 – RPE conversion table

Conversion table from 9-20 RPE scale to 0-10 scale. Table adapted from 2009 Exercise and Sport Science Australia Position Statement (Norton, Norton & Sadgrove, 2009).

Intensity	Category Scale	Category-Ratio Scale
Very Light/Sedentary	RPE < 9	< 1
Light	RPE 9 - 11	1 - 2
Moderate	RPE 12 - 13	3 - 4
Vigorous	RPE 14 - 17	5 - 6
Near-Maximal to Maximal	RPE ≥ 18	≥ 7

3.6 STATISTICAL ANALYSES

The data collected during therapy sessions were assessed for the guidelines of physical activity using 5 different variables; absolute HR, HRR, VO_2, RPE and MET-min. Descriptive statistics were used to quantify weekly durations of exercise for either "moderate" or "vigorous" intensities. A cut-off durations single-sample t-test was employed to test the mean duration of "moderate" or "vigorous" physical activity against the ACSM duration of 150 min·week^{-1} for "moderate" or 75 min·week^{-1} for "vigorous" physical activity to determine whether or not

participants were meeting these guidelines by attending their weekly therapy sessions.

To determine how many MET-min of physical activity participants were accumulating each week, the MET-min calculations for each activity for each participant were ensemble-summed and then halved since the data had been collected over two weekly periods. Single sample t-testing was used to compare the means of the MET-min calculations against the cut-off guidelines of > 500 MET-min·week^{-1} to determine if participants were undertaking sufficient physical activity to satisfy the ACSM recommendations.

Sub-group analysis of individuals with paraplegia versus tetraplegia, frequency of attendance and age groups was undertaken, and single sample t-testing was completed again to determine whether these variables had an impact on whether or not participants were satisfying the ACSM recommendations.

Mean durations and intensities were obtained for each activity code in order to objectively classify the activity being performed by each participant as part of their regular therapy.

Regression analyses were completed for HR and participant RPE and also HR and observer RPE to determine whether there was a significant relationship between the two. Regression analyses were also completed between mean HR values for each activity code and participant and observer RPE to determine whether there was a significant relationship between the HR of a particular activity code and RPE.

All data were presented as mean ±SD unless otherwise indicated. A confidence interval of 95% ($p<0.05$) was used to determine significance in all statistical testing and an exact p value is given for each statistic. Statistical analyses were performed using IBM-SPSS (version 21).

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

CHAPTER 4

RESULTS

4.1 DEMOGRAPHIC DATA

A total of 23 participants agreed to take part in this study and were subsequently assessed against eligibility criteria. All participants had a SCI and were enrolled as clients in Spinal Cord Injuries Australia's Walk On Program and as a result, had a physician's clearance to take part in moderate-to-intense exercise. Two participants' data were excluded as they were unable to complete the arm crank test. One participant had an elbow injury and the other was a high-level, low-functioning participant with tetraplegia.

Of the 21 participants whose data were used in the study, 16 were male and five were female. Their average age was 33.4 ± 13.4 years, average body mass was 76.7 ± 14.5 kg, average stature was 176.0 ± 6.2 cm, average BMI was 24.7 ± 4.4 $kg \cdot m^{-2}$ and average time enrolled in the WO program was 11.4 ± 8.9 months. The frequency of participants' attendance to the WO program ranged from once per week, to five times per week with the mean attendance being 2.4 times per week. Mean therapy time for each session was 112.48 ± 8.94 min. This led to a total mean duration of therapy per week of 257 ± 110 min. Fourteen subjects were tested at the Sydney WO site at the University of Sydney and 7 subjects were tested at the Melbourne WO site at Whitten Oval.

Participants had lesions ranging from C4 to L1 with 16 participants being individuals with tetraplegia and five being individuals with paraplegia. Five participants had complete injuries (American Spinal Injury Association Impairment Scale – AIS A) and 16 had incomplete injuries (AIS B-D).

4.2 EXERCISE AND AEROBIC FITNESS PERFORMANCE

4.2.1 Power Output

Participants' peak power output on the arm crank ergometer test ranged from 15 W to 65 W with the mean for all individuals being 38.8 ± 16.0 W, individuals with tetraplegia being 35.9 ± 14.5 W and individuals with paraplegia being 48.0 ± 18.9 W.

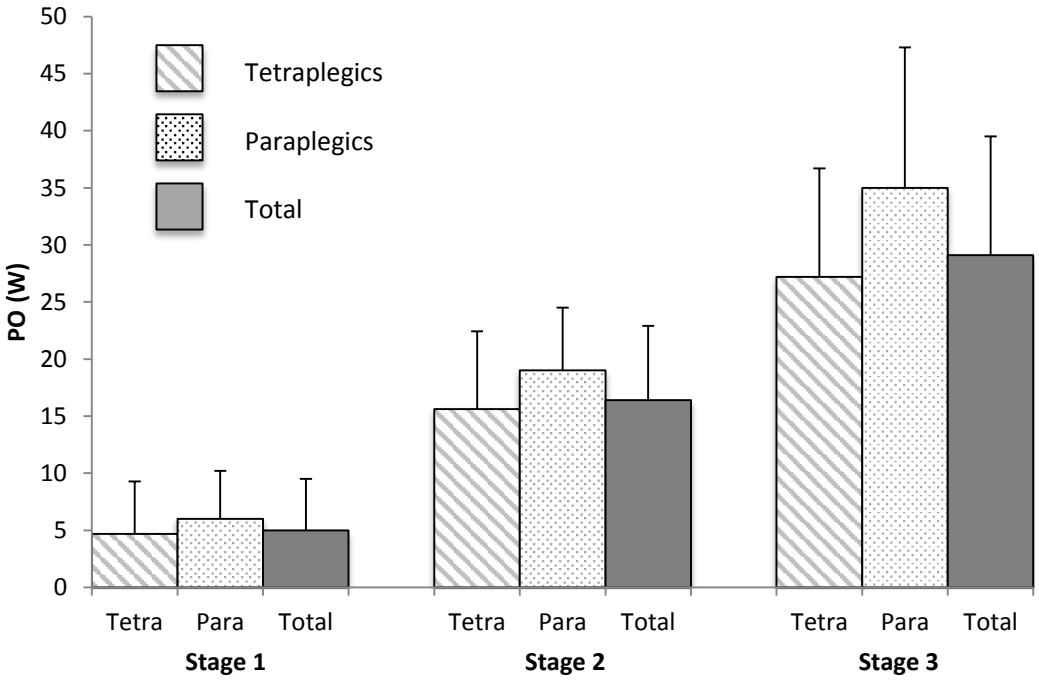

Figure 4.1. Power output during arm crank testing

Power output (W) during each stage of the arm crank test between individuals with paraplegia, tetraplegia and all participants together.

4.2.2 Heart Rate

Pre-exercise HR was 62.8 ± 9.2 b·min^{-1} and 88.6 ± 11.1 b·min^{-1} for individuals with tetraplegia and paraplegia, respectively. Mean peak HR for individuals with tetraplegia was 115.4 ± 24.4 b·min^{-1} and was 168.4 ± 20.1 b·min^{-1} for individuals with paraplegia.

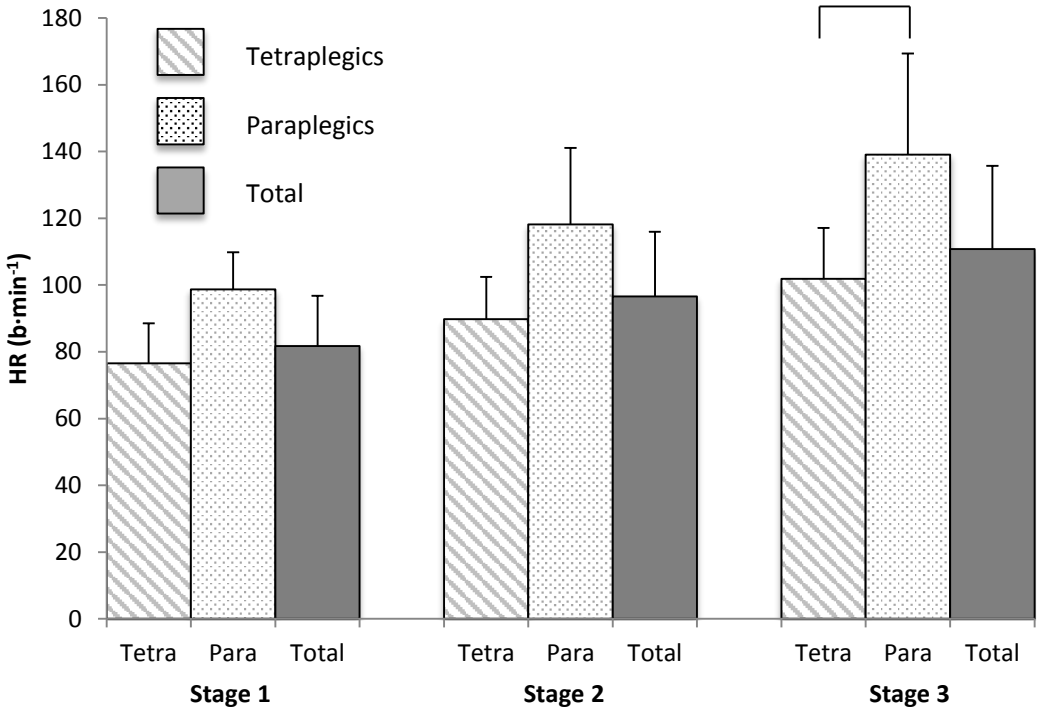

Figure 4.2. Heart rate during arm crank testing

Heart rate (b·min^{-1}) during each stage of the arm crank test between individuals with paraplegia, tetraplegia and all participants together. A bracket above two columns indicates a significant difference between the two values.

4.2.3 Oxygen Uptake

Mean resting VO_2 was 238.0 ± 57.6 mL·min^{-1} (3.1 ± 0.8 ml·kg^{-1}·min^{-1}) and 251.3 ± 44.2 mL·min^{-1} (3.3 ± 0.6 ml·kg^{-1}·min^{-1}) for individuals with tetraplegia and paraplegia, respectively. Mean peak VO_2 for individuals with tetraplegia was 947.8 ± 264.2 mL·min^{-1} (12.4 ± 3.5 ml·kg^{-1}·min^{-1}) and 1279.4 ± 358.2 mL·min^{-1} (16.6 ± 4.7 ml·kg^{-1}·min^{-1}) for individuals with paraplegia.

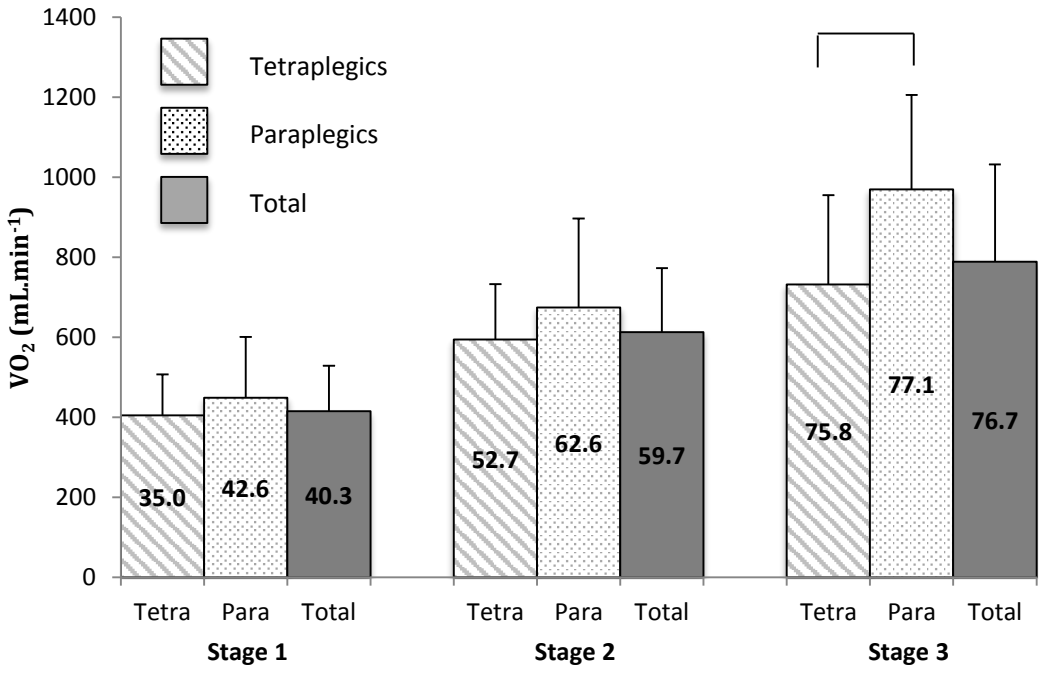

Figure 4.3. Oxygen consumption during arm crank testing

Oxygen consumption (mL·min^{-1}) during each stage of the arm crank test between individuals with paraplegia, tetraplegia and all participants together. The numbers in each column represent the percentage of VO_2peak. A bracket above two columns indicates a significant difference between the two values.

Table 4.1 and 4.2 below show the mean peak and resting values obtained during arm crank testing for all participants together.

Table 4.1 – Resting values prior to arm crank testing

Mean resting values obtained prior to arm crank testing for all participants together including resting HR and resting VO_2 (absolute and relative).

Resting Data		
HR ($b \cdot min^{-1}$)	VO_2 ($mL \cdot min^{-1}$)	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)
69.0 ± 14.6	241.2 ± 54.0	3.1 ± 0.7

Table 4.2 – Peak values during arm crank testing

Mean peak exercise values obtained from arm crank testing for all participants together including peak PO, peak HR, and peak VO_2 (absolute and relative).

Peak Data			
PO (W)	HR ($b \cdot min^{-1}$)	VO_2 ($mL \cdot min^{-1}$)	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)
38.8 ± 16.04	128.0 ± 32.6	1026.8 ± 314.6	13.4 ± 4.1

All but three individualised HR-VO_2 regression slopes were significant ($p < 0.05$). The non-significant regressions were $p = 0.07$ ($r = 0.93$), $p = 0.18$ ($r = 0.82$) and $p = 0.08$ ($r = 0.92$). All other regression slopes were between $r = .95$ and $r = 1.0$ ($p < 0.05$).

4.3 ACTIVITY-BASED THERAPY

4.3.1 Activity Code

Table 4.3 shows the mean intensity and duration of each activity that was included as part of participants' ABRT programs:

Table 4.3 – Activity code descriptors

Mean duration (min), HR (b·min^{-1}), percentage of heart rate reserve, rating of perceived exertion and metabolic equivalent for each activity code included in participant therapy.

Activity Code	Injury Classification	Duration (min)	HR (b.min^{-1})	%HRR	RPE	METs
1	Tetraplegia	16.4 ± 4.7	70.1 ± 3.0	32.6 ± 3.4	0 ± 0	1.2 ± 0.2
	Paraplegia	0	-	-	-	-
	Total	12.5 ± 3.9	70.1 ± 3.0	32.6 ± 3.4	0 ± 0	1.2 ± 0.2
2	Tetraplegia	19.7 ± 5.5	75.3 ± 2.9	47.7 ± 3.5	4.5 ± 0.2	1.9 ± 0.2
	Paraplegia	17.2 ± 9.7	106.2 ± 11.4	37.4 ± 7.7	3.3 ± 1.0	2.4 ± 0.3
	Total	19.1 ± 4.7	83.1 ± 5.2	45.1 ± 3.4	4.2 ± 0.3	2.0 ± 0.2

3	Tetraplegia	20.5 ± 2.5	87 ± 5.0	42.8 ± 11.4	6 ± 1.0	1.6 ± 0.1
	Paraplegia	9 ± 0	89 ± 0	29 ± 0	4 ± 0	1.5 ± 0
	Total	16.7 ± 4.1	87.7 ± 3.0	35.2 ± 10.0	5.3 ± 0.9	1.6 ± 0.1
4	Tetraplegia	46.5 ± 5.2	69 ± 3.3	32.7 ± 3.4	3.5 ± 0.4	1.4 ± 0.2
	Paraplegia	44 ± 6.0	106 ± 6.9	35.2 ± 6.2	4 ± 1.1	2 ± 0.2
	Total	45.8 ± 4.1	79.3 ± 5.0	33.4 ± 2.9	3.7 ± 0.4	1.6 ± 0.2
5	Tetraplegia	30 ± 11.0	88.3 ± 25.3	32.1 ± 1.2	3.6 ± 0.6	2.2 ± 1.0
	Paraplegia	25.4 ± 2.7	111.6 ± 7.7	40.5 ± 5.8	4.3 ± 0.7	2.3 ± 0.1
	Total	26.7 ± 3.2	105 ± 8.8	38.1 ± 4.3	4.1 ± 0.5	2.3 ± 0.2

6	Tetraplegia	38.4 ± 7.2	88.4 ± 4.0	54.3 ± 3.3	5.6 ± 0.6	2.3 ± 0.2
	Paraplegia	12 ± 1.0	102 ± 6.0	37.4 ± 0.7	5.5 ± 0.5	2.7 ± 0.1
	Total	32.6 ± 6.7	91.4 ± 3.8	50.5 ± 3.5	5.5 ± 0.4	2.4 ± 0.2
7	Tetraplegia	23.5 ± 2.9	83.3 ± 7.2	56.8 ± 9.2	5.5 ± 0.7	1.8 ± 0.4
	Paraplegia	0 ± 0	-	-	-	-
	Total	23.5 ± 2.9	83.3 ± 7.2	56.8 ± 9.2	5.5 ± 0.7	1.8 ± 0.4
8	Tetraplegia	25.7 ± 4.9	85.8 ± 13.9	42 ± 9.7	5.5 ± 0.8	2.1 ± 0.7
	Paraplegia	30.5 ± 5.5	120 ± 19.5	43.3 ± 21.3	4.8 ± 0.3	2.2 ± 0.5
	Total	27.6 ± 3.4	99.5 ± 12.9	42.6 ± 8.6	5.2 ± 0.5	2.1 ± 0.4

9	Tetraplegia	39 ± 15.0	87.7 ± 16.0	48.6 ± 4.0	5.5 ± 0.8	2.8 ± 0.5
	Paraplegia	18 ± 2.0	116 ± 8.0	41.6 ± 3.5	6.7 ± 1.7	2.9 ± 0.1
	Total	28.5 ± 8.7	101.8 ± 10.9	45.1 ± 3.0	6.1 ± 0.8	2.9 ± 0.2

4.3.2 Therapy Intensity vs ACSM Guidelines

The following figures show the percentage of total therapy time participants spent in the different intensity bands used to characterise the ACSM guidelines. These have been defined below using four contrasting intensity measures – percentage of heart rate peak (%HRPeak), percentage of heart rate reserve (%HRR), percentage of oxygen uptake reserve (%VO_2R) and rating of perceived exertion (RPE).

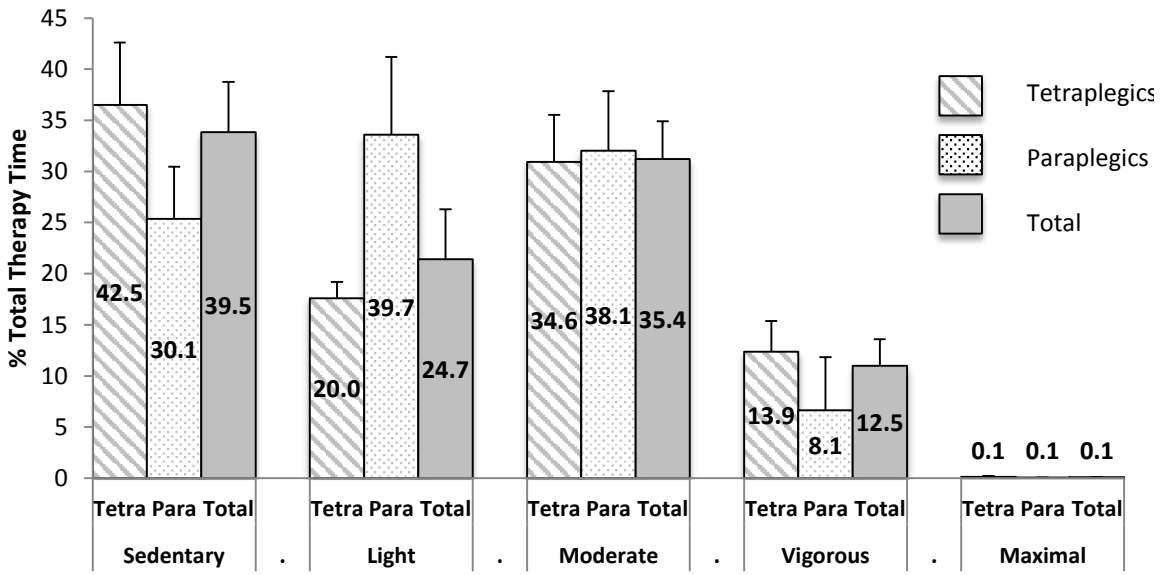

Figure 4.4. Percentage of total therapy time that individuals with paraplegia, tetraplegia and all participants together spent in the intensity bands classified by %HRpeak. Also shown are duration (min) in each band.

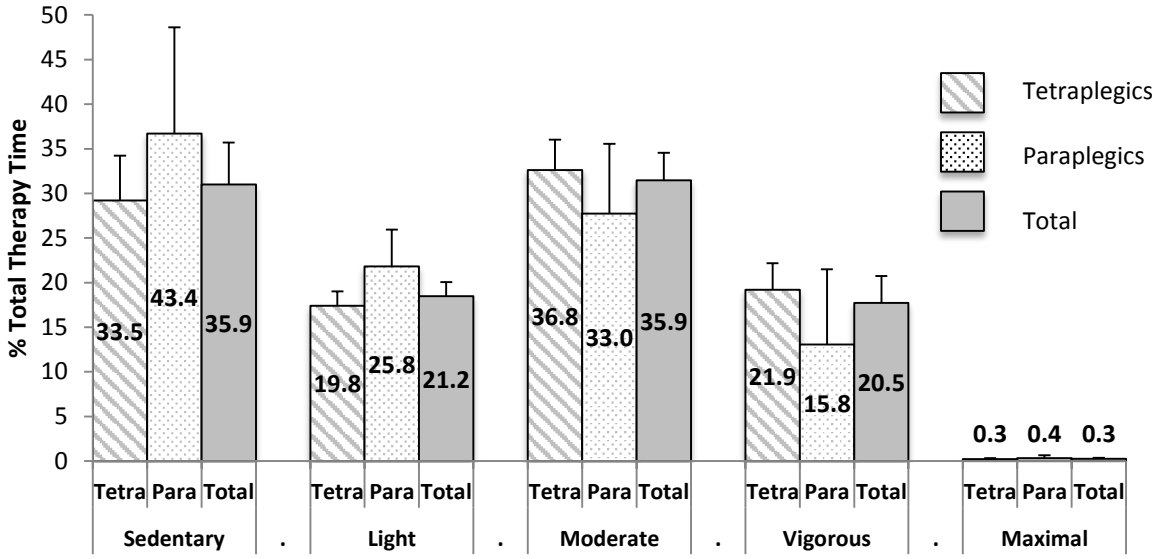

Figure 4.5. Percentage of total therapy time that individuals with paraplegia, tetraplegia and all participants together spent in the intensity bands classified by %HRR. Also shown are duration (min) in each band.

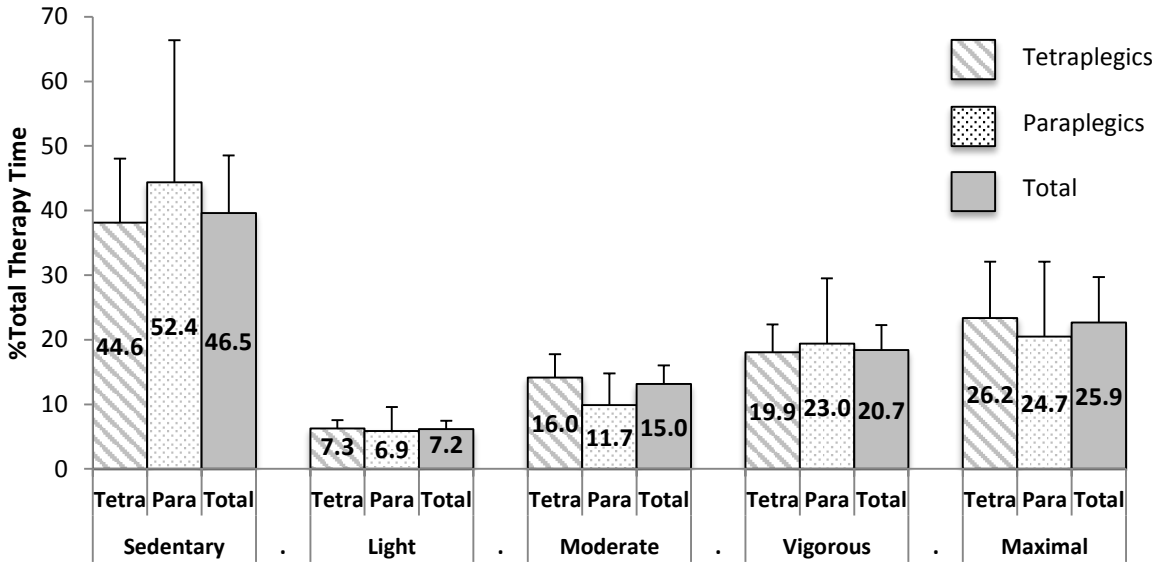

Figure 4.6. Percentage of total therapy time that individuals with paraplegia, tetraplegia and all participants together spent in the intensity bands classified by %VO2R. Also shown are duration (min) in each band.

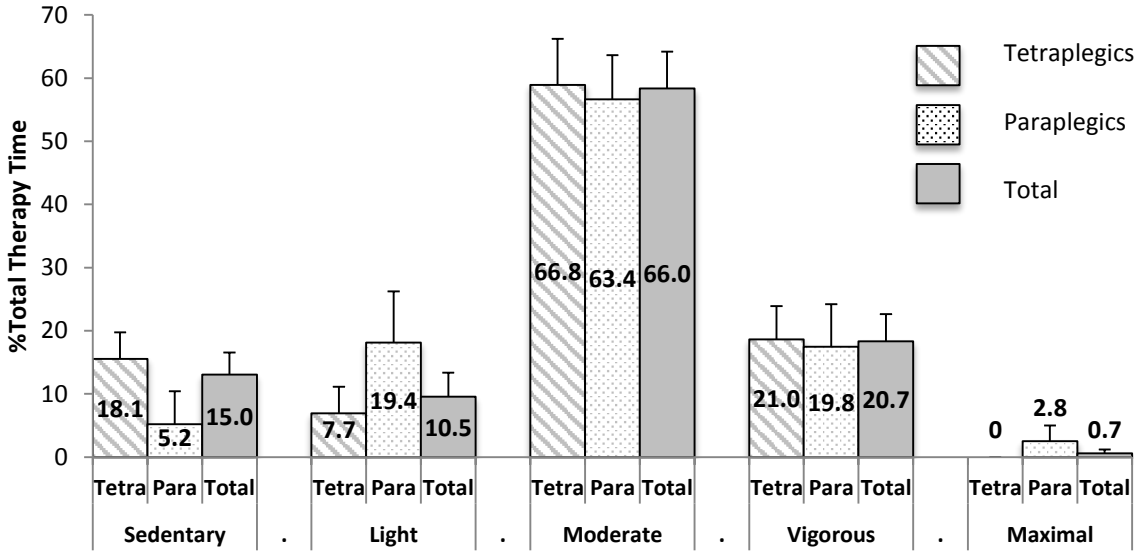

Figure 4.7. Percentage of total therapy time that individuals with paraplegia, tetraplegia and all participants together spent in the intensity bands classified by self-reported rating of perceived exertion (RPE). Also shown are duration (min) in each band.

Table 4.4 demonstrates the weekly mean durations of "moderate" and "vigorous" exercise for each of the four intensity measures and their significance.

Table 4.4 – Mean, weekly accumulated activity durations for each intensity measure.

Participants were required to accumulate over 150 min·week^{-1} of "moderate" intensity activity or over 75 min·week^{-1} of "vigorous" intensity activity to meet ACSM guidelines for health. The significance of results was when mean values were tested against these guidelines.

Intensity Measure	Moderate intensity duration (min)	Significance	Vigorous intensity duration	Significance
%HRpeak	100.1 ± 58.8	0.00	24.2 ± 21.7	0.00
%HRR	115.5 ± 66.2	0.03	37.7 ± 28.0	0.00
%VO_2R	146.9 ± 114.8	0.90	105.7 ± 95.6	0.16
RPE	200.4 ± 102.5	0.04	68.3 ± 64.1	0.64

Table 4.5 shows the total number of participants (N=21) who achieved a sufficient volume of exercise to meet the ACSM guidelines for health using each of the four different measures of intensity.

Table 4.5 – Total number of participants who met ACSM guidelines (N=21)

'Yes' indicates the number of participants who performed sufficient exercise to satisfy the ACSM guidelines for health whereas 'No' indicates the number of participants who did not.

	%HRPeak		%HRR		$\%VO_2R$		RPE	
	Yes	No	Yes	No	Yes	No	Yes	No
Moderate	5	16	7	14	10	11	12	9
Vigorous	0	21	2	19	12	9	6	15

Table 4.6 shows the number of participants who attended ABRT two or more times per week (N=16) who achieved a sufficient volume of exercise to meet the ACSM guidelines for health using each of the four different measures of intensity.

Table 4.6 – Total number of participants who met ACSM guidelines (N=16)

'Yes' indicates the number of participants who performed sufficient exercise to meet the ACSM guidelines for health whereas 'No' indicates the number of participants who did not.

	%HRpeak		%HRR		$\%VO_2R$		RPE	
	Yes	No	Yes	No	Yes	No	Yes	No
Moderate	5	11	7	9	10	6	12	4
Vigorous	0	16	2	14	11	5	6	10

Table 4.7 shows the number of participants who attended ABRT three or more times per week (N=9) who achieved a sufficient volume of exercise to meet the ACSM guidelines for health using each of the four different measures of intensity.

Table 4.7 – Total number of participants who met ACSM guidelines (N=9)

'Yes' indicates the number of participants who performed sufficient exercise to satisfy the ACSM guidelines for health whereas 'No' indicates the number of participants who did not.

	%Absolute HR		**%HRR**		**VO_2R**		**RPE**	
	Yes	No	Yes	No	Yes	No	Yes	No
Moderate	4	5	5	4	7	2	8	1
Vigorous	0	9	2	7	7	2	4	5

When using participant resting VO_2 to define 1 MET, 12 of the 21 participants undertook a sufficient volume of PA within ABRT to achieve > 500 MET-min per week however the mean of all participants was lower than that criterion (482 ± 247 MET-min·week^{-1}, p = 0.759). In contrast, eight of the 21 participants achieved > 500 MET-min (mean: 442 ± 255) per week of PA when using 1 MET = 3.5 ml·kg^{-1}·min^{-1}. This result was not statistically significant (p = 0.32). When the data from participants who were attending therapy three or more times per week were analysed separately, using 1 MET as participant resting VO_2, the mean volume of exercise was significantly higher than the 500 MET-min·week^{-1} cut-point (686.3 MET-min·week^{-1}, p = 0.02).

There was one significant result that met ACSM physical activity guidelines when participants were divided into individuals with paraplegia and tetraplegia and

analysed separately. Mean "moderate" intensity duration for individuals with tetraplegia when using self-reported RPE as an intensity guideline was 260.6 ± 90.4 min ($p = 0.00$). All other results were not significant.

A one-way ANOVA was completed between intensity variable and participants' age in months. There was no significant correlation between any of the intensity variables and age so this was not investigated further.

4.3.3 Relationship between RPE and HR

There was a very weak relationship between HR and participant RPE ($r = 0.28$, $p = 0.00$, $R^2 = 0.08$, $p = 0.00$) when analysing all RPE values over all activity codes together. Figure 4.8 shows a scatter plot of every recorded RPE value and its corresponding HR.

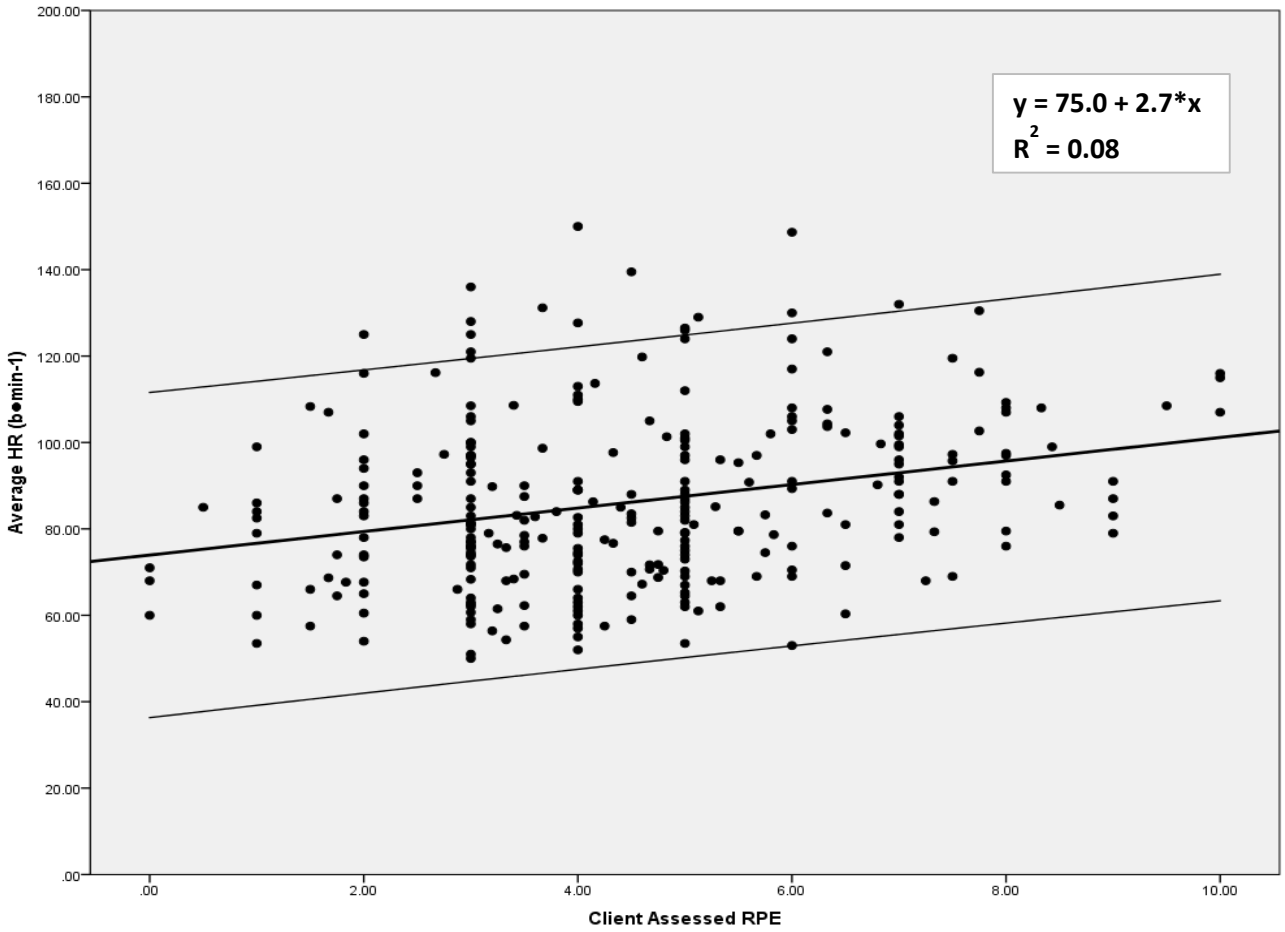

Figure 4.8. HR versus RPE for each activity

Distribution of client-reported RPE against HR ($b \cdot min^{-1}$). The bold line indicates the line of best fit and the two black lines indicate a 95% confidence interval.

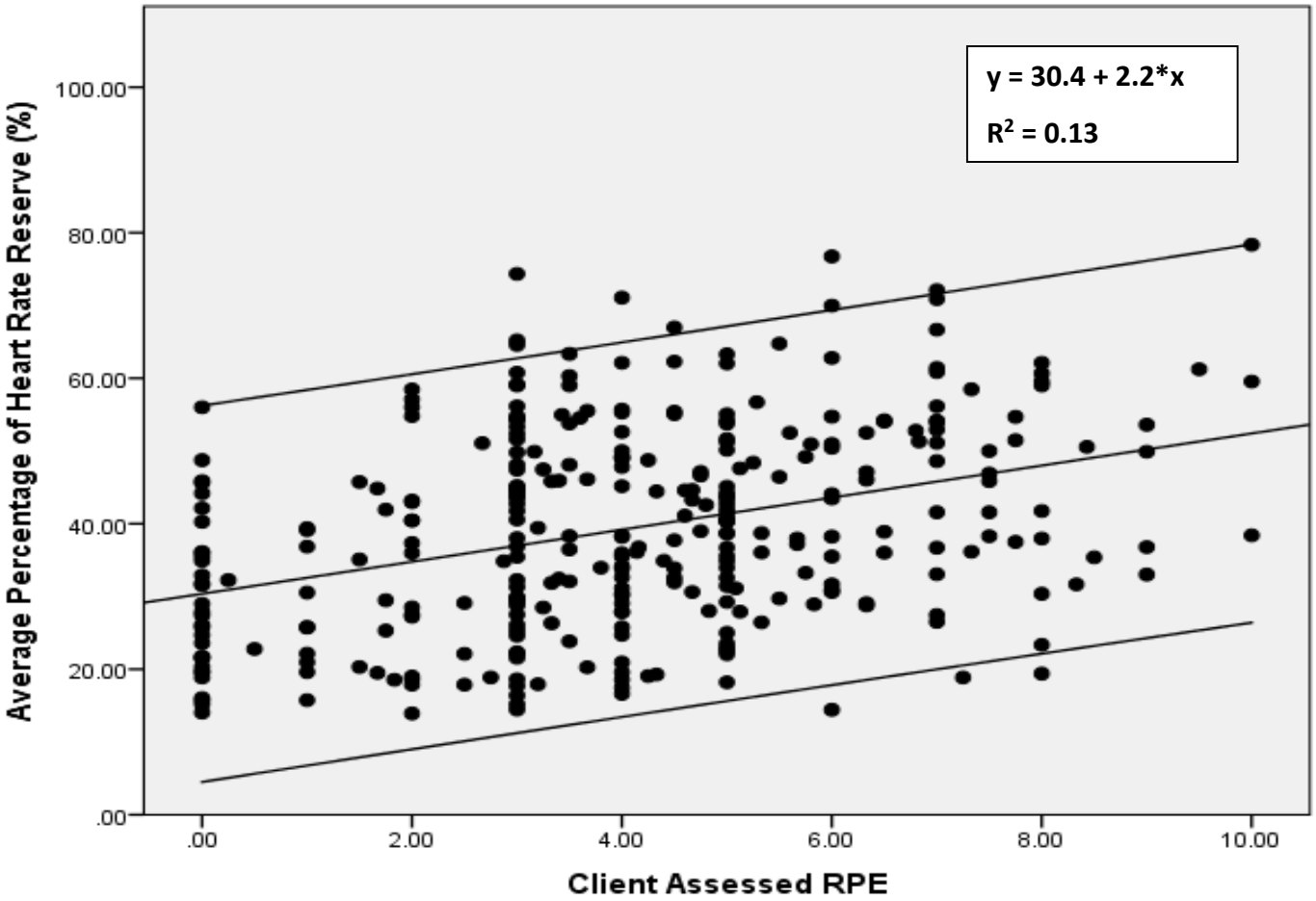

Figure 4.9. Percentage of HRR versus RPE for each activity

Distribution of client-reported RPE against percentage of HRR. The bold line indicates the line of best fit and the two black lines indicate a 95% confidence interval.

There was no relationship between HR and RPE or %HRR and RPE during activity in any of the different activity codes. There was also no relationship between HR and RPE when grouped for each separate activity code. Table 4.8 shows the linear regression values between participants' HR and RPE grouped for by activity code.

Table 4.8 – Linear regression values between heart rate and RPE

Linear regression values for the relationship between heart rate and rating of perceived exertion for each individual activity code.

Activity Code	Line slope (B1)	Significance	Regression (r)	Significance
2	85.1	0.00	0.03	0.81
3	72.1	0.00	0.49	0.09
4	67.8	0.00	0.26	0.02
5	92.9	0.00	0.01	0.59
6	83.8	0.00	0.11	0.51
7	77.0	0.00	0.14	0.62
8	93.6	0.00	0.00	1.0
9	70.2	0.00	0.43	0.06

**Note: Activity code 1 was not included as this was mainly when participants were setting up for other activities.*

The relationships between client-reported HR and RPE were still weak when individuals with tetraplegia and paraplegia were analysed separately ($r = 0.45$, $p < 0.01$ and $r = 0.30$, $p < 0.01$, respectively). There was also a weak relationship between participant HR and observer RPE ($r = 0.35$, $p < 0.01$).

4.4 SUMMARY OF FINDINGS

The following are the key findings from this study:

- For most participants and for most ACSM criteria used to classify "sufficient" intensity and duration of weekly, physical activity, only client-reported RPE achieved ACSM guidelines. As a group, > 150 min·week^{-1} of moderate intensity activity was achieved using RPE as an intensity measure (200.4 min.week^{-1}, p = 0.04) however this was the only significant result.
- After classifying participants by age or injury level (participants with tetraplegia vs paraplegia), there was found to be no difference when comparing their results for satisfying the ACSM physical activity guidelines.
- All activity codes as part of ABRT were classified by mean duration and intensity (HR, %HRR, METs and RPE).
- There was found to be only a weak relationship between HR and RPE measured during participant therapy when analysed using client-reported RPE, observer-reported RPE, RPE during each activity code and when looking at data obtained from individuals with tetraplegia and paraplegia separately.

CHAPTER 5

DISCUSSION

The aim of this thesis was to determine whether an activity-based therapy (ABRT) program for people with SCI, designed with the intention of promoting neurological improvements and enhancing functional outcomes, was of sufficient intensity and duration to meet current ACSM physical activity guidelines for improving cardiorespiratory fitness and general health. Depending on the ACSM criterion that was evaluated (%HRpeak, %HRR, %VO_2R, RPE and MET-min), between five and 12 participants in the current study were engaged in a sufficient volume (intensity, duration and frequency) of exercise to meet the ACSM physical activity guidelines. There were four criteria of exercise intensity whereby participant physical activity was significantly below the recommended guidelines (*moderate* and *vigorous* absolute %HRmax and *moderate* and *vigorous* HRR), one intensity measure that significantly exceeded the ACSM criterion (*moderate* RPE) and three intensity measures for which no definitive conclusion could be drawn (*moderate* and *vigorous* VO_2R and *vigorous* RPE). Twelve of the 21 participants achieved > 500 MET-min of activity over the two, one-week periods that were measured (group mean: 482 ± 247 MET-min per week). This result was not statistically different to 500 MET-min·week^{-1} ($p = 0.76$) which would indicate that participants met, but did not exceed the volume of exercise required to meet ACSM guidelines.

There was also poor association between HR and participant RPE ($R^2 = 0.08$, $p < 0.01$) or observer RPE ($R^2 = 0.12$, $p < 0.01$). This was consistent across each individual exercise classified with a pre-determined activity code. This raises doubts whether this criterion could be used to determine whether ACSM guidelines could be met in this group.

5.1 AEROBIC FITNESS AFER SCI

In this population, VO_2peak of the tetraplegic group (947.8 ± 264.2 ml·min^{-1}) was classified as "Average" when compared with physical activity norms in a Dutch population with SCI, while that of the paraplegic group (1279.4 ± 358.3 ml·min^{-1}) was rated as "poor" (Janssen et al., 2002). Compared to the reference norms of an American population of SCI (Simmons, Kressler, & Nash, 2014), the tetraplegic group was "Good", while the paraplegic group was classified as "Average". To the author's knowledge, our study is the first to measure cardiorespiratory fitness in individuals who were engaged in regular ABRT. A number of previous investigations have quantified the physiological responses during different modes of ABRT, including locomotor training (Harness & Astorino, 2011; Jack, Purcell, Allan, & Hunt, 2010) and FES (Davis et al., 2008), but none have described cardiorespiratory fitness in regular ABRT attendees. This is probably due to ABRT not being considered as a possible exercise modality that might improve cardiorespiratory fitness in people with SCI.

Since mean participant time enrolled in the ABRT program was 11.4 ± 2.0 months, and given their lower fitness values when compared to two normative populations of people with SCI (Janssen et al., 2002; Simmons et al., 2014), it might be speculated that regular ABRT participation did not result in improved fitness levels relative to the other forms of the SCI population's regular physical activity. This may suggest that the intensity of activity performed during ABRT was not high enough to elicit cardiorespiratory improvements in people with SCI,

even though the weekly duration exceeded 4 hours (group mean: 257 ± 100 min·week^{-1}).

However, a study by Hopman et al. (1996) which investigated cardiorespiratiory responses to wheelchair rugby training in individuals with tetraplegia, observed that 6 months of regular training did not significantly improve VO_2peak of most participants. Training frequency in this Dutch study ranged from 60 min to 135 min·week^{-1} and the study authors hypothesized that these variable durations across participants may have been the reason for their lack of improvement of VO_2peak. Both the study by Hopman et al. (1996) and the current investigation utilised arm crank ergometry to measure VO_2peak, and it may be that training specificity has a significant impact on VO_2peak testing in people with SCI, as participants in neither study trained regularly using arm cranking,

Previous studies have found improvements in cardiorespiratory fitness of people with SCI as a direct result of upper-body exercise training (Brurok et al., 2011; Jacobs, 2009). For example, following arm cranking at 70-85% of HRpeak, three times per week over 12 weeks, Jacobs (2009) observed an 11.8% increase in VO_2 (1.27 to 1.42 L·min^{-1}) in participants with paraplegia. The initial VO_2peak values in the Jacobs study were similar to those measured from arm crank testing in the current investigation. However, for a variety of reasons, VO_2peak values were not measured again after therapy in this study. These reasons included difficulty controlling all factors during the intervention, having a large range of injuries and fitness levels between participants, participants not wanting to interrupt their regular therapy due to cost and time constraints and also the aim of this study was not to conduct a training intervention. Therefore, no definitive conclusions

can be drawn about whether participants of the current ABRT program realised any improvements in their cardiorespiratory fitness.

When comparing POmax values of individuals with tetraplegia (35.9 ± 14.5 W) and paraplegia (48.0 ± 18.9 W) in the Dutch study with norms for people with SCI, the current participants were rated as "good" and "poor" respectively (Janssen et al., 2002). Compared with norm findings in the American study (Simmons et al., 2014), the POmax of participants with tetraplegia in the current study was rated as "Excellent" and "Fair" for participants with paraplegia. It is interesting to note that there was a large discrepancy between the peak power outputs between individuals with tetraplegia and paraplegia. This might suggest that individuals with tetraplegia who undertook ABRT may have developed significantly more anaerobic power relative to all people with SCI than those with paraplegia; however, it was unusual that this was not evident across both injury levels. This might suggest that ABRT is more beneficial as a means of training for cardiorespiratory fitness in individuals with tetraplegia than those with paraplegia.

5.2 EXERCISE INTENSITY MEASUREMENT IN SCI

Different intensity criteria were used in this study to compare the volume of physical activity that participants performed as part of their regular ABRT with the ACSM guidelines for physical activity. Findings in this study, as to whether the 21 participants met ACSM guidelines and the differences in time spent at different intensities depending on which intensity parameter was measured, suggested

that some of these criteria were either less reliable or less quantifiable than others. Alternatively, it may be that the different, supposedly equivalent criteria actually measured quite different aspects of exercise intensity. These contrasting results raise the question of which criteria might be more valid measures of exercise intensity in a population of individuals with SCI.

Indirect calorimetry (measurement of VO_2) has been reported to be an accurate measure of exercise intensity in people with SCI (Sykes, Campbell, Powell, Ross, & Edwards, 1996). In the current study, VO_2 during ABRT was estimated from steady state heart rates, and this estimation may have been less accurate than direct measurement of VO_2 using a portable metabolic system. Unfortunately, it would have been a major inconvenience to participants to ask them to wear a portable gas analysis system during ABRT, as this would likely have altered their ability to perform the ABRT exercises correctly for the neurological benefit it was purported to have. Additionally, such impact might have led to results not being a true indication of the exercise intensity of their usual therapy sessions. Therefore, this study sought to estimate VO_2 using "individually calibrated"[1] HR-VO_2 regression equations for each participant. This method of intensity quantification has previously been shown to accurately estimate the energy demands of a range of different activities for people with paraplegia (Hayes et al., 2005; Lee et al., 2010). Therefore it was assumed that comparisons with PA

[1] Individually calibrated HR-VO_2 regression equations were calculated using VO_2 and HR data obtained at different submaximal steady-state workloads during each participant's arm-crank testing. A linear regression was statistically fitted through these points, and the equation of this linear regression was used to estimate VO_2 from HR data obtained during ABRT.

guidelines using estimated VO_2R might be more accurate than RPE which was supported by the measured relationship between HR and RPE discussed later in this chapter.

There is a strong linear relationship between HR and VO_2 above 2-2.5 METs in able-bodied people (Strath et al., 2000) suggesting that HR is an accurate predictor of exercise intensity in people without SCI. However, absolute HR has been shown to be a much less accurate estimate of exercise intensity in people with SCI than in able-bodied people (Hayes et al. 2005), in particular at lower intensities due to the "foot" region of the HR-VO_2 relationship (Lee et al., 2010). This accuracy is reduced further for those with tetraplegia, due to the loss of supraspinal control over the sympathetic nervous system in people with injuries above T6 (Grigorean et al., 2009). As the majority of physical activity performed during ABRT is of a lower intensity, it was crucial to improve the accuracy of intensity measurement at the lower end of the physical activity spectrum. One method that has been used in the past to address this is the "flex-HR" method (Leonard, 2003) which involves establishing where the "flex point" is (the point on the HR-VO_2 relationship graph where there is an increased gradient) and using resting VO_2 for any HR values below this point. This method has been shown to improve accuracy by 2-3%, however determining the flex point is subjective and may affect the error rate (Spurr et al., 1988; Wareham, Hennings, Prentice, & Day, 1997) and as a result was not utilised in this study. Determining individually calibrated HR-VO_2 relationships was shown to provide significantly more accurate results in people with SCI (Lee et al., 2010) which was the method used to calculate VO_2 from HR data in this study.

Due to the restricted heart rates in people with SCI (Krassioukov & Claydon, 2006), it would have been difficult for participants to meet the PA guidelines using absolute HR as a criterion measure. This viewpoint was supported by the current findings, whereby, mean durations of PA for both *moderate* and *vigorous* intensity 'cut-points' were substantially lower in terms of absolute HR, than with other measures of intensity (Table 4.4). As people with high-level SCI have further blunted HR responses to exercise compared with people with lower level SCI (Coutts et al., 1983), it would be expected that individuals with paraplegia would spend a longer duration at higher absolute HR intensities than those with tetraplegia. Interestingly, this assumption was not supported in the current study, as participants with tetraplegia had a longer duration at *moderate* and *vigorous* intensities than their counterparts with paraplegia (122.7 ± 63.3 min vs 101.9 ± 18.4 min and 31.2 ± 24.8 min vs 21.7 ± 13.1 min respectively). This could be due to both groups working at a similar absolute intensity but participants with tetraplegia working at a higher relative intensity due to their blunted HR response to exercise or it could also be that participants with tetraplegia in the study were more motivated and pushed themselves harder during therapy resulting in a higher HR.

HRR and VO_2R are both relative measures of exercise intensity that take into account the lower peak HR and VO_2 of people with SCI. Measures with individual calibration have been shown to be much more accurate estimates of exercise intensity in this population (Hayes et al., 2005; Lee et al., 2010), therefore it was expected that these criteria would provide the most reliable data when comparing participant exercise during ABRT with ACSM guidelines. This also may

be the reason that these intensity measures provided results with slightly higher total times in higher intensity criteria (figures 4.5 & 4.6) than absolute HR (figure 4.4). Although both *moderate* and *vigorous* intensity criteria for HRR were still significantly below cut-points for meeting ACSM guidelines, both *moderate* and *vigorous* intensity criteria for VO_2R were not found to be significantly different to the durations required to meet ACSM guidelines. This suggests that *moderate* and *vigorous* intensity criteria for VO_2R may have met the required volume of physical activity to satisfy ACSM guidelines however duration of *moderate* or greater exertion was insufficient to exceed the recommendations. The findings for VO_2R were inconclusive however the findings for HRR further support the general notion that ABRT might not provide most people with SCI with a sufficient dose of exercise to meet current ACSM physical activity guidelines.

In this study, a weak relationship was observed between HR and RPE across all activity classifications ($r = 0.28$, $p < 0.01$), and in both individuals with tetraplegia ($r = 0.45$, $p < 0.01$) and paraplegia ($r = 0.30$, $p < 0.01$), with HR increasing by only a small amount for each incremental increase of RPE. A weak relationship was also observed between %HRR and RPE across all activity classifications ($r = 0.36$, $p < 0.01$). These results were similar to findings in several other studies of people with SCI. In particular, Lewis et al. (2007) and Jacobs et al. (1997) noted RPE was an inaccurate measure of exercise intensity in people with SCI when compared with a number of different physiologic indicators (HR, VO_2 and minute ventilation – V_E). In contrast, a study by Goosey-Tolfrey et al. (2010) found RPE to be a reliable method of controlling moderate and vigorous exercise intensities during handcycling exercise in people with SCI. It is important to note though that the

participants in the Goosey-Tolfrey study all reached the HRpeak of their age-predicted maximum, including the participants with higher lesion level injuries, and that the mean VO_2peak of participants was 2.62 $L \cdot min^{-1}$, indicating that they were well-conditioned. The study indicated that using RPE as a measure of intensity in SCI had "encouraging potential" however that its "conclusions must be interpreted with caution". These results taken together with the results of the current study suggest that other measures of intensity (such as VO_2R) are likely to be more valid for the purpose of prescribing exercise intensity in this population until further research has been completed.

Yet, using RPE as a criterion measure of intensity provided the only statistically significant result where participants exceeded the volume of physical activity required to meet ACSM guidelines. This suggests that SCI individuals believe that they are exercising at the upper end of their maximum capacity with little self-perceived ability to exercise at higher intensities during ABRT. If so, this raises the question as to why this relationship does not exist in people with SCI. As observed from previous studies (Jacobs et al., 1997; Lewis, Nash, Hamm, Martins, & Groah, 2007), the weak relationship between RPE and exercise intensity in SCI may have a variety of causes, including their unique circulatory responses to exercise or their reduced trunk and lower extremity stabilisation leading to activities that are simple for able-bodied people, being self-perceived as much more difficult to perform after SCI.

The weak relationship between RPE and exercise intensity in people with SCI also raises a question of what may be classified as "true exercise intensity" in this population. If people with SCI experience only a small increase in physiological

indicators (HR and VO_2) with relatively larger changes in RPE values, are they routinely "over-reporting" RPE values during ABRT? Participants may have over-reported higher RPE values during some exercises due to therapist verbal encouragement. During ABRT, therapists were observed to frequently encourage participants using phrases such as "you're working really hard, keep going" which may have led to participants believing that they were exercising more intensely than if they had not been 'primed' by their therapist's encouragement.

Participants "over-reporting" RPE may also be due to a lack of knowledge of what "maximal effort" entails, or it may be that people reporting an RPE of 10 are exerting themselves as much as physically possible even though there is scant physiological evidence that this is their true peak exertion. Possibly, people with SCI are not even capable of achieving "true" values of maximal exertion due their neurological impairments. It may be that their central neurological drive is at a maximum, but the peripheral component of RPE is blunted due to their lesion, resulting in a very low apparent physiological stress. Whatever the reason for the discrepancy in intensity measurement when using RPE, it is clear further research is needed to determine the relationship between perceived exertion and exercise intensity in people with SCI.

5.3 DID ABRT MEET CURRENT PHYSICAL ACTIVITY GUIDELINES?

The findings of the current study suggest that most participants were unlikely to have performed a sufficient volume of exercise as a result of taking part in regular ABRT to significantly exceed the current ACSM physical activity guidelines for developing and maintaining cardiorespiratory fitness and general health. However, the duration and intensity of exercise performed when investigating some intensity measures was close enough to meeting the guidelines to be of "clinical significance". This study also found there to be no significant difference between the total volume of exercise that participants were performing and the 500 MET-min·week^{-1} criterion for ACSM guidelines indicating that participants met the criterion but did not exceed it.

"Clinical significance" denotes a finding that is not statistically significant, yet is still of practical beneficial impact on a person's daily life. The link between PA and health in able-bodied people is well established (ACSM 2013; Lee, Hsieh & Paffenbarger, 1995) and there is strong evidence to support a "dose-response" relationship between an increased volume of physical activity and a reduction in mortality risk (Lee & Skerrett, 2001; Manini et al., 2006; Oja, 2001). There is also a limited amount of evidence to confirm that this relationship also exists in the SCI population (Jacobs & Nash, 2004). If it were the case, the increased amount of PA that participants performed as a direct result of taking part in ABRT would be of meaningful clinical significance. This volume of physical activity is likely to provide them with significant health benefits over people with SCI who do not

engage in any structured PA, even if participants did not achieve the criteria for sufficient duration and intensity of exercise to meet ACSM guidelines.

Moderate intensity RPE was the only statistically significant outcome where participants performed a sufficient duration and intensity of exercise to meet the ACSM guidelines. Yet this study found there was no significant relationship between HR and RPE, which suggested that physical exertion reported using RPE was less likely to give meaningful interpretation of exercise intensity, due to likely over-reporting of RPE. Mean durations of *moderate* and *vigorous* VO_2R and *vigorous* RPE were not statistically "different" to the cut-point criteria when compared with ACSM guidelines indicating that participants may have met the guidelines but not exceeded them. These results could be considered as clinically significant as it is likely that this amount of exercise would result in some benefit to participants' health even though the duration and intensity of exercise was not sufficient to exceed the ACSM guidelines. Given the lack of statistical significance in these findings though, it is not possible to generalise this result to the SCI population.

A single ACSM criterion that takes into account both intensity and duration within a single variable is the MET-minute. A metabolic equivalent (MET) is defined as the ratio of the energy expenditure during a specific physical activity to a reference resting energy expenditure, usually the basal metabolic rate of 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for able-bodied people (Ainsworth et al., 2000; Jette, Sidney, & Blumchen, 1990). In this study, resting VO_2 of participants was 241.2 ± 54.0 $mL \cdot min^{-1}$ (3.1 ± 0.7 $ml \cdot kg^{-1} \cdot min^{-1}$). This value reflects findings from a number of other studies that observed resting VO_2 to be lower in people with SCI than in

able-bodied populations (Collins et al., 2010; Harness & Astorino, 2011; Tanhoffer, Tanhoffer, Raymond, Hills, & Davis, 2012). Collins et al. (2010) found the value of 1 MET to be 2.7 ml·kg^{-1}·min^{-1} in people with SCI. The study by Harness & Astorino (2011) used each participant's resting VO_2 as a measure of 1 MET during the study however 1 MET was consistently found to be lower than 3.5 ml·kg^{-1}·min^{-1}. As a result, in this study, 1 MET was defined as each participant's resting VO_2 rather than 3.5 ml·kg^{-1}·min^{-1}.

The group mean for MET-min·week^{-1} results for all participants was below the minimum cut-point of 500 MET-min·week^{-1} criterion when calculating METs using measured pre-exercise VO_2 (482 ± 247 MET-min.week^{-1}) and also when using standardised 3.5 ml·kg^{-1}·min^{-1} (442 ± 255 MET-min.week^{-1}). This suggests that the volume of activity that was performed during ABRT was just below the necessary level to satisfy the ACSM physical activity guidelines. However, as these results were compared against cut-point criteria and did not provide significantly "different" results ($p = 0.76$ and $p = 0.32$ respectively), these findings may be of clinical significance, since participants clearly performed a substantial duration of exercise as a direct result of taking part in regular ABRT even if the intensity was not of sufficient vigour to satisfy ACSM physical activity guidelines. It may be possible for participant therapy sessions to be modified to increase their duration and/or intensity. This could be achieved by "re-ordering" exercises to present more vigorous movements in close proximity to each other to raise exercise intensity. If participant mean exercise volume could be increased by roughly 20 MET-min per week, it could suggest ACSM criteria for cardiovascular health were being met.

There are a number of reasons why participants may not have met the guidelines for some of the intensity criteria. The most likely explanation is that participants simply did not perform at a high enough exercise intensity during their regular therapy sessions. The main aim of ABRT is to promote neurological improvement and functional outcomes after SCI – ABRT is not designed to satisfy PA or general health guidelines, nor even to improve an individual's cardiorespiratory fitness. Therefore, a finding that ABRT was able to meet PA guidelines would have been an unexpected benefit additional to the putative functional outcomes.

Another possible explanation for the lack of significant results when comparing participant physical activity to ACSM guidelines could be related to the small sample size. As there were a number of results where the mean durations of exercise were very close to 'cut point' criteria for satisfying PA guidelines, or where mean durations actually did exceed those cut points but not significantly so, it is possible that a larger sample size may have led to more positive findings. If a few more participants joined the study and performed a similar duration and intensity of exercise as those participants who were already enrolled in the study, a number of measured criteria that which had means above cut-points may have led to statistically significant results.

Of note were the higher proportion of participants who met > 500 MET-min·week^{-1} guidelines when analysing a reduced number (N = 9) of participants who attended treatment three times per week or more. This suggested that increased frequency of attendance generally would lead to more participants satisfying the guidelines as a result of therapy. This is discussed further in 5.5 – What factors contributed to ABRT meeting physical activity guidelines?

5.4 PHYSICAL ACTIVITY GUIDELINES FOR THE SCI POPULATION

Designing effective PA guidelines specifically for people with SCI is difficult due to the current lack of evidence about the PA levels that people with SCI can realistically achieve (Martin Ginis et al., 2011). The American College of Sports Medicine suggests that PA guidelines for people with neurological impairments (including SCI) should be the same as those for people without spinal cord injury (ACSM, 2013). Yet, the very sedentary nature of the SCI population (Buchholz et al., 2003) their daily duration of seated (wheelchair) confinement (Yang, Chang, Hsu, & Chang, 2009), and their reduced motor capabilities (Lazar et al., 1989), all impact upon lifestyle, and it seems likely that this population find it very difficult to meet the same guidelines as able-bodied people.

An alternative set of PA guidelines based on a consensus panel deliberations designed specifically for people with SCI was recently published by Martin Ginis et al. (2011). These new recommendations have suggested that people with SCI should engage in "at least 20 minutes of moderate to vigorous intensity aerobic activity two times per week". The authors state that these guidelines should be sufficient to improve cardiorespiratory fitness in people with SCI. However, the authors observed that, as yet, there was insufficient evidence to justify PA recommendations related to reducing disease risk in people with chronic SCI. The report also stated that there was not sufficient evidence to suggest that these guidelines would be sufficient to improve functional performance. Consensus

panel deliberations do not provide the "weight of evidence" inferred from quasi-experimental or RCT findings, so must be interpreted with caution.

Regardless of which intensity measure is used, the findings of this study were that the majority of the 21 participants met the Martin Ginis guidelines (2011) for physical activity. Using results from Figures 4.4 – 4.7, if time spent at *moderate, vigorous* and *maximal* intensities is summed for participants with paraplegia, tetraplegia and all participants together, the total would exceed 40 minutes (20 min, twice weekly) for every intensity measure.

The duration of exercise required to satisfy the Martin Ginis et al. (2011) guidelines is considerably lower than the ACSM PA guidelines. As the Martin Ginis guidelines were developed specifically for people with SCI in a rigorous and widely acknowledged framework (AGREE II instrument) (Brouwers et al., 2010) using only SCI-related evidence, this may suggest that the ACSM guidelines have been set too high and it may be unreasonable to expect them to be achieved by people with SCI.

For the study that is the subject of this thesis, it was decided to compare the exercise levels achieved as part of the ABRT program with ACSM physical activity guidelines rather than these new population-specific recommendations. This was because the SCI-specific guidelines are not as widely recognised, nor as specific with regards to exercise intensity as the ACSM guidelines, and they do not provide a total volume of activity that would be able to satisfy the guidelines as the ACSM ones do.

However, there is obviously a large discrepancy between the two different sets of recommendations – ACSM versus Martin Ginis et al. (2011). Also there is a wide range of physical capacities and motor capabilities for people with SCI, so designing one set of PA guidelines for the entire population, a set that will not be too easy for some and unattainable for others, would be challenging. Clearly, further research is required to determine exactly how much activity is required by this population to improve their health and reduce burden of disease risk. The results of this study will add to this body of evidence and will assist in determining more appropriate guidelines for future research.

5.5 WHAT FACTORS CONTRIBUTED TO ABRT MEETING PHYSICAL ACTIVITY GUIDELINES?

The results of this study indicated that the only demographic data or physical characteristics to have any impact on whether or not participants met the guidelines was the frequency of attendance at ABRT. Those who attended therapy three or more times per week were more likely to have completed a sufficient volume of exercise to satisfy the ACSM physical activity guidelines, compared to those who only attended therapy once or twice per week. Participants who attended therapy three or more times per week showed significant, positive results for satisfying PA guidelines for total volume of physical activity when using measured resting VO_2 as 1 MET (686.3 ± 181 MET-min·week^{-1}, $p = 0.02$), as well as a significantly positive result again for *moderate* RPE (294.1 ± 77.5 min·week^{-1}, $p < 0.01$). These participants also showed a positive result when

measuring intensity using *vigorous* VO_2R (158.3 ± 94.8 min·week^{-1}, p = 0.03). These results strongly suggest that the single most important factor affecting whether or not participants were meeting current ACSM physical activity recommendations was their frequency of attendance. However, benefits of increased attendance may be offset by the cost of therapy. Cost to the patient to attend ABRT is quite high due to the trained therapists and unique equipment used as part of therapy. Many people are therefore unable to afford to attend therapy at least three times per week. If costs could be reduced or contained this may lead to better outcomes. Otherwise, one might question whether it is practical for the majority of people with SCI to be involved in a sufficient volume of ABRT to improve their health.

Age did not display any relationship to the intensity of activity performed as part of therapy and analysing participant data separately by injury level (individuals with tetraplegia vs paraplegia) was not shown to have an impact on which ACSM guidelines criteria were met. The latter finding was of interest because one would have expected the intensity of activity performed by individuals with paraplegia to be higher than that of those with tetraplegia given their greater physical capacity. One reason for this result could have been the standardisation of activities performed as part of therapy for all participants regardless of injury type or function. In other words, participants were not given the freedom to engage in the amount or intensity of activity that they may otherwise have chosen to undertake.

5.6 CLASSIFICATION OF "EXERCISE" IN ABRT

This study classified all activities performed as part of participant ABRT sessions under one of nine different categories which were devised by the researcher and senior therapist of the Walk On program (see Appendix C for categories). These categories aimed to subdivide ABRT into different activities which could each be measured individually with regards to their intensity and duration. This was done to give the independent researcher a more detailed insight into which aspects of ABRT were more or less intense than others and which may be contributing more or less to participants meeting or not meeting ACSM physical activity guidelines.

Interestingly, there was a very small range of intensity differences between the different activity categories (1.7 MET difference) with the most intense activity category being "whole body functional activities" (2.9 METs) and least intense activity category being "sitting down, no activity/deep muscle stimulation/set-up for activities" – 1.2 METs. The average intensity of all activities performed as part of therapy was classified as "light" based on the ACSM classification system (intensity < 2.9 METs, ACSM 2013) so it would be very difficult to accumulate sufficient time spent at higher intensities to satisfy the ACSM guidelines given these findings. This could have been due to the fact that the program only incorporates low intensity activities, however it may also indicate that the activity categories were too broad to distinguish between them. Another reason for the low intensity of the activities may have been due to the time participants spent resting between "sets" of the same activity which was not coded as a

different activity rather included in the one activity code. If this were the case, then it may be possible to reduce time spent between sets to elevate the intensity of different activities and hence elevate the overall intensity of therapy.

The activity that participants spent the most time performing on average was "lying supine/prone, activity with upper limbs, lower limbs and/or trunk" (45.8 ± 4.1 min) which is not surprising as almost all therapy sessions included a significant amount of "active assisted lower-limb exercises" where participants spent time lying on a plinth with a therapist manually stimulating their limbs. The amount of effort that participants appeared to put into this activity varied with some seeming to let the therapist move their limb passively through its range of motion while others had significant strain on their faces while performing this activity and would tend to give this activity a higher RPE. This activity also had the second lowest intensity (1.6 METs) which may give some indication as to why more participants were not meeting the ACSM physical activity guidelines. If the duration of this activity were reduced, then patients would have more time to spend performing activities of a higher intensity hence increasing the dose of exercise that they were receiving as part of ABRT. However, this would need to be a trade-off and would only be feasible if reducing the duration of this activity didn't have a significant impact on the functional benefits gained from therapy.

The results from the activity code data allowed a more detailed look at the overall intensity of ABRT. Intensity has been shown to be a critical factor in improving cardiorespiratory fitness and health in able-bodied and people with SCI (De Groot, Hjeltnes, Heijboer, Stal, & Birkeland, 2003; Lee, Hsieh & Paffenbarger, 1995), but also an important factor for gaining functional improvements from

therapy for people with SCI (Fritz et al., 2011; Harness et al., 2008). Harness et al. (2008) noted that people with SCI who were performing unsupervised activity engaged in almost twice the duration of PA as people in the supervised ABRT program, however, their improvements in motor score were significantly less. This suggests that intensity of activity is a crucial factor in improving functional outcomes. Since there is a linear relationship between exercise intensity and functional improvements, the potential of ABRT to improve functional outcomes could be improved by increasing the intensity of activity done in the program.

If ABRT is found to be effective for improving both neurological and functional outcomes, then results from this study could be used to either modify current ABRT programs or to design a new and improved ABRT program. Changes would likely include more intense activities or a combination of intense activities and activities which were proven to be more beneficial to functional outcomes via other means. Conversely in both past and future studies where ABRT was not found to have a significant impact on functional outcomes, then it may be that the intensity of activity in the program was not sufficient.

5.7 SUMMARY

In summary, it is unlikely that ABRT exceeded ACSM physical guidelines as most findings were inconclusive. However, if the frequency of ABRT attendance is increased to three or more times per week, then patients are much more likely to meet ACSM guidelines. Further research is needed on larger numbers of participants to definitively determine whether or not people with SCI may be able

to meet PA guidelines as a result of taking part in ABRT. ABRT does however provide patients with a substantial duration of exercise, albeit of low intensity, which may not be sufficient to exceed current PA guidelines but might produce some clinical significance. The PA that people engaged in as a direct result of ABRT is likely to have provided some health or cardiorespiratory fitness benefits to people regularly attending ABRT programs. It may also be possible to make minor adjustments to current therapy programs in order to increase their intensity and increase the likelihood that patients are meeting current PA guidelines as a result.

CHAPTER 6

CONCLUSION

The primary objective of this study was to examine whether the physical activities performed in a community-embedded ABRT program for people with SCI was of sufficient duration and intensity to meet current ACSM guidelines for improving and maintaining cardiorespiratory fitness and health. This is important because people with SCI have much lower levels of physical activity than their able-bodied counterparts (Buchholz et al. 2003), and as a result, are at a much greater risk of a number of chronic diseases (Cowan & Nash, 2010). Secondary objectives were; 1) to determine whether there were any demographic factors impacting on this result, and, 2) to determine whether there was a relationship between intensity measures of HR and RPE in people with SCI.

To satisfy the objectives of this study, the following null hypotheses were constructed:

1. *The intensity and duration of activity in the Walk On program would not be sufficient to meet the ACSM guidelines for developing and maintaining cardiorespiratory and general health.* The findings of this study **upheld** this hypothesis. Although there was one significant intensity measure that met current ACSM guidelines, this intensity measure may not have had acceptable reliability due to the lack of evidence relating to its accuracy in people with SCI.
2. *Meeting the ACSM guidelines for developing and maintaining cardiorespiratory and general health would be dependent upon patients' frequency of attendance to the ABRT program.* This hypothesis was **upheld**. People who attended the ABRT program three or more times per

week demonstrated a higher likelihood of meeting current ACSM guidelines when measuring the volume of their exercise.

3. *There would be a relationship between activity intensity and injury level but not between activity intensity and age.* This hypothesis was **rejected**. There was no relationship between participants meeting ACSM guidelines based on their injury level, nor was there any significant relationship between participants' age and their activity intensity.
4. *There would be no direct relationship between HR and the RPE when measured by the patient or a person observing the ABRT activity.* This hypothesis was **upheld**. There was no relationship between HR and RPE measures of intensity when rated by either the participant or an observer.

In conclusion, the results from this study would indicate that people with SCI, involved in a community-embedded ABRT program, were unlikely to meet current ACSM physical activity guidelines for health as a result of their therapy unless they attend therapy three or more times per week. This finding was independent of other factors such as age or intensity level. Findings have also suggested that RPE may not have been a good measure of intensity in people with SCI. This study has also added to the body of evidence classifying the intensity of different activities for people with SCI.

6.1 CLINICAL IMPLICATIONS

Given the finding that the exercises performed as part of the ABRT were generally insufficient to meet guidelines for the majority of SCI participants, there are several recommendations to come out of this study. First, it may be possible to modify current therapy to meet the needs identified in this study. Recommendations for achieving this are outlined below. Second, as exercise frequency of program attendance was the most significant predictor of a positive outcome, it may be appropriate to make programs more available and of lower cost to allow participants greater access to their benefits. Finally, if the above recommendations are unable to implemented, it may be necessary to suggest that people with SCI take part in supplementary means of increasing their PA levels. This is critically important as people with SCI are at high risk of CV disease (Myers, Lee & Kiralti, 2007; Janssen et al. 1997), and the CV health benefits of engaging in regular activity for people with SCI are well documented (Buchholz et al. 2009).

Guidelines for modification of current ABRT programs

The following recommendations could be used to modify current ABRT programs so that people with SCI are more likely to engage in increased intensity of exercise while taking part in the program:

1. **Increasing the frequency and duration of "whole body activities"**

   Whole body activities (activity code 9) were found to have the highest level of intensity (2.9 METs) relative to the other activities. If the proportion of such activities could be increased within therapy, this would increase the overall intensity of physical activity that people with SCI were performing during activity-based therapy. This would likely result in more people meeting or getting closer to meeting the current PA guidelines as a result of therapy.

2. **Reducing time spent "lying supine/prone, activity with upper limbs, lower limbs and/or trunk"**

   This activity (activity code 4) had the highest average duration of any activity code after "sitting down, no activity/DMS/set-up for activities" (activity code 1, 1.2 METs). During therapy, most participants would perform this activity for a substantial amount of time particularly at the beginning of their session. If the duration patients spent performing this activity was reduced without negatively impacting on possible functional gains made as a result of therapy, this would allow patients to spend more time performing other, higher-intensity activities.

3. **Reduce the rest time between sets of activities**

   If the rest time between sets of exercises was reduced, this would keep patients' HR elevated for longer and would increase the average intensity of the different activities. This would lead to an overall increase in the intensity of therapy as a whole and would mean patients would be more likely to be meeting current PA guidelines as a result.

6.2 STUDY LIMITATIONS

One obvious limitation to the interpretation of the results in this study was the small sample size. As this was only a pilot study, the small subject numbers were justified; however, a future study with a larger sample size would give more power to detect significant results. This could be achieved by recruiting and combining results from participants from all four WO sites around Australia.

A related limitation was the small number of individuals with paraplegia relative to those with tetraplegia. This meant secondary analyses were limited and results could have been somewhat biased/weighted towards data obtained from individuals with tetraplegia. This also necessarily limited the generalizability of the findings to the specific populations.

Another limitation was the lack of current appropriate guidelines with which to compare the results of this study. If there had been more appropriate guidelines to compare the activity that participants were performing then results may have been more interpretable. However, the results from this study will add to the pool of evidence that can be used for comparison in future studies.

A final limitation was the inability to directly measure VO_2 during therapy, as this would have impacted significantly on participant ability to perform a number of their activities. Therefore, VO_2 could only be estimated using individualised regression equations. This method of VO_2 measurement has been shown by previous studies to produce reliable results (Lee et al. 2009; Hayes et al. 2005);

however, as it is only an estimation, it may have limited the interpretation of the results.

6.3 FUTURE RESEARCH

Proceeding from this work are some recommendations for future research:

1. It is clear that future research is still needed to design realistic and effective PA guidelines specifically for people with SCI. Further research is also needed to determine the dose-potency of PA and the classification of activity in the SCI population before it is possible to design effective guidelines that are able to say with some confidence that they will have a positive impact on health.
2. Further studies are also needed to replicate and extend this research with larger participant numbers. This could be achieved by using other sites around Australia. This will further increase the accuracy of results and give more accurate classification of activity undertaken by people with SCI involved in ABRT.
3. Finally, further research is needed to determine the most valid and reliable measure or measures of exercise intensity for people with SCI. There are currently a number of different measures being used with this population; however, more evidence is needed to confirm which are better than others.

6.4 CONCLUSION

In accordance with the objectives of this study, the following overall conclusions were drawn:

1. People with SCI were unlikely to meet current ACSM PA guidelines as a result of taking part in regular ABRT.
2. Participant ability to meet PA guidelines was independent of other factors such as age or intensity level, however, frequency of attendance to ABRT had a significant impact on whether or not people with SCI met current PA guidelines.
3. "Whole body activities" were the most intense activities performed by people taking part in ABRT.
4. There is no relationship between HR and RPE in people with SCI.

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APPENDIX A –ETHICS FORMS, PARTICIPANT INFORMATION STATEMENT

AND PARTICIPANT CONSENT FORM

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Measurement of cardiovascular health benefits in people undertaking the Walk On program

PARTICIPANT INFORMATION STATEMENT

(1) What is the study about?

This study will look at the possible cardiovascular benefits gained from the Walk On program. It will do this by determining whether the Walk On program meets the guidelines for exercise set down by the American College of Sports Medicine (ACSM) and American Heart Association (AHA).

(2) Who is carrying out the study?

The study is being conducted by David O'Brian and will form the basis for the degree of Master of Applied Science at The University of Sydney under the supervision of Professor Glen Davis.

(3) What does the study involve?

The study will be conducted immediately before and during your regular training sessions in the Walk On program. Before your training session, we ask that you perform a maximal exercise test on an arm crank machine. This will take approximately 10 minutes and will require you to exercise as hard as you can. This may result in some discomfort in the form of breathlessness or fatigue and we require that you complete a PAR-Q questionnaire to confirm that you are ready to exercise. If you answer 'yes' to any of the questions, are over 45 and male or over 55 and female, we will ask that you obtain a medical clearance before undertaking the maximal test. You will be monitored closely during the test and will be able to stop at any point if you feel uncomfortable or if the researcher feels that the test should be terminated for any reason. Before you start your regular training sessions, you will be fitted with a chest-strap and wrist-watch to measure heart rate. This fitting process should take no longer than 5 minutes and then you will participate in your exercise program as you normally would. You may be asked occasionally (about every 15-30 minutes) to let your trainer know how hard you are working by indicating a value between 0 - 10. This will be explained to you in more detail should you agree to participate. A person will be watching you during your training session and recording your progress but will not interfere with your program nor give you feedback at any time. At the end of the session, the recording equipment will be removed. This will take approximately the same amount of time as it did to put it on. We ask that you allow us to record data from your training session every day that you train over two weekly periods.

(4) How much time will the study take?

The study should only take about an extra 10 minutes (to put on and take off our recording equipment) on top of the normal amount of time your training would usually go for. The maximal exercise test will take a further 10 minutes and will be conducted outside of your regular training session at a time that is convenient for you (possibly before one of your regular training sessions).

(5) Can I withdraw from the study?

(5) Can I withdraw from the study?

Participating in this study is completely voluntary - you are not under any obligation to consent and if you do consent, you can withdraw at any time without affecting your relationship with The University of Sydney, the researchers or the Walk On program.

(6) Will anyone else know the results?

All aspects of the study, including results, will be strictly confidential and only the researchers and Walk On trainers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(7) Will the study benefit me?

The study will not have any extra effect on top of the benefits you are gaining from your current exercise program. If you wish, you will be able to see and discuss your results with the researcher at the end of the week and be made aware of any useful information we may discover.

(8) Can I tell other people about the study?

Yes.

(9) What if I require further information about the study or my involvement in it?

When you have read this information, David O'Brian will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Glen Davis or David O'Brian by email or telephone. (Ph) 9351 9566 (Email) g.davis@usyd.edu.au.

(10) What if I have a complaint or any concerns?

Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

This information sheet is for you to keep.

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Web: http://www.usyd.edu.au/

PARTICIPANT CONSENT FORM

I, ...[PRINT NAME], give consent to my participation in the research project

TITLE: Measurement of cardiovascular health benefits in people undertaking the Walk On program.

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved (including any inconvenience, risk, discomfort or side effect, and of their implications) have been explained to me, and any questions I have about the project have been answered to my satisfaction.

2. I have read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

3. I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher(s) or the University of Sydney or the Walk On program now or in the future.

4. I understand that my involvement is strictly confidential and no information about me will be used in any way that reveals my identity.

5. I understand that being in this study is completely voluntary – I am not under any obligation to consent.

6. I consent to:

   i) Receiving Feedback YES ☐ NO ☐
   If you answered YES to the "Receiving Feedback Question (iii)", please provide your details i.e. mailing address, email address.

Feedback Option

Feedback Option

Address: _____

_____

Email: _____

Signed: .....

Name: .....

Date: .....

THE UNIVERSITY OF SYDNEY

RESEARCH INTEGRITY
Human Research Ethics Committee
Web: http://sydney.edu.au/ethics/
Email: ro.humanethics@sydney.edu.au

Address for all correspondence:
Level 6, Jane Foss Russell Building - G02
The University of Sydney
NSW 2006 AUSTRALIA

Ref: [MF/KFG]

8 August 2011

Professor Glen Davis
Director
Clinical Exercise and Rehabilitation Unit
Discipline of Exercise and Sport Sciences
Faculty of Health Sciences
Cumberland Campus – C42
The University of Sydney
Email: glen.davis@sydney.edu.au

Dear Glen

Thank you for your correspondence received 8 August 2011 addressing comments made to you by the Human Research Ethics Committee (HREC).

I am pleased to inform you that with the matters now addressed your protocol entitled **"Measurement of cardiovascular health benefits in clients undertaking the Walk On program"** has been approved.

Details of the approval are as follows:

Protocol No.:	**08-2011 / 13991**
Approval Period:	**August 2011 – August 2012**
Annual Report Due:	**31 August 2012**
Authorised Personnel:	**Professor Glen Davis** **Dr Jacqueline Raymond** **Mr David O'Brien**
Documents Approved:	**Participant Information Statement (version 2, 25/07/2011)** **Participant Consent Form (version 1, 01/07/2011)** **PAR-Q**

The HREC is a fully constituted Ethics Committee in accordance with the National Statement on Ethical Conduct in Research Involving Humans-March 2007 under Section 5.1.29.

The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Research Involving Humans.

A report on this research must be submitted every 12 months to the Human Research Ethics Committee from the final approval period or on completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of ethics approval for the project. Please download the Annual Report/Completion Report Form from the Human Ethics website at: http://sydney.edu.au/research_support/ethics/human/forms.

The HREC approval is valid for four (4) years from the Approval Period stated in this letter and is conditional upon submission of Annual Reports. If your project is not completed by four (4) years

Manager Human Ethics
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ABN 15 211 513 464
CRICOS 00026A

from the approval period, you will have to submit a Modification Form requesting an extension. Please refer to the guideline on extension of ethics approval which is available on the website at: http://sydney.edu.au/research_support/ethics/human/extension.

Chief Investigator / Supervisor's responsibilities to ensure that:

1. All serious and unexpected adverse events should be reported to the HREC within 72 hours.

2. All unforeseen events that might affect continued ethical acceptability of the project should be reported to the HREC as soon as possible.

3. You must retain copies of all signed Consent Forms and provide these to the HREC on request.

4. It is your responsibility to provide a copy of this letter to any internal/external granting agencies if requested.

5. All research participants are to be provided with a Participant Information Statement and Consent Form, unless otherwise agreed by the Committee. The following statement must appear on the bottom of the Participant Information Statement: Any person with concerns or complaints about the conduct of a research study can contact the Manager, Human Ethics, University of Sydney on +61 2 8627 8176 (Telephone); + 61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

6. Any changes to the protocol including changes to research personnel must be approved by the HREC by submitting a Modification Form before the research project can proceed. Please refer to the website at http://sydney.edu.au/research_support/ethics/human/forms to download a copy of the Modification Form.

7. A Completion Report should be provided to the Human Research Ethics Committee at the completion of the Project.

Please do not hesitate to contact Research Integrity (Human Ethics) should you require further information or clarification.

Yours sincerely

Dr Margaret Faedo
Manager, Human Ethics
On behalf of the HREC

cc: David O'Brien
dobr0677@uni.sydney.edu.au

APPENDIX B – PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

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.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

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

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

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.

1:12

Supported by: Health Canada Santé Canada

continued on other side...

APPENDIX C – ABRT ACTIVITY CODES USED IN THIS STUDY

1. Sitting down, no activity/DMS/Set-up for activities
2. Sitting down, activity with upper limb, lower limb and/or trunk
3. Sitting down, FES cycling
4. Lying supine/prone, activity with upper limbs, lower limbs and/or trunk
5. Standing in parallel bars, activities with upper limb, lower limb and/or trunk
6. Standing in frame, activities with upper limb, lower limb and/or trunk
7. Body weight supported walking on treadmill with overhead harness
8. Crawling/kneeling activities involving upper limb, lower limb and trunk
9. Whole body functional activities

APPENDIX D – HR VS TIME PERIODOGRAM