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The energy expenditure of people with spinal cord injury while walking compared to an able bodied population

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirement for the degree of Master of Science in Physiotherapy

Johannesburg, 2013

DECLARATION

I, Jana Vosloo declare that this research report is my own work. It is being submitted for the degree of Master of Science in Physiotherapy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.


_____ [Signature of candidate]

22nd day of September, 2013

DEDICATION

To all the wonderful patients who colour our lives,
With passion and enthusiasm far beyond our understanding,
Courage beyond measure.
I am blessed to have you as my educators
on how to embrace life!

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1. To God Almighty for granting me the patience and endurance to pursue and complete this chapter in my life. For all the times of carrying me through valleys and over mountains I could not do in my own strength anymore.

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LIST OF ABBREVIATIONS

SCI	Spinal Cord Injury
ROM	Range of motion
FIM	Functional independence measure
ASIA	American Spinal Cord Injury Association Impairment Scale
WHO	World Health Organisation
MVA	Motor vehicle accident
TB	Tuberculosis
HIV	Human immunodeficiency virus
BMI	Body mass index
CNS	Central nervous system
CPG	Central pattern generator
WISCI	Walking index for spinal cord injuries
SCS	Spinal cord stimulation
KAFO	Knee-ankle-foot-orthosis
AFO	Ankle foot orthosis
10MWT	Ten meter walk test
6MWT	Six minute walk test
MAS	Modified Ashworth scale
EE	Energy expenditure
EE/m	Energy expenditure per meter

ABSTRACT

Background and purpose of the study

In the field of spinal cord injury research there is an emphasis on the ability to ambulate as a functional outcome. With the tendency towards lower levels of physical activity in the SCI population it is of vital importance to facilitate any possible improvement in ambulation within this population. By having data of the energy expenditure during a mobility assessment compared to an able bodied age, gender and body-mass-index comparable group, several valuable observations can be made. These include the level of endurance, walking speed and energy expenditure the participants have in comparison to an able bodied population and the level of rehabilitation required to perform the same task.

Research methods and procedures employed

This was an observational cross-sectional study that included 45 participants in the spinal cord injured group and 21 in the able bodied group. Consecutive sampling was done until the sample size was met. The following were used to establish factors that influenced energy expenditure while walking: A self developed demographic questionnaire to capture participants' age, date of onset of spinal cord injury, level of the lesion, level of mobility, use of assistive devices, duration and extent of rehabilitation received and presence and frequency of pain; the modified Ashworth scale for spasticity; a goniometer for range of movement; American Spinal Cord Injury Association Impairment Scale (ASIA) assessment for patient classification; an accelerometer for amount of energy expended and the six minute walk test for endurance. Height and weight measurements were taken for Body Mass Index calculation.

Results

The mean energy expenditure per meter for the SCI sample was 0.33cal/m (SD=0.29) compared to 0.08cal/m (SD=0.02) for the able bodied group. A decrease in velocity resulted in an energy expenditure increases of 0.06 ($p < 0.001$) and a decrease in sensory score resulted in an energy expenditure increase of 0.3 ($p = 0.02$). With a decrease in hip extension and knee flexion there was an increase of 0.3 in energy expenditure per meter and with a decrease in hip flexion the energy expenditure per meter increased by 0.5. A significant difference was observed between energy expenditure during crutch use compared to walking frame use ($p=0.03$) with crutch walking utilising 0.34cal/m less energy than walking frame. Participants who had a SCI duration of >10years had 0.26 less energy expenditure than those who had less

than six months SCI duration ($p = 0.05$), Participants with SCI who were currently still in acute in-patient stage had 0.23 more energy expenditure than those in outpatient therapy and those who did not have out-patient rehabilitation had 0.52 more energy expenditure than those in outpatient therapy.

Conclusion

Significant differences exist between energy expenditure while walking between the able bodied- and SCI population. From a therapeutic point of view, factors to consider in order to maximise energy efficiency while walking are: maintenance of hip flexion and extension and knee flexion ROM, optimising velocity of walking, sensory re-education and educating and encouraging continued therapy beyond the in-patient rehabilitation phase. Selection of an assistive device to optimise energy expenditure while walking should be considered when clinically relevant.

Keywords:

Energy expenditure, factors affecting energy expenditure, range of motion, velocity, assistive devices, ongoing therapy.

CHAPTER 1

BACKGROUND AND NEED

1.1 INTRODUCTION

In the field of spinal cord injury research there is an emphasis on ability to ambulate as a functional outcome and also as an indicator of quality of life for people with a spinal cord injury (SCI) (Jackson et al., 2008). Participation and engaging in home and community activities is essential to personal identity, and restrictions encountered by people with health conditions contribute to the experience of disability (Cahil, 1998; WHO, 2001). Participation is an important aspect of quality of life (Dijkers, 1999; Post & Noreau, 2005). For most people, walking is an efficient method of moving from one place to another, especially when walking at a self selected pace (Waters and Mulroy, 1999). In SCI functional walking is defined as the ability to walk with or without assistive devices in a safe manner in order to perform mobility related activities of daily living (Lam et al., 2008). Walking for routine activities of daily living will often require a patient to cover distances greater than 250 meters and on average spend at least 10 minutes walking (Ulkar et al., 2003).

In the population of people with SCI, natural gait patterns are significantly altered because of decreased strength, endurance, proprioception, and spasticity (Jackson et al., 2008). People with SCI also have reduced muscle mass and sympathetic nervous system supply available for mobilisation and exercise. As a result they have reduced peak physiological response compared to able bodied individuals (Price, 2010). These impairments result in the use of orthotic devices which can substantially increase energy demands (Field-Fote & Fluet, 2001). When energy expenditure during orthotic assisted gait is compared to able bodied individuals the energy cost is far higher during orthotic gait (Kawashima et al., 2006).

Another factor that would greatly impact the efficiency of the gait pattern as well as the energy required to generate it is the level of neurological impairment. The higher the level of the lesion, the slower the cadence, and the higher the relative physiological intensity (Kawashima et al., 2006). Measuring metabolic energy expenditure provides comprehensive information on gait performance and a means of quantifying the energy expended resulting from pathological gait (Waters et al., 1993). It has been stated that a patient's acceptance or preference of one

walking aid/orthotic to another is dependent on the ease of operation, which has bearing on the metabolic energy required to operate it (Ulkar et al., 2003).

It is clear from the literature that several factors could potentially affect gait performance and energy expenditure in the SCI population. The excess energy expenditure to ambulate and burden on particularly the upper limbs presents a challenge in achieving functional walking. It is therefore vital to explore options to reduce the excess physiological load in order to optimise physical activity (Kawashima et al., 2006). The following factors have been implicated to affect walking: being overweight (Yamakawa et al., 2004); older age (Scivoletto et al., 2003); spasticity (Skold, 2000; Adams & Hick , 2005; Mahoney et al., 2007), pain (Ravenscroft & Burnside, 2000; Richards et al., 2004), gender (Greenwald et al., 2001; Skipski et al., 2004), range of motion (Kawashima et al., 2006), level of lesion (Kawashima et al., 2005), assistive devices (Waters & Mulroy, 1999; Kawashima et al., 2006), extent of treatment (Patrick, 2003; Olmos et al., 2008; Scivoletto et al., 2008) and duration since the injury (Kirshblum et al., 2004).

There is a dearth in literature available investigating the effect the above mentioned factors will have on energy expenditure while walking for people with spinal cord injuries. The purpose of this study was to determine the energy expenditure for gait in SCI and also formulate a better understanding of how these factors could impact on performance, more specifically energy expenditure.

1.2 PROBLEM STATEMENT

At present there is very little literature available on the walking energy expenditure in spinal cord injured patients. Although functional walking is suggested to be one of the most important patient goals in the SCI population (Ulkar et al., 2003; Ditunno et al., 2008), there is limited guidance in the research to assist the therapist in relation to structuring the rehabilitation program to attain efficient walking ability.

1.3 RESEARCH QUESTION

What is the energy expenditure of spinal cord injured patients while walking compared to an able bodied population?

1.4 AIM OF THE STUDY

To assess the energy expenditure of people with a SCI while performing a walking assessment and compare it to an able bodied population.

1.5 OBJECTIVES OF THE STUDY

1.5.1 To establish the energy expenditure of participants with SCI while performing a Six Minute Walk Test (6MWT).

1.5.2 To establish the energy expenditure of participants in an able bodied population while performing a Six Minute Walk Test (6MWT).

1.5.3 To compare the energy expenditure between participants with SCI walking and the able bodied population.

1.5.4 To establish factors that influence energy expenditure while walking of participants with SCI compared to an able bodied population.

1.6 SIGNIFICANCE OF THE STUDY

Restoration or regaining walking is given high priority by people with spinal cord injuries, irrespective of the severity of the initial injury, the time lapsed after the injury or the age of onset of the spinal cord lesion (Ditunno et al., 2008). Walking for the able bodied population can be sustained for longer periods of time without exhaustion due to its efficiency (Waters & Mulroy, 1999). Thus estimating the energy expenditure of walking is essential to assess gait efficiency of individuals with SCI (Ulkar et al., 2003).

Having evidence of walking energy expenditure for individuals with SCI compared to an able bodied population would enable the therapists to draw conclusions regarding the discrepancies that may exist. Conclusions regarding the success of the rehabilitation programs in enabling the patient to regain functional walking can also be commented on based on the findings.

CHAPTER 2

2. LITERATURE REVIEW

2.1 INTRODUCTION

There is a dearth in literature reporting on the incidence and prevalence of spinal cord injuries in the world but a far greater lack in reporting exists in South Africa (SA) and other developing countries (Draulans et al., 2011). This is attributed to a lack in financial resources and other tools to effectively record and report on incidence and prevalence of SCI (Mothabeng, 2011). There is also a lack in appropriate referrals to specialised centers for the individuals with SCI to receive the necessary treatment and enable recording of data (Mothabeng, 2011). Furthermore there are also an insufficient number of these centers providing rehabilitation to serve the public and private health care sector in SA (Mothabeng, 2011). Of the published research in SA, studies are focused on the aetiology of a specific sample size collected in a particular region or hospital (Hart & Williams, 1994; Velmahos et al., 1995; Fielingsdorf et al., 2007; Hermanus et al., 2010; Vlok et., 2010). There is no published data looking at prevalence of SCI in a South African context as a whole.

Cripps et al. (2011) reported a global prevalence of SCI of between 236-1009 cases per million people and an incidence of 15-39 cases per million. Wyndaele & Wyndaele (2006) reported an international incidence between 10 and 83 per million inhabitants per year. Based on a recent review by Van den Berg et al. (2010) looking at international figures most studies investigating traumatic SCI incidence showed a bimodal age distribution. Young adults between the ages of 15 and 29 years presented the first peak and a second peak in older adults (mostly ≥65 years). Motor vehicle accidents (MVAs) and falls were the most common causes of injury accounting for nearly equal percentages. Another age pattern in non-traumatic SCI reflected steadily increasing incidence with advancing age.

The main aetiologies reported by Cripps et al. (2011) for South African incidence are land transport (MVA and pedestrian vehicle accidents) and violence. Motor vehicle accident related SCI's ranged from 28% to 34% and violence-related SCI's from 25-62% in the Gauteng and Western Cape provinces respectively. Falls were attributed for 3–12% of SCI's. In recent decades there has been an increase in people sustaining SCI as a result of HIV-related diseases such as tuberculosis of the spine (TB spine) (Mothabeng, 2006 cited in Mothabeng,

2011). This further emphasises the need for effective rehabilitation programs which include the re-education of walking for individuals with the potential to regain this function post SCI.

This literature review looks at studies on energy expenditure while walking as well as possible factors which influence the walking capacity and energy use of people with SCI. Literature was also reviewed for the most appropriate instruments and outcome measures for the study. The following databases were searched for literature: Cochrane, PeDRO, Pubmed and EBSCO. The following keywords were used in the search: spinal cord injury, accelerometer, body mass index, assistive devices/walking aids, energy expenditure, level of lesion, spasticity, gender differences, age, functional outcomes, extent of treatment, duration since injury, range of movement and pain. This literature review is presented using the following format:

2.2 Energy expenditure when walking.
2.3 Factors which affect the level of energy expenditure during walking in the SCI population
- 2.3.1 Age
- 2.3.2 BMI
- 2.3.3 Gender
- 2.3.4 Pain
- 2.3.5 Spasticity
- 2.3.6 Level of the lesion (ASIA)
- 2.3.7 Use of assistive devices
- 2.3.8 Range of motion
- 2.3.9 Extent of treatment
- 2.3.10 Duration since injury

2.4 Gait performance in SCI

2.2 ENERGY EXPENDITURE WHEN WALKING

Human movement is done in the most economical fashion where by muscles only perform the necessary mechanical work required to complete a particular task. This energy conservation principle is relevant in costly locomotor tasks such as walking (Zelik & Kuo, 2012). Walking involves progression in a forward motion while utilising the least amount of mechanical and physiological energy expenditure. This involves low amplitude displacement of the center of gravity in the vertical and lateral directions. During normal walking the rate of energy

expenditure is relatively low and can be sustained for prolonged periods without exhaustion (Waters & Mulroy, 1999).

To ensure the least amount of energy expenditure during normal gait, mechanical and neural interactions take place between functions and structures of the neuromusculoskeletal system of the human body. Movement is created by distinct muscles action and its intensity is efficiently controlled by the central nervous system (CNS) (Lehmann et al., 1999)

It has been observed that human locomotion will occur at a speed that minimises the metabolic cost to ambulate. Each speed of gait will have adjustment in stride length to minimise energy expenditure, which is estimated by the mechanical work required by muscle, and the metabolic cost of the muscle activity during gait respectively (Rodrigo et al., 2010a). O'Connor et al. (2012) investigated the effect step variability would have on energy expenditure during walking in a young able bodied sample. They concluded that significant increased energy expenditure was observed in the step variability group compared to the control group. Step variability is prominent in gait disorders, neurological impairments as well as in older adults. The increased energy expenditure during walking is suggested to be due to the variability in stepping due to sensorimotor impairment which is a common complication for people with SCI (O'Connor et al., 2012).

Neural coordination of locomotion should occur at three levels in order to activate muscles and efficient locomotion. These levels are as follows: a) motorneuronal level which act directly on the muscles; b) the central pattern generator (CPG) which indirectly controls whole limb movement or intra-limb coordination (flexion or extension); and c) at a higher neural level (CNS). The sensory feedback from the leg controls the activation intensity of individual muscles to minimise the energy cost during gait (Rodrigo et al., 2010b). Normal walking speed for able bodied adults (between age 20 and 60 years) is between 1.0 and 1.67 meters/second. The distance covered is usually 60-100meters/minute (Walters et al., 1999).

2.3 FACTORS WHICH AFFECT THE LEVEL OF ENERGY EXPENDITURE DURING WALKING IN THE SCI POPULATION

2.3.1 Age

An increase in life expectancy along with biomechanical changes in the vertebral column has had a resultant increase in incidence of SCI in the elderly population (Cifu et al., 1999a, Kannus

et al., 2000; Ehara & Shimamura, 2001). A SCI in the elderly is associated with more frequent complications, poorer tolerance to immobility, poorer neurological recovery of mobility and walking and higher mortality rates (Cifu et al., 1999a; Scivoletto et al., 2003; Gulati et al., 2011). A poorer prognosis and inferior neurological recovery is also expected with advance in age compared to a younger individual with a similar SCI lesion (Cifu et al., 1999a; Dai, 2001; Scivoletto et al., 2003; Gulati et al., 2011). In a study by Hagen et al. (2005) they concluded that elderly patients benefit from rehabilitation and can make good neurological recovery. However they recommended that the rehabilitation program for elderly patients should be less intensive in therapeutic input than the program offered to younger individuals (Cifu et al., 1999b).

The aetiology for SCI in the older population is usually due to a minor fall or degenerative changes in the cervical spine. This is thought to be due to bone density, fibrosis of feeding arterioles supplying the vertebral column and other degenerative changes being synonymous with older age (Cifu et al., 1999a, Kannus et al., 2000; Ehara & Shimamura, 2001). Associated prognosis and functional recovery is considered poorer in the older population due to the structural changes and degenerative processes which lead to the SCI (Cifu et al., 1999a; Dai, 2001; Ehara & Shimamura, 2001; Scivoletto et al., 2003; Hagen et al., 2005; Gulati et al., 2011).

In a study by Penrod et al. (1990) the ability to walk independently upon discharge from rehabilitation was significantly higher in the SCI population below 50 years of age compared to the people with SCI above 50 years of age. In the study by Dai in 2001 the older group with an age above 60 years had lower ASIA scores on admission and discharge compared to the younger group. The study highlighted the effect of age on the prognosis and showed that the age of the patient is negatively related to the ASIA scores both on admission and at discharge. Hagen et al. (2005) found that 63% of the SCI patients aged above 60 showed improvement in ASIA scores from admission to discharge but the study did not include a younger group for comparison in terms of scores. The literature illustrates that there is clearly poorer recovery expected in ASIA scores and walking ability in the older population after sustaining a SCI although some recovery is still possible.

The negative effect of increasing age on the walking abilities of patients with SCI has already been reported in the literature: Burns et al. (1997) found that walking recovery in patients with incomplete SCI depends on the age of the individual and occurs more frequently in young patients. Penrod et al. (1990) also found similar results. Scivoletto et al. (2003) during a study

examining patients over or under 50 years of age, using the WISCI (Walking Index for Spinal Cord Injury) to evaluate walking ability, concluded that the younger patients reached the walking function more frequently. In the same study the 6MWT (Six Minute Walk Test) negatively correlated with age in the regression analysis, the older the person, the shorter the distance walked in 6MWT. It was therefore assumed that age affects the outcome measures requiring long distances of walking and endurance. This finding is believed to be associated with the energy expenditure and muscle fatigue which would be two factors influencing the performance in the elderly.

Age related differences in outcome was also reported in a study by Newey et al. (2000) who reported poor recovery in patients with SCI over the age of 70; however the sample size was not evenly distributed over the age groups. In a study by Dvorak et al. (2005) age at the onset of injury was analysed and it was found that there was significant association between age and ASIA motor improvement. Advanced age was identified as a predictor of increased disability which may be further complicated by co-morbidities, poor initial ASIA motor scores and the type of injury.

A study by Fiser et al. (2010) investigating the effect age has on energy expenditure during walking in an elderly, able bodied population, found that with an increase in age there is a decrease in the speed of walking, which had a resultant increase in energy expenditure to walk at a self selected pace. Similar findings were reported in a study by Schrack et al. (2012). Cardiorespiratory demands during walking were also found to be higher in older adults which again correlated with reduced walking speed and higher energy expenditure as a result (Fiser et al., 2010). Consistent findings of a decline in walking speed with age was found in similar studies, which was attributed to age related physiological function and biomechanical efficiency (Samson et al., 2001; Malatesa et al., 2003; Malatesa et al., 2004; Mian et., 2006). These findings imply that even in the absence of a SCI, age will negatively affect energy expenditure during walking. It can therefore be concluded that age will increase energy expenditure during walking for SCI and able bodied due to the age related physiological changes and reduction in gait speed.

2.3.2 Body Mass Index

The World Health Organisation (WHO) recommended a classification system of bodyweight that include degrees of underweight and gradations of excess weight. Classifications are based on body-mass index (BMI), which is calculated as weight in kilograms divided by height in metres squared (kg/m2). It is an easy to obtain measure of relative weight and an acceptable proxy of to describe thinness and fatness. A BMI above the normal range has been directly related to health risks and death rates in many populations (WHO, 1995). The current WHO BMI cut-off points of <16 kg/m2 (severe underweight), 16·0–16·9 kg/m2 (moderate underweight), 17·0–18·49 kg/m2 (mild underweight), 18·5–24·9 kg/m2 (normal range), 25 (overweight), 25–29·9 kg/m2 (pre-obese), 30 kg/m2 (obesity). 30–34·9 kg/m2 (obese class I), 35–39·9 kg/m2 (obese class II), 40 kg/m2 (obese class III) should be retained as international classification (WHO, 2000).

Body weight comprises lean tissue, bone mass and fat tissue. With greater or lesser amounts of these variables, adiposity may not be accurately identified if BMI is used as a single measure. BMI is the most frequently used measure of excess body mass in patients with spinal cord injuries. This may underestimate the amount of body fat and many patients may not appear obese yet carry large amounts of adipose tissue (Jones et al., 2003; Spungen et al., 2003; Weaver et al., 2007). A study by Laughton et al. (2009) shows that the current BMI cut-off fails to identify obese individuals in the SCI population and suggest that BMI values greater than 22kg/m2 be considered high risk for obesity and obesity related chronic diseases in this population. There is currently a dearth in published information regarding the energy expenditure on specific populations such as people with SCI. This is particularly concerning, as people with SCI largely depend on wheelchairs for mobility and/or present with impaired walking ability, and have widely reported reduced activity levels which increase the risk for obesity and other cardiovascular disease risk factors (Buchholz et al., 2003; Jones et al., 2003; Gupta et al., 2006; Weaver et al., 2007; Laughton et al., 2009; Den Hoed & Westerterp, 2008).

Tasiemski et al. (2000) have found that after SCI many people significantly reduce or cease physical activity and in a follow up study found approximately half of the patients with SCI in their study did not participate in physical activities beyond the daily mobility required in order to function. The findings of this study revealed that higher satisfaction with life in general was demonstrated in respondents with SCI involved in sports or physical recreation compared to those not participating in physical activities (Tasiemski et al., 2005). Buchholz et al. (2003)

found that with investigating the physical activity in free-living chronic paraplegic patients that there is a need to engage in more frequent physical activity of higher intensity and duration within the SCI population to prevent a positive energy balance which leads to weight gain. Mean level of activity in this group was lower than that reported in able-bodied adults and was consistent with the WHO definition of limited physical activity (WHO, 2000). This may be one of the reasons for the high incidence of obesity in this sample.

In a study by Gupta et al. (2006) the prevalence of overweight and pre-obesity (BMI of 25 kg/m2 or more) was found to be significantly higher in paraplegics compared to tetraplegics and this trend was visible at all ASIA levels. The prevalence of obesity (BMI of 30 kg/m2 or more) was also higher in paraplegics versus the tetraplegics across all ASIA levels. The speculative conclusion was made in the study that it could be attributed to the ability to use both upper limbs in the case of paraplegic individual which allows for independence to eat freely. The tetraplegics would often be reliant on a carer for assistance and better control regarding energy intake (Gupta et al., 2006). However, a study by Munakata et al. (1997) suggests that tetraplegia is associated with significantly lower rates of energy expenditure than the paraplegic population, due to greater muscle denervation found in those with cervical lesions. It is assumed that irrespective of their lower energy expenditure the people with tetraplegia still presented with a lower BMI compared to paraplegics due to their controlled dietary intake.

Patients with complete SCI lesions presented with lower daily energy expenditure than those with incomplete lesions (Buchholz et al., 2003; Gupta et al., 2006). These findings are supported by the basis that those with complete lesions have greater absence of sensory and motor function below the level of the injury and may thus have more mobility limitations compared to those with incomplete lesions (Buchholz et al., 2003).

In a study looking at functional ambulation in the community within a group of older obese individuals the results suggest that increased obesity relates to a decrease in functional ambulation (Yamakawa et al., 2004). A significant inverse relationship was identified between BMI and walking velocity and an even stronger association between ambulation measured in steps/day and distance walked. A decrease in BMI was associated with an increase in number of steps taken per day and distance covered in daily walking. For obesity and ambulation the study shows a causative cycle where poor caloric expenditure leads to obesity which makes

ambulation more energy intensive and uncomfortable which results in increased obesity (Yamakawa et al., 2004).

A study by LeCheminant et al. (2009) found that energy expenditure was significantly higher for able bodied women with a high BMI (obese, average BMI 27.2) compared to women with normal weight during normal walking and jogging. Similar findings were reported by Mattson-Prince et al. (1997); Melanson et al. (2003) and Browning et al. (2005) including findings of higher reported energy expenditure for males with high BMI scores. It is therefore concluded that a higher BMI results in higher energy expenditure while walking for able bodied individuals.

Based on the limited available literature on the influence of BMI on energy expenditure for people with SCI it is suggested that an increased BMI score is associated with a reduced level of physical activity which in turn reinforces a higher BMI and subsequent further reduction in activity. Individuals with SCI already have a significantly reduced level of activity. Inactivity is associated with increased energy expenditure during walking. Based on BMI studies involving able bodied individuals it is clear that an increased BMI will lead to increased energy expenditure during walking. The same is suggested to apply to people with SCI when BMI scores are higher than normal.

2.3.3 Gender

Spinal cord injuries have traditionally been considered a condition mostly affecting the male population. The ratio was described as male to female ratio of 4:1 by Sekhon & Fehlings (2001). In a more recent global review on incidence, prevalence and epidemiology, Wyndaele & Wyndaele (2006) found a gender distribution ratio of men:women as 3.8:1. In traumatic SCI, the male:female ratio is much higher than in the non-traumatic cases. This is assumed to be due to majority of the working population being male and that females are less prone to road traffic accidents and falls (Van den Berg et al., 2010; Draulans et al., 2011). However considering an aging population, the increase in non-traumatic lesions and greater survival rates among SCI patients due to medical advances, the numbers of females are increasing. In a South African context the high infection rate of Human Immunodeficiency Virus (HIV) and Tuberculosis (TB) with related non-traumatic SCI conditions (Draulans et al., 2011) should also implicate that there will be an increase in females with SCI although literature on this is not currently available. Gender distributions of SCI vary according to the aetiology of the SCI (Kay et al 2010).

A study by Greenwald et al. (2001) investigated the gender-related differences in a population of SCI participants with a ratio of male: female being 1:1, who were matched according to age, ASIA motor impairment classification, and level of neurological injury. Results revealed that there were no gender related differences in the Functional Independence Measure (FIM) scores on admission and discharge, no differences in ASIA motor score improvements and no difference in length of stay in the rehabilitation setting. Similar findings were reported by Scivoletto et al. (2003) including traumatic and non-traumatic SCI. They also concluded that based on ASIA impairment grade, ASIA motor scores, Barthel Index, Rivermead Mobility Index and Walking Index for Spinal Cord Injury males and females yielded the same functional and neurological recovery. Catz et al. (2004) and New et al., (2007) had similar finding in their investigation of recovery in non-traumatic spinal cord injuries, no significant gender role was identified in recovery. Based on the literature it would appear that gender does not play a role in the neurological recovery post SCI. However, Skipski et al. (2004) found that gender differences for a given level and degree of neurological injury, men tended to perform better functionally at time of discharge from rehabilitation.

Browning et al. (2005) compared the energy expenditure of walking between able bodied men and women and found that females have higher energy expenditure than males during walking. Morio et al. (1997) had contradicting findings in their investigation of the effect gender has on energy expenditure during walking in an elderly able bodied population. They concluded that there was no difference between males and females once the variables for speed of gait, step length and body weight was corrected for.

Based on the limited available literature relating to the differences in gender performance and energy expenditure in the able bodied population, the findings are inconclusive. Based on the current evidence, nothing could be inferred about gender and energy expenditure in the SCI population. Further studies are needed with clear methodology accounting for speed, step length and BMI to ensure these variables are corrected for.

2.3.4 Pain

Neuropathic pain is described as pain arising as a direct consequence of a lesion or disease affecting the somatosensory system (Jensen et al., 2011). In the spinal cord injured population the prevalence of neuropathic pain has been described as between 40-50% of individuals, of which one third experience the symptoms as severe (Werhagen et al., 2004; Budh et al., 2003;

Siddall et al., 2003). A study by Ehde et al. (2003) found that the prevalence of pain was reported between 11%-94% of SCI patients of which one third complain of intensity being severe. A more recent study by Modirian et al. (2010) showed that the prevalence of pain after SCI was 65.7% with 21.7% reporting severe pain. The pain sensation is most often described as a burning pain (Cruz-Almeida et al., 2005; Modirian et al., 2010) which is a characteristic of neuropathic pain.

Although neuropathic pain is the most common pain experienced by individuals with SCI, musculoskeletal pain and allodynia (unpleasant sensations with non-noxious stimulation of the skin) also regularly occur (Haisma et al., 2007; Finnerup et al 2001). Pain has also been rated as one of the worst disabling consequences of a SCI (Kennedy et al., 2006; Budh et al., 2007). This is attributed to the difficulty to effectively manage its chronic nature and severity in presentation (Ehde et al., 2003; Siddall et al., 2003; Widerstrom-Noga et al., 2003; Budh & Lundeberg, 2005).

Looking at the predictors of pain and its severity several factors have been investigated. With regard to gender and prevalence to pain no relationship was reported in several studies (Turner et al., 2001; Cardenas et al., 2004; Modirian et al., 2010). In a review by Dijkers et al. (2009) the pain prevalence ratio of male to female was investigated in eight studies. The two groups were not homogenous in rate of pain prevalence but based on the presence of pain in a male to female ratio across the studies they concluded that females are slightly more prone to experience pain and report pain. In the same review article the results suggested that the differences in pain prevalence in completeness of injury - incomplete versus complete, also does not show conclusive evidence in favour of either (Dijkers et al., 2009). With regards to the level and completeness of the lesion in other studies, both have been indicated to affect the perceived pain. Incomplete spinal injuries have been found to be associated with pain more frequently after SCI than complete injuries (Finnerup et al., 2001; Modirian et al., 2010).

The level of injury was associated with presence of pain in a recent study by Modirian et al. (2010). They concluded that lumbar lesions have a higher reported perceived pain. This was supported by results in previous studies which also found a link between level of lesion and perceived pain (Ullrich et al., 2008; Rintala et al., 1998). Some studies have also found the level of injury relates to the intensity of pain (Modirian et al., 2010; Siddal et al., 2003; Cardenas et al., 2002). The level of the injury also had restricted relevance to variation of pain prevalence

(Dijkers et al., 2009; Finnerup et al., 2001). It is clear that some controversy still exist in the literature about the predictors of pain.

Pain in the SCI population has been reported to have many adverse effects on daily functioning. Studies have shown a negative impact on mood and it has been reported to cause an increase in depressive symptoms, higher levels of perceived stress, reduced level of self assessed health and perceived quality of life. Reduced level of physical activity which includes performance of activities of daily living and self-care, mobility and exercise, work and outdoor activities have also been reported. Sleep disturbances and poorer community re-integration have also been widely reported (Modirian et al., 2010; Dijkers et al., 2009; Krause et al., 2007; Donnelly & Eng, 2005; Jensen et al., 2005; Putzke et al., 2002; Siddall & Loeser, 2001; Widerstrom-Noga et al., 2001).

A study by Buchser et al. (2005) investigated the effect of spinal cord stimulation (SCS) on the walking ability in people with spinal stenosis with reduced activity levels as a result of pain. They found that walking distance, speed of walking and stride length was improved in the absence of pain. Although not measured in this particular study, both speed of walking, step length and improved physical activity are associated with more efficient energy expenditure (Fiser et al.,2010; O'Connor et al.,2012; Schrack et al.,2012)

It is clear from the available literature that pain affects overall function in people with SCI, however very little literature is available linking the impaired mobility directly with increased energy expenditure while walking.

2.3.5 Spasticity

Spasticity is a symptom often associated with damage to the central nervous system. Although not inevitable, it is a widely reported sequelae of SCI (Barnes., 2001; Adams & Hick, 2005; Haisma et al., 2007; Elbasiouny et al., 2010). Controversy still exists about the definition of spasticity. It has also been defined in other studies as a symptom of the upper motor neurone syndrome characterised by an exaggeration of the stretch reflex secondary to the hyperexcitability of the spinal reflexes (Adams, 2005). The associated symptoms have been grouped into positive and negative symptoms associated with the spasticity which is evident on clinical examination. Positive symptoms include involuntary movements, stiffness in muscles and joints caused by increased tone, hyperreflexia and a reduction in inhibition. The negative

symptoms include paresis, loss of fine dexterity and fatigability of voluntary muscles (Tilton & Bernard, 2001; Young, 1994). Spasticity may vary in its intensity during the course of the day, often being worse in the morning and late afternoon or evening.

The following have been found to increase spasticity: contractures, infection, temperature, pain, emotional state, and pressure. Pharmaceutical intervention, certain surgical procedures, self stretching and physiotherapy have been shown to decrease spasticity (Sköld, 2000; Mahoney et al., 2007). Spasticity has been reported to inhibit energy efficient walking, restrict activities of daily living and self care, cause pain and fatigue which negatively impacts on quality of life.

Spasticity predisposes the individual to develop secondary complications such as contractures, increased resistance to passive stretches, stiff joints, pressure ulcers which overall impede the rehabilitation process (Sheean, 2002; Elbasiouny et al., 2010; Roy & Edgerton, 2012). Studies on the relationship between spasticity and walking in the spinal cord injured population are scarce and mainly focused on the effect of various therapeutic interventions for spasticity while ambulating (Barbeau & Norman, 2003; Adams & Hick, 2005; Barbeau et al., 2006; Mehrholz et al., 2008; Domingo et al., 2012). Spasticity has been found to negatively correlate with 6MWT performance in a study evaluating the clinical factors influencing walking performance in SCI. The study included traumatic and non-traumatic SCI participants (Scivoletto et al., 2008). A recent study has suggested that inefficient walking patterns, such as those caused by increased muscle tone, are linked with increased energy expenditure while walking (Rodrigo et al., 2010a).

In the study by Scivoletto et al. (2008), the researchers concluded that walking performance was negatively affected by spasticity due to elevated muscle tone impairing the fluidity of movement. This presents an obstacle with timed tests due to movements being restricted or rather, movements need to overcome spasticity. Spasticity also tends to increase with an increase in effort or physical work. This leads to an increase in energy expenditure during walking and also causes a reduction in distance that can be walked before fatigue.

Spasticity has been identified as one of the factors predicting functional outcome in SCI population (Patrick, 2003; Dvorak et al., 2005). In the study by Dvorak et al. (2005) the presence of spasticity was measured at the follow up appointment two years post injury. Several participants presented with good improvement in motor scores but were still negatively related to outcome measures such as the FIM which indicates poor functional performance despite

strength. This was attributed to the degree of spasticity which negatively influenced function. The study concluded that patients with significant motor improvement and subsequent high motor scores are often plagued by spasticity which would impede their actual functional capacity. Reduced functional scores as a result of spasticity measured by the Barthel Index were also reported in a study by Tow & Kong (1998). Twenty percent of the study participants experienced spasticity requiring pharmaceutical intervention to control its adverse effects on muscle movement (Tow & Kong, 1998). Norman et al. (1998) found that using anti-spasmodic treatment improved gait speed and reduced need for assistance with walking.

From the limited literature available on the effect of spasticity on walking for people with SCI it is suggested that spasticity increases the energy expenditure required for walking due to the increased resistance to perform muscle movements. Gait speed is reduced (Norman et al., (1998) and therefore energy expenditure will again be expected to be higher than in the absence of spasticity. Walking distances are reduced due to the increased effort of walking (Scivoletto et al., 2008) which suggests reduced physical activity and higher energy expenditure to achieve walking.

2.3.6 Level of the lesion

The extent of functional impairments associated with a SCI is determined by the level and completeness of an injury. The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) developed by the American Spinal Injury Association (ASIA) and endorsed by the International Spinal Cord Society, is an internationally recognised classification of neurologic deficit after SCI (ASIA, 2003; Marino et al., 2003; Marino & Graves, 2004). The ASIA assessment uses dermatomal light touch and pin prick sensation and motor strength of selected muscle groups of the upper, lower extremities and trunk to determine the neurologic level of the injury. The ASIA Impairment Scale (AIS) classifies the extent of the SCI according to motor complete (AIS grades A and B) and motor incomplete injury (AIS grades C and D). AIS grade C differs from AIS grade D based on the proportion of key muscle groups below the level of injury that have muscle grades of three or higher (ASIA, 2003; Marino et al., 2003). The examination was designed to classify impairment, however, a recent clinical trial has used motor scores and AIS category conversion as a measure of therapeutic efficacy. ASIA grade was also found to be the strongest predictor of ambulation potential (Stuart et al., 2009). This is also found in a study by Barbeau et al. (2006) concluding the level of initial ASIA grade is a major predictor of walking ability after spinal cord injury. Early responses, between two days and four

weeks post SCI, in lower limb and sacral pin prick sensation as well as lower limb motor scores have been correlated with walking after one year post injury (Gittler et al., 2002; Oleson et al., 2005; Van Middendorp et al., 2009).

The relationship between lesion level and energy expenditure was investigated in a study by Kawashima et al. (2005). They found that higher level thoracic lesions resulted in higher energy expenditure in order to produce gait. During a motion analysis they concluded that the slower gait speed as a result of higher lesions contributed to limited hip motion and presumed excess load on the upper limb, making the gait inefficient. Hence, neurological level and subsequent paralysis considerably influence the achievement of orthotic gait and energy expenditure required (Kawashima et al., 2006). People with SCI inevitably require more energy for orthotic gait because they need to produce complementary upper limb and trunk motion in order to move the paralysed body segments and assistive devices (Solomonow et al., 2000). ASIA lower extremity motor scores produced a high correlation coefficient with the 6MWT in terms of gait speed and distance walked in a study investigating the relationship of muscle strength with ambulatory capacity in SCI (Kim et al., 2004).

Energy expenditure during walking is therefore dependent on the level of the lesion based on the fact that lower lesions, with subsequent higher lower extremity scores, require less compensation from the upper limbs and trunk in order to produce the walking movement and possibly fewer orthotic devices. Gait speed and stride length are also affected by the level of the lesion which also affects the energy expenditure required to produce gait.

2.3.7 Use of assistive devices

Normal gait involves smooth advances of the body through space with the least mechanical and physiological energy expenditure (Lehmann et al., 1999; Waters & Mulroy, 1999; Rodrigo et al., 2010a). The goal of walking is to progress in a forward motion while maintaining symmetry and low amplitude displacement of center of gravity in a vertical and lateral directions. Muscle activity is responsible for producing limb movement. Interruption in the normal gait cycle and energy conservation characteristics of the trunk and limbs due to inefficient contraction and compensation due to muscle weakness result in increased energy expenditure (Waters & Mulroy, 1999; Kawashima et al., 2006). The majority of individuals with SCI have a variety of mobility aids to assist them to be independent in that domain and achieve the highest quality of life possible (Biering-Sorensen et al., 2004).

An individual with a complete paraplegic lesion would require crutches or a walking frame and a bilateral knee-ankle-foot-orthosis (KAFO's) in order to stabilise the knees as they usually lack abduction and extensor muscles to stabilise the hips. The arms need to lift the entire body weight to enable a swing with the trunk and lower limbs to allow forward propulsion. The arms also need to supply anti-gravity support during the stance phase to control the trunk and hips. Considering all the above implications it is easy to understand why people with SCI are generally slow ambulators. Walking velocity is approximately around 0,48 meters/second and distances covered are around 29 meters/minute.

Despite the slow walking speed, energy expenditure in people with SCI is very high (Waters & Mulroy, 1999). With adequate knee control, gait can be assisted by an ankle-foot-orthosis (AFO). This will allow for passive dorsiflexion of the ankle which assists the swing through of the lower limb during gait. If one lower limb has fair muscle strength in the quadriceps to enable knee locking during gait a single KAFO can be used and a reciprocal gait pattern using crutches adopted.

The use of assistive devices, such as crutches or walker, to support lower limb weight bearing during gait requires significant upper extremity effort. This is associated with an elevated heart rate and increased energy expenditure. It has also been suggested that the energy demand of ambulation is dependent on the extent of orthosis required to stabilise the paralysed limb (Solomonow et al., 2000; Kawashima et al., 2006). As lower extremity paralysis increase, patients substitute for the loss with exerting higher upper extremity forces on crutches and slowing the gait speed. The magnitude of upper extremity exertion has been found to be proportional to the physiological energy expenditure. Therefore the physiological intensity of orthotic gait is strongly dependent on the level of the lesion (Kawashima et al., 2006; Ulkar et al., 2003; Waters & Mulroy, 1999).

People with SCI inevitably require more energy expenditure for orthotic gait because they need to produce complementary upper limb and trunk motion in order to move the paralysed body segments (Solomonow et al., 2000). Orthotic gait requires high energy expenditure which usually leads to exhaustion after a few minutes. This often leads to abandonment of orthotic use (Waters & Mulroy, 1999; Merati et al., 2000; Ulkar et al., 2003; Ohta et al., 2007).

In an investigation to clarify the effect of lesion level on the cardio-respiratory and biomechanical characteristics of walking, Kawashima et al. (2006) found that the SCI group had six times more energy cost in orthotic assisted SCI gait compared to able bodied individuals. Different walking aids have been shown to affect the walking speed in the same subjects resulting in a more or less efficient gait. Crutches were found to be more energy efficient than walkers (Ulkar et al., 2003).

Based on the available literature, it can be assumed that the use of assistive devices in order to produce walking in the SCI population does increase energy expenditure due to the involvement of the upper limbs and trunk in order to produce lower limb movement.

2.3.8 Range of motion

Joint flexibility is defined as the range of motion (ROM) allowed in a joint. ROM values usually decline with age but without detriment to the person's quality of life or activities of daily living (ADL) performance (Magee, 2006). This is not the case when pathology limits the active ranges in joints which then often results in a decline in performance of walking (Patrick, 2003). A loss of ROM is usually obvious in the case of a contracture however it may be easily missed if it is a mild loss of range or a limitation caused by spasticity in people with SCI (Patrick, 2003).

Sköld et al. (1999) reports a significant association between spasticity and loss of ROM due to contracture formation in SCI. Investigating the cause of ROM limitations is vital to successful treatment. Poor foot clearance during the swing phase of gait could be due to a partial or complete paralysis of the ankle dorsiflexors, or some degree of spasticity of the ankle plantarflexors. Muscle imbalance at a joint is supposedly an easy clinical judgement but complications with dynamic control are often overlooked. This is often seen in patients with SCI during supine examination but the true pathology is revealed during a walking assessment (Patrick, 2003). Another example includes an inappropriate action of the rectus femoris muscle in swing phase preventing knee flexion, through its distal attachment to the tibia. This 'lengthens' the limb during swing and prevents foot clearance and creates a need for circumduction of the leg (Patrick, 2003).

There is a dearth in literature reporting on the effects of ROM on energy expenditure during walking in the SCI population. In a study by Kawashima et al. (2006) investigating the effect of the lesion level on the orthotic gait performance in complete thoracic SCI, the results suggest that ROM does affect the energy expenditure while walking. Higher thoracic lesions and

resultant increased paralysis in the trunk and hip musculature produce smaller ROM at the hips during walking than lower thoracic lesions. This is suggested to be due to the upper body motion being insufficient to produce leg swing (as a result of the increased relative paralysis). In a study investigating the nature, severity and location of spasticity after traumatic SCI in an out-patient setting the researchers found that impaired ROM potentiates spasticity in this population. It was therefore concluded that preservation of full range is of paramount importance to limit the debilitating effects of spasticity (Skold et al., 1999). An increase in spasticity has been suggested to also increase the energy expenditure during an activity such as walking (Scivoletto et al., 2008). Therefore a loss of ROM can increase spasticity patterns which in turn will increase the energy expenditure required in order to produce gait. Spasticity pattern can also prevent normal joint movements required in the absence of limits in ROM which again will increase energy expenditure to overcome the spasticity patterns and produce gait.

Upper limb ROM was evaluated in a recent study to investigate the impact limited ROM at discharge would have one year later on functional performance. Newly injured SCI participants were included and shoulder ROM was measured at discharge from initial rehabilitation and again one year later. Their findings were that participants with limited ROM of the upper limbs at discharge are more limited in their functional activities on re-assessment (Eriks-Hoogland et al., 2011). This would play a role in the use of assistive devices such as crutches or a walking frame due to the increased energy expenditure required to compensate for the loss of ROM in order to perform walking.

Based on the available literature, ROM does affect energy expenditure during walking as it causes the individual to either compensate with upper limbs and trunk for the loss of ROM in the lower limbs due to loss of muscle control or due to spasticity causing a loss of ROM. Upper limb ROM may also affect energy expenditure when assistive devices are required for walking.

2.3.9 Extent of treatment

There is a growing body of evidence to suggest that physical exercise improves strength, functional performance and endurance in the spinal cord injured population. The quality and duration of ongoing treatment along with extent of muscle power loss, level of lesion, degree of spasticity present, type of lower limb joint deformity and patient specific details such as age and BMI will determine the prognosis of walking in people with SCI (Patrick, 2003; Olmos et al., 2008; Scivoletto et al., 2008). Waters & Mulroy (1999) reported that early recovery of muscle

strength has been identified as a good predictor of ambulatory capacity. However a clinical guideline on the exercise prescription and extent of treatment remains vague in terms of intensity and duration required.
Performance of ADLs is considered insufficient exercise to maintain fitness and a lack of participation in a regular exercise program may increase risk for cardiovascular disease along with other lifestyle diseases (Devillard et al., 2007). Several training programs have been investigated in people with SCI and despite a lack of consensus about training recommendation (type, intensity and frequency) endurance training has been shown to have beneficial effects (Rimaud et al., 2005).

In a review investigating the effects of training programs in SCI the researchers concluded that physical training and reconditioning programs should aim to achieve optimal functions in cardio-respiratory, cardiovascular, metabolic, bone health, muscle strengthening, functional capacity and in doing so also optimise quality of life (Devillard et al., 2007). Strength training has been directly linked with improved walking performance in terms of gait speed, step length and improved walking endurance (Kim et al., 2004; Scivoletto et al., 2008). This in return reduces energy expenditure during gait performance (Scivoletto et al., 2008).

In some of the available literature therapeutic intervention is mainly focused on upper-body training. Rimaud et al., (2005) reported tremendous variability in the training regimens utilised in their review. They reported on a study which recommended 30 minutes of rhythmic exercises, three days per week at 70% of the maximum heart rate (HR) for eight weeks, to improve cardiovascular endurance as the only guideline in terms of exercise intensity prescription. Hicks et al. (2011) reported that exercise should be performed 2-3 times per week at moderate to vigorous intensity to improve muscle strength and physical capacity. Valent et al. (2007) concluded that upper body exercise may increase physical capacity among people with SCI but no specifics of intensity were discussed.

Harkema et al. (2012) reported significant improvements made in Berg Balance Scale scores, distance improvement in the 6MWT and velocity in the 10MWT. The treatment regime consisted of 90 minutes of gait training and followed by community integration exercise. Although still vague on how frequently out-patients were seen and range of treatments was between 20-251 sessions, the results suggest an improvement in energy expenditure would be expected with walking parameter improvement. Kay et al. (2007) reported in-patient length of

stay as a mean of 60 days however no specifics on treatment program was given but significant improvements in FIM scores were reported for locomotion.

There is very limited literature available on the intensity of treatment and none which directly link the effect it would have on energy expenditure while walking. It can however be concluded that with improved muscle strength, stride length, gait speed and walking endurance, energy expenditure would be reduced.

2.3.10 Duration since injury

Within the literature on the neurological recovery post SCI research has mostly looked at the recovery within the first or second year post injury (Marino et al., 1999; Patrick, 2003; Burns et al., 2012). Previous studies have reported on the major factors determining recovery in the first year post traumatic SCI including neurological level of injury, the initial motor strength and most importantly if the lesion was complete or incomplete. The motor recovery takes place mainly during the first six months post injury and the most rapid recovery takes place within the first three months post SCI (Kirshblum et al., 2004). Looking at neurological recovery in the chronic SCI, Kirshblum et al. (2004) reported improvements in neurological recovery up to five years post injury in traumatic SCI cases. McDonald et al. (2003) also reported motor recovery up to five years. Hicks et al. (2011) concluded that in the chronic SCI population there is good evidence to suggest that exercise is effective in improving physical capacity and muscle strength. Dvorak et al. (2005) reported improvement in motor scores up to 12 years post SCI.

The aetiology of the injury plays a role in predicting neurological recovery by predisposing whether the lesion is complete or incomplete (Ditunno et al., 1997; 1998; Marino et al., 1999). SCI caused by violence is more likely to result in a complete lesion (Marino et al., 1999). Kirshblum & O'Connor (1998) found that recovery is more favourable in persons with incomplete tetraplegia than complete with more than 50% becoming ambulatory. However some recovery does take place in complete lesions. Most patients with complete tetraplegia will regain at least one motor level during recovery (Kirshblum & O'Connor, 1998; Marino et al., 1999). The preservation of pin prick sensation relative to light touch alone is also a good prognostic sign to motor recovery. People with SCI who convert from complete to incomplete within the first three months post injury have a better prognosis for functional lower extremity recovery (Kirshblum et al., 2004).

Harkema et al., 2012 investigated the effect of an intensive locomotor training program for participants in out-patient therapy, with duration since injury between 32days-25 years. Functional improvement was evaluated for balance and walking ability. The study concluded that although patients in the group > 3years post injury did not improve as much as in the other groups (less than a year and 1-3 years post injury respectively), the improvements made in the >3years group were still significant in Berg Balance Scale, distance improvement in the 6MWT and velocity in the ten meter walk test (10MWT) (Harkema et al., 2012). Based on improvement in gait speed and endurance it would be suggested that energy expenditure would also be decreased with this improvement (Fiser et al., 2010; Schrack et al., 2012).

What can be gleaned from the literature above is that although neurological recovery for people with SCI is suggested to be mainly during the first two years post injury, literature investigating the effect of intensive programs in the chronic SCI population have revealed that significant recovery in walking speed, muscle strength, balance and endurance is still occurring. It may therefore be suggested that with a greater duration since injury, walking ability may be faster and more efficient than during the more acute stages due to ongoing recovery. Although no direct link was made between duration since injury and energy expenditure, faster self selected walking speed and improved muscle strength have been linked with lower energy expenditure.

2.4 GAIT PERFORMANCE IN PATIENTS WITH SPINAL CORD INJURY

People with SCI describe the inability to ambulate as one of the most devastating consequences of their injury (Anderson, 2004). Regaining the ability to walk has been described as one of the highest priorities during recovery for people with SCI (Ulkar et al., 2003; Ditunno et al., 2008; Scivoletto et al., 2008). Recent reports have brought to light the importance of walking but also the walking performance, particularly speed and distance (Lapointe et al., 2001; Scivoletto et al., 2008; Stuart et al., 2009; Van Hedel et al., 2009). Functional walking has been reported to have the following requisites: safety (need for walking aid), velocity, comfort and distance (Scivoletto et al., 2008).

In a study by Scivoletto et al. (2008) they investigated the clinical factors that affect walking in chronic SCI. The study included participants who had traumatic and non-traumatic SCI. The study results revealed that lower limb strength was related to walking performance with regards to velocity (10MWT), walking level (WISCI) and endurance (6MWT). Normal walking speeds for able bodied adults (between age 20 and 60 years) are between 1.0 and 1.67 meters/second.

The distance covered is usually 60-100 meters/minute (Waters & Mulroy, 1999). The spinal cord injured population has a reduced muscle mass as a result of the lesion on the spinal cord as well as a reduced sympathetic nervous system available for exercise. This result in reduced peak physiological responses and absolute power output compared to able bodied individuals (Price, 2010, 2009). The walking activity for people with SCI does not only require the individual to have the capacity to move their legs but also requires well defined coordination of neural input to maintain an upright posture and balance as well as adapt to environmental demands. Energy expenditure after a SCI is higher due to greater upper limb and trunk involvement during walking compared to able bodied individuals in order to swing their paralysed lower limbs and maintain balance (Ijzerman et al., 1999).

Energy expenditure is an important variable which has to be monitored in order to determine the efficiency of gait and an individual's functional independence in ambulation (Lapointe et al., 2001). Results from Lapointe's study also revealed that comfortable walking speed for able bodied people was twice that of incomplete SCI participants. The SCI participants could not reach the velocity to safely manage community ambulation such as crossing the road at an intersection. When walking at maximal speed, although still short of the required velocity, the energy expenditure increases significantly which then impedes their endurance (Lapointe et al., 2001). Safe community ambulation would require a walking speed of an estimated 1.22 meters/second in order to safely cross at a pedestrian crossing (Stuart et al., 2009).

Stuart et al. (2009) also found that gait speeds for people with SCI at discharge from rehabilitation was significantly less than that of able bodied individuals. Gait speed was reported to be one fifth to one quarter of normal scores. Endurance measured in the 6MWT was less than a third of the reported normal scores and suggested to be insufficient to allow safe community ambulation (Stuart et al., 2009). Waters & Mulroy (1999) also concluded that gait speed for people with SCI is not compatible with safe and efficient community ambulation. They also found in a previous study that energy expenditure of walking after SCI is above normal (Waters et al., 1989).

In a study by Van Hedel et al. (2009) gait speeds within different categories of SCI mobility levels were investigated and evaluations were done at one, three, six and twelve months post SCI. Their results showed that participants who were wheelchair-dependent achieved a walking velocity of 0.1 meters/second. Supervised walkers achieved 0,34 meters/second, indoor walkers

who were wheelchair dependent outdoor achieved 0,57 meters/second, assisted walker (using a walking aid) achieved 0.88 meters/second and participants who did not require a walking aid achieved 1,46 meters/second.

Based on the available literature it is clear that gait for people with SCI is performed at a significantly reduced speed compared to the able bodied population and with significantly reduced endurance. Energy expenditure during SCI gait is suggested to be much higher than able bodied gait due to the reduced self selected speed and greater upper limb and trunk involvement in order to achieve lower limb movement and upright balance during walking.

2.5 CONCLUSION

This literature review was conducted to review the current body of knowledge relating to the energy expenditure during walking for both spinal cord injured as well as able bodied participants. Research pertaining to the factors which may influence the energy expenditure during walking was also reviewed. The literature reviewed has shown that age increases energy expenditure during walking for SCI and able bodied individuals due to the age related physiological changes and reduction in gait speed. Limited literature is available on the influence of BMI on energy expenditure for people with SCI however based on literature on the able bodied population an increased BMI will lead to increased energy expenditure during walking.

There is an absence of literature in the SCI population regarding the role (if any) gender plays in energy expenditure while walking. In the able bodied population the research is contradicting and no clear conclusion can be drawn to allow inferences to be made regarding the SCI population. Pain is clearly illustrated in the literature as a common complication following SCI and that it does affect overall function. There is a dearth of literature linking the impaired mobility to an increase in energy expenditure while walking. Spasticity was found to be a common post-SCI complication and energy expenditure while walking was higher in individuals with SCI who had spasticity. This is due to the increased resistances to move as well as reduced gait speed that results from spasticity.

Level of lesion is suggested by the literature to have an impact on energy expenditure – the higher the lesion the greater the upper limb, trunk and orthotic compensation need and therefore the higher the energy expenditure during walking. Based on the available literature,

ROM does also affect energy expenditure during walking as it causes the individual to compensate with upper limbs and trunk for the loss of ROM in the lower limbs.

There is very limited literature available on the intensity of treatment and none which directly link the effect it would have on energy expenditure while walking. It can however be concluded that with improved muscle strength, stride length, gait speed and walking endurance, energy expenditure would be reduced while walking.

CHAPTER 3

3. METHODOLOGY

3.1 TYPE OF STUDY

This was an observational cross-sectional study.

3.2 SAMPLE SIZE

The required sample size was determined as follows:

From the pilot study performed with 10 participants in each group, the able bodied participants' mean energy expenditure had a standard deviation of ±0.018 cal/m. Due to the small variation it was decided to recruit SCI participants and able bodied participants in a 2:1 ratio. Sample size of at least 28 SCI participants and at least 14 able bodied participants had 90% power to detect a change in energy expenditure. A standard deviation of ±0,018cal/m was used and testing was two-sided at the 0.05 level of significance. The final sample included was 66 participants, 45 SCI- and 21 able bodied participants.

3.3 SAMPLE SELECTION

3.3.1 Source of subjects:

Participants for the study were recruited from the following SCI rehabilitation units: Muelmed Medi-Clinic, Netcare Rehabilitation Hospital, Life New Kensington, Life Riverfield Lodge, Life Eugene Marais, Rehabmatters, Natalspruit Hospital and Tshwane Rehabilitation unit. A process of consecutive sampling was used until the required number of participants was reached according to the determined sample size. For the able bodied groups the required number of participants based on a 2:1 ration was collected in both male and female participants to ensure the groups are comparable at the end. This was done by requesting therapists and other staff members from the rehabilitation units, family and friends meeting the criteria to participate.

3.3.2 Inclusion criteria

- Participants with a SCI who were ambulatory prior to SCI.
- Participants with a complete thoracic level 10 or below and those with incomplete lesions at any spinal level, who were ambulating.
- Participants who were 18 years of age or older.

- Participants who could comprehend and follow instructions given.
- Participants who could walk ten meters unassisted including those who used other orthotics such as callipers, backslabs, ankle-foot-orthoses and walking aids to assist in their gait.
- Able bodied participants who were comparable in age, gender and BMI to participants with SCI.

3.3.3 Exclusion criteria

- Participants who had other medical conditions or co-morbidities such as cardiac, orthopaedic, respiratory or neurological conditions that would limit mobility.
- Participants with SCI for whom exercise and mobility was contra-indicated.

3.4 INSTRUMENTATION AND OUTCOME MEASURES

The following instruments were used during the data collection process:

3.4.1 Demographic questionnaire

A demographic questionnaire (Appendix A) was developed which captured the following information about the participants with a SCI: gender, age, date of onset of SCI, use of assistive devices and walking aids for general mobility as well as the extent of their mobility. Other items that could also potentially influence the energy expenditure such as body mass index (BMI), level of the lesion, presence and frequency of pain, extent and duration of rehabilitation were also included. The matched able bodied participants only filled in the parts of the demographic questionnaire which were applicable to them. This included age, gender and mobility. Their height weight, body mass index and energy expenditure were also recorded on the questionnaire sheet. The questionnaires were coded in order to maintain confidentiality.

3.4.2 The American Spinal Cord Injury Association Impairment Scale (ASIA)

Each participant in the spinal cord injured group had an ASIA score assessment to classify the severity of the SCI. Both motor and sensory scores were assessed with the ASIA Impairment Scale to establish the level of the spinal cord lesion – Appendix B.

The ASIA Impairment Scale has become the standardised and routinely adopted classification for patients suffering from SCI (Marino et al., 2003). It is currently regarded as the standard measure of neurological outcomes (ASIA, 2002; Lammertse et al.,

2007). Reliablility of the ASIA assessment was established by Curt & Dietz (1997) and Clifton & Donovan (1996). The validity was established by Cifu et al. (1999b) for acute tetraplegia, van Hedel et al. (2009) for acute SCI patients and by Marino et al. (2006) for chronic SCI.

Categories of ASIA Impairment Scale are as follows:

ASIA A — A complete injury where no sensory or motor function is preserved in sacral segments S4-S5.

ASIA B — An incomplete injury where sensory, but not motor, function is preserved below the neurologic level and extends through sacral segments S4-S5.

ASIA C — An incomplete injury where motor function is preserved below the neurological level, and most key muscles below the neurologic level have muscle grade less than 3 (active full-range movement against gravity).

ASIA D — An incomplete injury where motor function is preserved below the neurological level, and most key muscles below the neurologic level have muscle grade greater than or equal to 3.

ASIA E — Normal sensory and motor functions (ASIA 2002)

3.4.3 Height, weight and BMI

Each participant had their height and weight measured prior to starting assessments. This was used to calculate body-mass index (BMI). The BMI was calculated as weight/height^2. Weight was measured to the nearest 0,1 kg using the SECA 813 digital scale in order to calculate BMI. The scale and measurement protocol to determine BMI has been used in a study by Van Cauwenberghe et al., (2011) in their study which assessed the feasibility and validity of accelerometer measurement for toddlers. The BMI is an easy to use tool with low cost used to identify obesity or risk of developing obesity (Laughton et al., 2009). The WHO has identified a BMI of 30 kg/m^2 and above

as the cut off point at which people are considered obese (WHO, 2000). In the able bodied population the BMI had to be comparable to the SCI group. Based on the fact that ranges for normal BMI was 18.5-24.9kg/m^2 which is a 6.4 point difference, the range for this study was determined as no more than three points difference to allow for some more accurate comparability (WHO, 2000). In other words if the group of SCI participants had a collective average of 22 kg/m^2 the able bodied group could be up to 25 kg/m^2 as a group average or down to 19 kg/m^2.

3.4.4 RT3 Accelerometer

The amount of energy expended while performing the walking assessment was evaluated using a Tri-axial accelerometer (RT3). It has been identified as an assessment tool ideally suited to measure energy expenditure during mobilisation (Welk, 2005). It was shown to be a reliable tool to use for the assessment of energy expenditure in a study with patients who have Multiple Sclerosis (Hale et al., 2007). The validity of the RT3 was established in a group of non-disabled participants (Hendrick et al., 2010).

The RT3 is a battery powered research grade activity monitor. The device detects and records 3-Axis motion (along three anatomical axes). The RT3 accelerometer (Stayhealthy, Inc, Monrovia California) is a small accelerometer weighing only 65g. The RT3 is superior to its predecessors because of its accuracy of measuring movement which is based on the ability to integrate three electronic measures into one data chip and subsequently provide more information on the movements occurring. These measurements are then used with the participant's physical characteristics like height, weight, age and gender to determine the most accurate caloric energy value for the particular activity (Hale et al., 2007).

The RT3 provides data measured in 'activity units' and can be converted to estimate energy expenditure in total calories or metabolic equivalent (METS). The formula used to convert recorded data to activity kilocalories was developed through internal clinical trials and is based on mass and integrated acceleration (Hale et al., 2007). This process was computed by the RT3 software once recording of activity units was completed. The RT3 is able to store data in one second intervals and has capacity to record readings for nine hours on this setting. This device can therefore be used to measure discrete movement or physical activity over longer periods of time. For the purposes of this study we were

interested in the evaluation of the most discrete movements that would influence the energy expenditure over a set distance. Data was recorded in one second intervals. Each participant's energy expenditure score was recorded on their demographic questionnaire.

3.4.5 Six minute walk test (6MWT)

The 6MWT was used to measure the distance the participants could walk, for the duration of six minutes. This is an outcome measure often used to determine level of endurance. It is a self-paced timed measure of ambulation which measures the distance that a patient can walk on a flat, hard surface in six minutes and assesses the sub-maximal level of functional capacity (ATS, 2002). It has been described as easier to administer, better tolerated, and more reflective of activities of daily living than other walking tests. There are many factors that influence the variability in performance which include; height, age, body weight, sex, and motivation (ATS, 2002). The test evaluates the integrated response of pulmonary, cardiovascular, and circulatory systems, in addition to level of motor control, functional neuromuscular units, and muscle (Ditunno et al. 2007). It was originally developed as a test of aerobic capacity in cardiopulmonary disease and has shown to have good test-retest reliability, inter-observer reliability, construct validity and responsiveness to change (Lam et al., 2008; Van Hedel et al., 2006; Jackson et al., 2008). The 6MWT has been used in several studies to evaluate the recovery of gait and gait performance in the spinal cord injured population, thus illustrating its validity (Olmos et al., 2008; Van Hedel et al., 2006; Van Hedel et al., 2007; Jackson et al., 2008; Lam et al., 2008; Stuart et al., 2009).

3.4.6 Polar pulse rate monitor was used to measure base line and end of walking pulse rate. Pulse rate is an indicator of cardiac regulation which has been used in research as a gross estimation of energy expenditure in people with SCI during walking (Hayes et al., 2005). The Polar pulse rate monitor has been used in SCI research on physiological cost of gait during walking to establish the heart rate (Arazpour et al., 2012). Nunan et al. (2009) also found the Polar to be a reliable and valid instrument for heart rate measurement.

3.4.7 The Modified Ashworth Scale (MAS) was used to measure the intensity of spasticity where applicable. It is very difficult to objectively quantify spasticity in clinical practice, however there is a need to define its presence and extent in order to assess the efficacy of therapeutic intervention as well as its impact on various functions in neurological pathology. The Modified Ashworth Scale is a widely used tool in order to quantify the effects of spasticity in the neurological world (Kakebeeke et al., 2002). It measures the movement-provoked spastic muscle resistance (increased muscle tone). (Skold, 2000). It is a measure frequently used for research and clinical practice (Kohan et al., 2010). However there is some controversy about the validity of this measure due to its subjective nature (Kohan et al., 2010). The MAS has been shown to have moderate reliability in assessment of muscle spasticity in some studies (Ansari et al., 2008). However others have concluded a higher reliability with its assessment in upper limbs than lower limbs (Kohan et al., 2010; Pandyan et al., 1999). MAS was described to have sufficient test-retest and interrater reliability in a recent study. The researchers recommend providing training and clear instructions as it will improve the reliability of the MAS (Waninge et al., 2011; Gregson et al., 1999).

The scoring of the muscle tone is as follows:

0 No increase in muscle tone

1 Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part(s) is moved in flexion or extension.

1+ Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM

2 More marked increase in muscle tone through most of the ROM, but affected part(s) easily moved

3 Considerable increase in muscle tone, passive movement difficult

4 Affected part(s) rigid in flexion or extension (Bohannon and Smith, 1987).

3.4.8 A goniometer was used to measure the range of motion for the lower limbs to indicate possible loss of range where applicable.The goniometer is a standard device for measuring angles in order to determine range of motion in physiological movements. It consists of three parts, the circular base with degree markings on it referred to as the body, and two arms - a moving arm which moves with the patient's joint to indicate the extent of movement and a stationary arm which remains fixed to the body (Magee, 2006). Goniometer assessed ROM have been used in studies to assist with defining the extent of certain neurological complications including spasticity and progressive deterioration in upper limb function in paraplegics within the SCI population (Kakebeeke et al., 2002; (Skold et al., 1999; Eriks-Hoogland et al., 2011). In the study by Kakebeeke et al., the researchers commented on the possible subjective bias which could influence results due to manual testing with the goniometer for the ROM. In a review of the validity and reliability for the use of the universal goniometer, the clinical validity of its use in measurements of range was confirmed. With respect to factors such as differences of motions measured, methods of application, variation among different patient types, the reliability of the universal goniometer was also concluded. The universal goniometer also yielded high intra- and inter tester reliability in a more recent study assessing active range in people with knee ROM restrictions (Brosseau et al., 2001).

3.5 PROCEDURE

3.5.1 Content validation of the demographic questionnaire

In order to establish content validity of the demographic questionnaire, a panel of SCI rehabilitation therapists who work in the SCI field were approached. This panel was made up of four physiotherapists. They assisted the researcher with identification of the factors that could influence the energy expenditure of a participant with SCI while walking performing a 6MWT. Identification of factors to consider was based on clinical experience and relevant literature. Once the factors were listed and consensus reached amongst the members on the panel the questionnaire was constructed and the considered ready for data collection process.

3.5.2 Pilot study

The pilot study was conducted after ethical clearance was obtained. The purpose of the pilot was to establish the standard deviation of energy consumption during a walk test within the normal population in order to assist with the sample size calculation. It also served to determine the time it took to complete the entire assessment process from the questionnaire up to completion of the 6MWT. In order to simplify comparison between the two groups (able bodied and participants with SCI) ten male participants in each group were included in the pilot study. The process started with administering the demographic questionnaire. The ASIA assessment followed. Upon completion of the ASIA, the modified Ashworth and ROM testing was done.

Each participant had their height and weight measured before positioning the pulse rate monitor for base line pulse rate recording. The base line pulse reading was recorded on the demographic questionnaire. Once the accelerometer was programmed with the participant's information including height, weight, age and gender, the accelerometer was positioned on the participant. The 6MWT was then performed. The pulse rate was taken again upon completion of the walking assessment and recorded on the demographic questionnaire along with the distance walked during the 6MWT.

During the able bodied participant assessment the procedure started with filling the applicable sections on the demographic questionnaire followed by height and weight measurement and base line pulse measure. The accelerometer was programmed with participant particulars and then positioned on the posterior aspect on the midline secured to a belt or back of participants pants. The process was concluded with the completion of the 6MWT as above, pulse rate measure and recording of distance on the demographic questionnaire.

3.5.2.1 Changes to the demographic questionnaire

As a result of the pilot study minor changes were made to the demographic questionnaire:

- Adding a selection block for N/A (not applicable) in the section for therapy after hospital discharge. This was done in order to indicate when participants were still in their acute in-patient rehabilitation stage,
- Adding EE/m (energy expenditure per meter) below the 6MWT measures already listed in order to add each participant's energy value per meter by dividing the

energy expenditure measured by the accelerometer by the distance they walked during the 6MWT.

3.5.2.2 Changes to procedure:

During the pilot study several data collection difficulties were identified with sequence and flow of assessments. The process was adjusted to ensure minimal exertion for the patient. Changes included:

- Weight measurement was not performed during demographic questionnaire.
- Physical assessments, procedures which were performed in supine/lying down (ROM, ASIA, MAS, height) were performed in sequence followed the procedure in standing - weight measurement.
- Resting in between assessment completion and walking assessment was added to ensure more accurate results during the walk test.
- Due to the pilot study indicating that several of the SCI participants required sit down rests and could not manage 30 meters before doing so, distance was reduced to 10 meter unlike the suggested 30 meters by the American Thoracic Society (2002). This was measured on a smooth, even surface using a measuring tape and indicated every 2,5 meters with sticking tape as markers.
- Handling skills with the accelerometer required some practice in order to improve efficiency of assessor. Overall duration of participant assessment was very long (90 minutes) in the case of the SCI assessments but with practice during the pilot study the assessment time improved to a more efficient 45 minutes.

3.5.2.3 Results and implication of the pilot study:

The results of the able bodied energy expenditure (n=10) was used to determine the sample size needed for the main study. The able bodied participants' mean energy expenditure per meter during a 6MWT was observed as 0.1 cal/m (calories per meter walked) for which the standard deviation was ±0.018 cal/m. In view of this small variation in the able bodied group it was decided to recruit SCI participants and able bodied participants in a 2:1 ratio. For the purposes of this study, a 20% increase in energy expenditure was assumed to be clinically relevant in order to indicate sufficient difference between able and SCI participants. Based on that assumption, sample size of at least 28 SCI participants and at least 14 able bodied participants had 90% power to detect such an increase.

3.5.2.4 Conclusion of the pilot study

This reduction in assessment time was satisfactory for the assessor and the participants. This allowed for multiple assessments per data collection morning/afternoon at a particular rehabilitation setting as well as assuring participants that the entire process will be completed in less than an hour.

3.5.3 Main Study

After the permission was obtained to continue with the study, participants who met the inclusion criteria were identified. This was done by being in regular contact with the SCI rehabilitation facilities to enquire about suitable participants. The potential participants were then provided with the information clearly stating the aims of the study and what was expected if they chose to participate. As the consecutive sampling process took place participants willing to be involved were requested to give written consent. The demographic questionnaire was completed with the assessor at the start of the participant assessment. The participant was then placed in a supine position to start the physical assessments in lying. The ASIA assessment was done first. This was followed by the MAS - For the muscle which primarily performs flexion at a joint, the limb was positioned in maximal flexion and moved into maximal extension over one second. The opposite occurred when a muscle of primary extension was tested.

The height measurement followed which was also done in supine on the plinth with legs and trunk straightened and ankles in a neutral position (plantargrade). No shoes were worn during this measurement. Arms were positioned by their side. A mark was made on the surface at the top of the head and between the bases of the heels with the ankles in neutral. The participant then moved aside to allow measurement of the two points to establish the height. Measurements were done using a measuring tape.

Range of motion was assessed for lower limbs using a goniometer. The participant was then left to relax in supine for three minutes to avoid the spasticity being evoked by the ROM measurements (Craven and Morris, 2010). Prior to weight measurement the SECA 813 scale was calibrated by using a three kilogram dumbbell weight before each weight measurement was performed. The weight measurement was done by stepping onto the scale which was positioned within the parallel bars. The participants were allowed to use the bars to get onto the scale and to steady themselves until balanced. If the participant

was dependent on orthotics to maintain balance, the assistive devices were weighed afterwards and the weight subtracted from the weight of initial measurement. Where participants were unable to statically stand without external support it made accurate weight measurement difficult and it was noted on the demographic questionnaire.
Shoes were standardised to lace up running shoes for the walking assessment.

Before the 6MWT assessment, the energy expenditure measurement procedure was started by attaching the accelerometer to the docking station. The relevant participant specific data was entered including participant code, height, weight, age and gender. The mode of collection was set to collect every second interval and information was transferred to acceleromer via the RT3 software. It was then taken from its docking station and positioned as close to the participant's centre of gravity as possible. This was done by securing the accelerometer on to the participant's belt or pants on the posterior aspect in the midline by a clip to minimise movement other than that of the patient performing the ambulatory assessment.

Once the data collection was started by selecting the start button the recording was not stopped until it is docked again or ran out of memory. This prevented tampering with the recording by the participant (RT3 User Manual Version 1.1, Stayhealthy, Inc.). After the data was collected, the RT3 was placed on the RT3 dock and data transferred and interpreted independently (RT3 User Manual Version 1.1, Stayhealthy, Inc.).

The pulse monitor was attached and baseline pulse rate recorded on the demographic questionnaire sheet. The participants then walked at a comfortable self-selected speed along the well indicated 10 meter line which was marked at 2.5 meter intervals. Pulse rate was recorded again after completion of 6MWT. The velocity for the 6MWT was calculated for the actual distance completed in six minutes irrespective of the amount of resting for both groups. No numeric adjustments were made in scoring with the use of assistive devices, orthotics or pharmaceutical anti-spasmodics but the use of these products were recorded in the demographic questionnaire.

Able bodied participants were recruited to participate in the study in a ratio of 2:1 (SCI: able bodied) for each gender group. The groups had to have a comparable average age and BMI score. The rehabilitation units participating in the study, friends and family were

screened for possible inclusion. The assessment process, which included filling certain sections on the questionnaire, the height and weight measurement, setting and fitting of the accelerometer, obtaining baseline pulse rate and completing the 6MWT on a well indicated 10 meter line was completed as stipulated above. Post assessment pulse and distance was again recorded on the demographic questionnaire.

3.6 ETHICAL CONSIDERATIONS

- Ethical clearance was applied for and obtained from the Committee for Research on Human Subjects of the University of the Witwatersrand (clearance number: M110944; Appendix E).
- At the time ethical clearance was applied for the title was 'Energy expenditure of people with spinal cord injury while walking using elbow crutches compared to a matched able bodied population'. After meeting with the Physiotherapy department to present the proposal the title was changed to 'The energy expenditure of people with spinal cord injury while walking compared to an able bodied population'.
- Permission was requested and obtained from the hospital CEO of the various hospital groups applicable and government (Appendix F). Private practice owners and department heads were also approached and approval granted (Appendix G). The following institutions granted permission: Muelmed Medi-Clinic (Appendix H), Netcare Rehabilitation Hospital (Approval number UNIV 2012-0005, Appendix I), Life New Kensington, Life Riverfield Lodge, Life Eugene Marais (Approval number 120203, Appendix J), Rehab matters, Natalspruit Hospital and Tshwane Rehabilitation unit (Appendix K). All department heads and private practitioners provided consent via email (not attached).
- Participants were provided with an information letter (Appendix L) explaining the aims and objectives of the study and that participation is voluntary. Written consent was obtained from all participants (Appendix M).

3.7 DATA ANALYSIS

Data were captured in Microsoft Excel on a spreadsheet for data cleaning and coding purposes. Missing values, extreme values and inconsistencies on the Excel spreadsheets were checked and information retrieved where possible. None of the participants had

missing data. Characteristics of the study participants were summarised using descriptive statistics.

Data were analysed for comparison between the able bodied and SCI sample using the Two-sample t-test for the following: age, BMI, energy expenditure, energy expenditure per meter, distance walked, velocity of walking, pulse before and pulse after walking. Mean, mean difference, p values and 95% confidence intervals were presented. For factors where the assumption of equal variance between groups may appear to be violated the conclusion of the t-test was confirmed using the non-parametric ranksum test.
Pearson product moment correlations were used to establish the relationship between identified factors and energy expenditure while walking which included – age, BMI, velocity, pulse after walking, ASIA motor score, ASIA sensory score, spasticity, length of stay in rehabilitation and ROM while the point biserial correlation described the association between gender and energy expenditure.

The correlation coefficient (r) and p values were recorded. Scheffé comparison was used to analyse the differences in energy expenditure yielded while walking with different assistive devices. This was presented in a table with differences in mean scores and p values. Univariate regressions were done for factors such as pain, duration since injury and therapy services received. This was also presented in a table with correlation coefficient, standard error, t and p values and 95% confidence intervals. Multivariate stepwise regressions were done for ROM, ASIA categories, velocity, ASIA sensory score. This was also presented in a table with correlation coefficient, standard error, t and p values and 95% confidence intervals. Testing was done at the 0.05% level of significance.

CHAPTER 4

4. RESULTS

4.1 INTRODUCTION

The objectives of the study were to establish: the energy expenditure of participants with SCI while performing a six minute walk test (6MWT), the energy expenditure of participants in an able bodied population while performing a Six Minute Walk Test (6MWT), comparing the energy expenditure between participants with SCI walking and the able bodied population and lastly to establish the factors that influence energy expenditure while walking of participants with SCI compared to an able bodied population.

The results will first describe the sample size and characteristics of the study sample. This includes age, gender, BMI, presence of pain, presence of spasticity, level of injury, rehabilitation services received, duration since injury, and extent of treatment. Energy expenditure results will then be presented for both SCI and able bodied participants for comparison. Lastly the factors which had an influence on energy expenditure while walking for the SCI sample will be presented.

4.2 SAMPLE SIZE

Figure 4.1 represents the sample size used in the study.

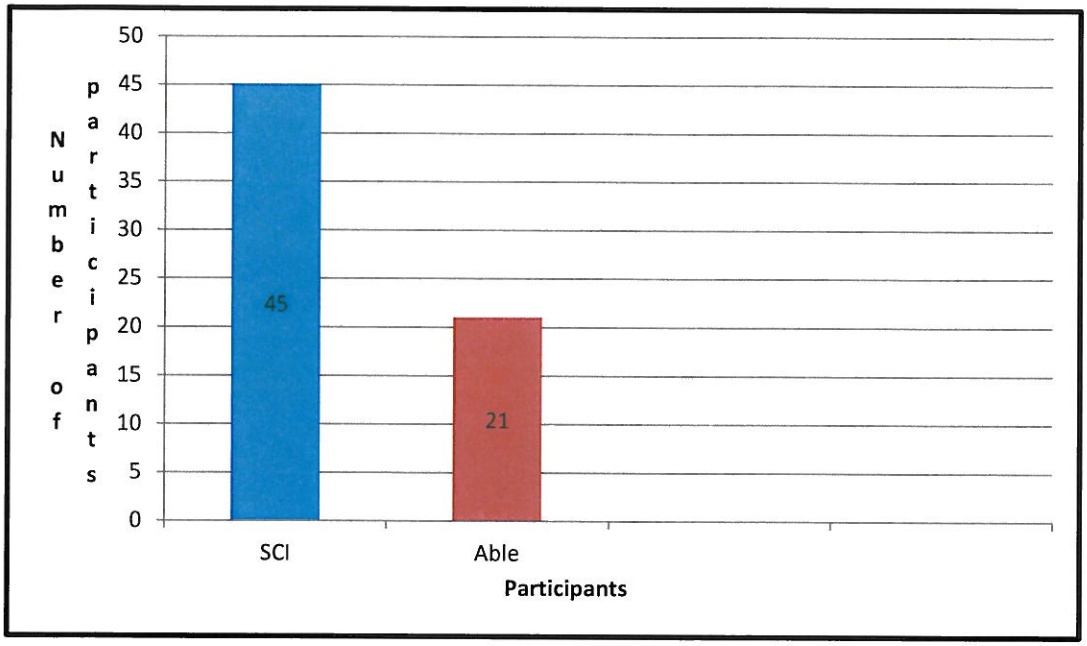


Figure 4.1 Sample size (n = 66)

The SCI sample consisted of 45 participants and the able bodied sample of 21 participants.

4.3 CHARACTERISTICS OF THE STUDY SAMPLE

4.3.1 Age of Sample

The mean age of the SCI sample was 38.9 years with a standard deviation of ±13.6. The youngest patient was 18 years and the eldest 70 years. The mean age of the able bodied sample was 34.7 years with a standard deviation of ±9.7. The youngest was 25 years and the eldest 66 years. The difference between the age of the participants with SCI and able bodied group was not statistically different (p= 0.21).

4.3.2 Gender Distribution

Figure 4.2 below shows the gender distribution of the study sample.

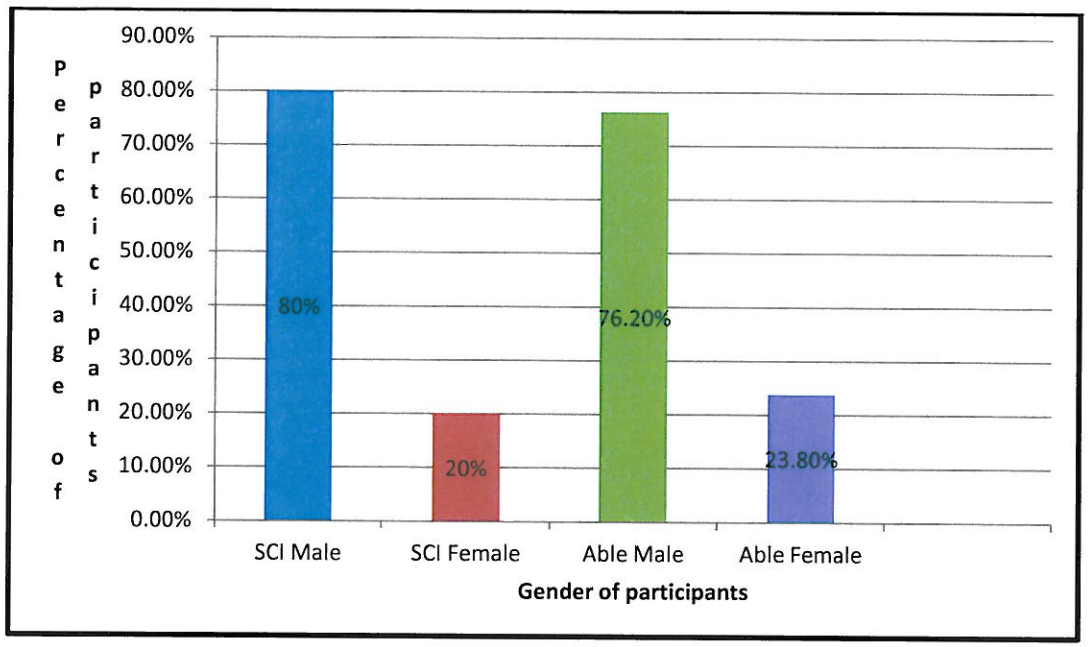


Figure 4.2 Gender distribution (n = 66)

There were more male than female participants in both groups. The male sample in the able bodied group constituted 76.2% of the sample and the SCI males constituted 80% of the sample. The difference between the SCI participants and able bodied participants' gender was not statistically significant (p=0.75; Fisher's exact test).

4.3.3 BMI Distribution

Figure 4.3 presents the BMI distribution between the SCI and able bodied participants.

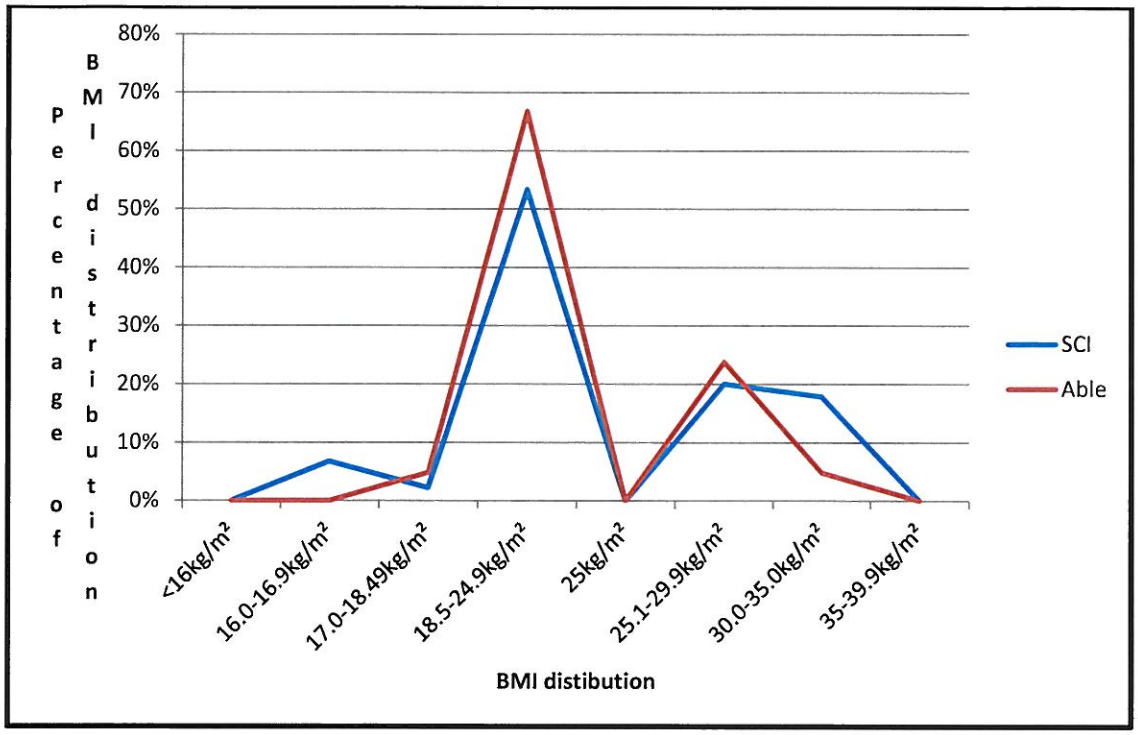


Figure 4.3 BMI Distribution (n =66)

The mean BMI for the SCI sample was 23.9 (normal range) with a standard deviation of ±5.1. It ranges from 16.0 (moderate underweight) as the lowest value to 34.1 (obese class 1) at the highest value within the SCI group. The mean BMI for the able bodied sample was 23.8 (normal range) with a standard deviation of ±4.4. The lowest was 17.2 (mild underweight) and ranged to 34.0 (obese class 1). No significant differences were found between the SCI and able bodied BMI (p=0.93).

4.3.4 Pain

Figure 4.4 presents results of the presence of pain measured by a self-report scale in the demographic questionnaire in the SCI sample.

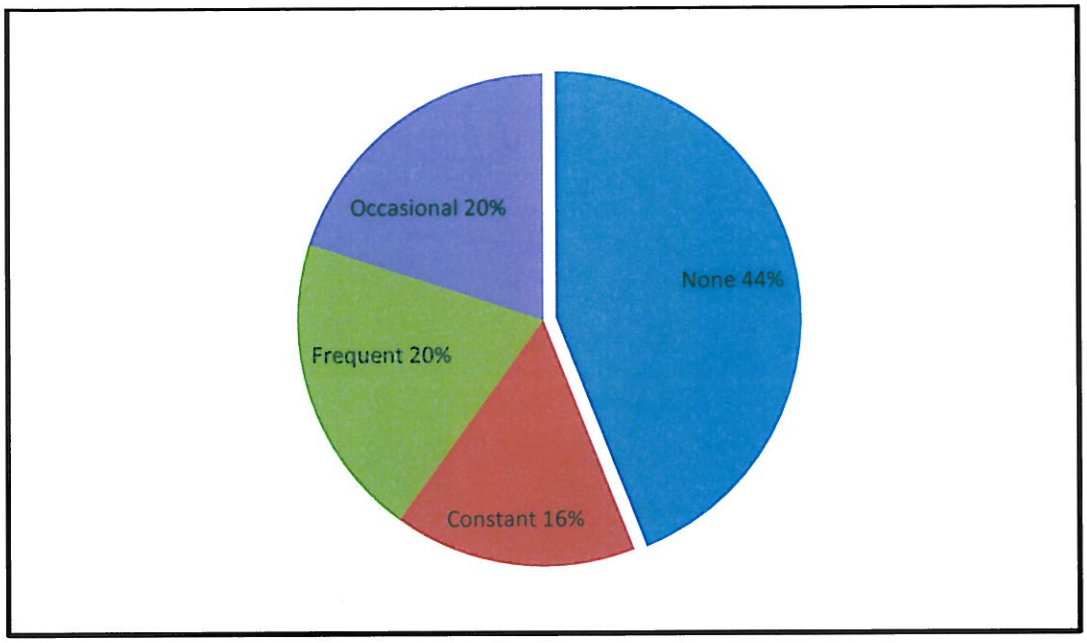


Figure 4.4 Presence of Pain (n=45)

Majority of the participants (56%) reported that they had pain but the frequency was different. Participants mostly had occasional or frequent pain (20% respectively).

4.3.5 Spasticity

Figure 4.5 presents results of the presence of spasticity, measured by the Modified Ashworth Scale in the SCI sample.

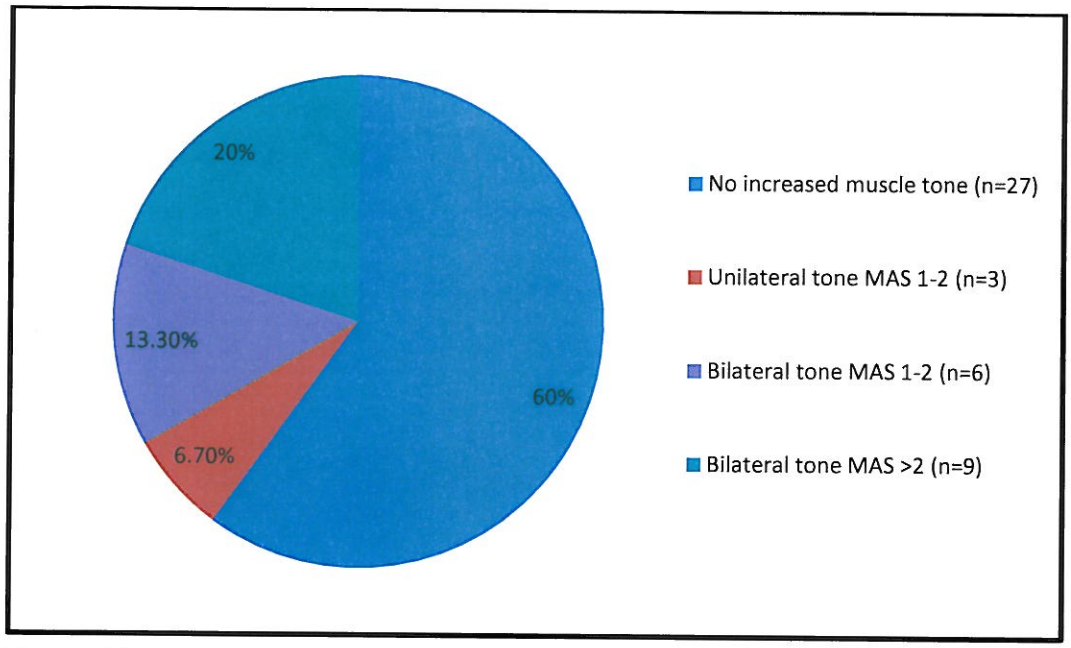


Figure 4.5 Presence of spasticity (n = 45)

Forty percent of SCI participants had increased tone however, only 20% of the sample had increased tone bilaterally and throughout ROM (Modified Ashworth Scale score ≥ 2).

4.3.6 ASIA classification and Neurological level of lesion

Table 4.1 presents the results of the ASIA classification and mean sensory and motor score.

Table 4.1 ASIA classification (n=45)

ASIA	A	B	C	D
Number of participants: n (%)	6(13)	1(2)	12(27)	26(58)
Mean sensory score	147.30	175	179.50	183.80
Mean motor score	54.80	65	68.40	74.10

The mean motor and sensory scores are higher for ASIA D and progressively reduce with each category to have the lowest scores in ASIA A.

The neurological level of lesion is presented in Figure 4.6.

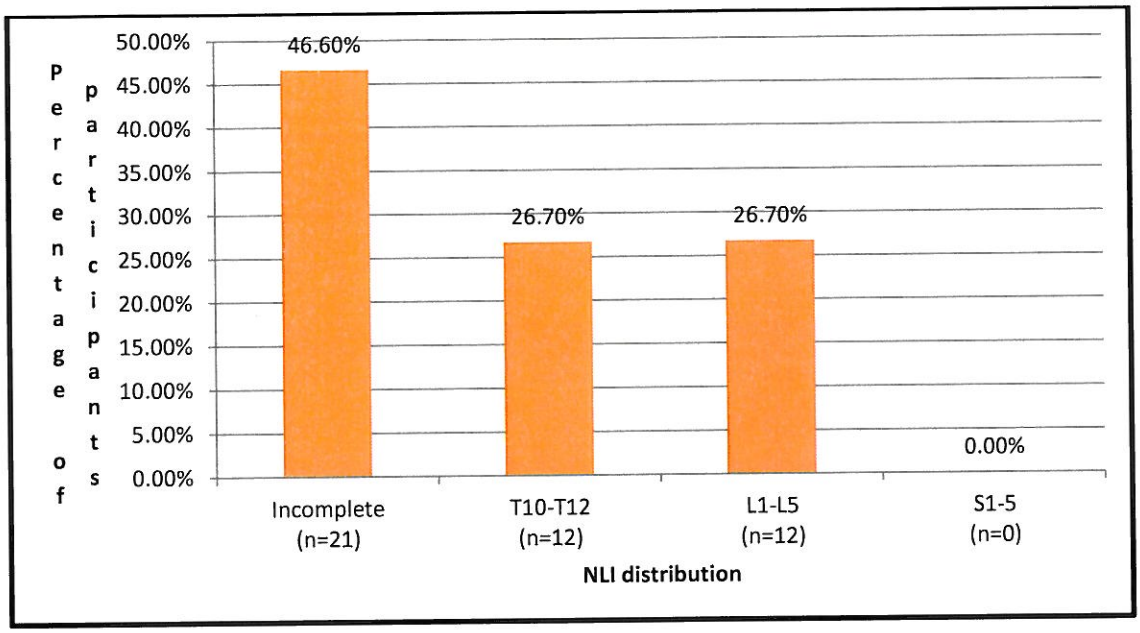


Figure 4.6 Neurological level of lesion (n = 45)

**NLI Neurological level of injury*

Of the participants, 46.6% (n=21) had an injury above T10 which was incomplete and therefore still enabled them to walk. Thoracic spinal cord injuries, T10-T12, were observed in 26.7% (n=12) of participants. Lumbar spine injuries, L1-L5, also represented 26.7% of the SCI group.

4.3.7 Duration since spinal cord injury

Table 4.2 presents the results on the duration since the spinal cord injury.

Table 4.2 Duration since SCI (n=45)

Duration since SCI	n (%)
<6months	17 (38)
≥ 6months-1yr	10 (22.2)
>1-2yrs	6 (13.3)
>2 yrs - 5yrs	5 (11)
>5yrs - 10yrs	6 (13.3)
>10yrs	1 (2.2)

Most of the participants (38%) had a duration of less than six months since SCI and 22.2% (n=10) had their injury between six months and a year. Only one individual had more than 10 years duration post SCI.

4.3.8 Extent of treatment

All 45 participants in the SCI group had in-patient rehabilitation between two and >10weeks. Figure 4.7 presents the distribution of rehabilitation services received by the participants.

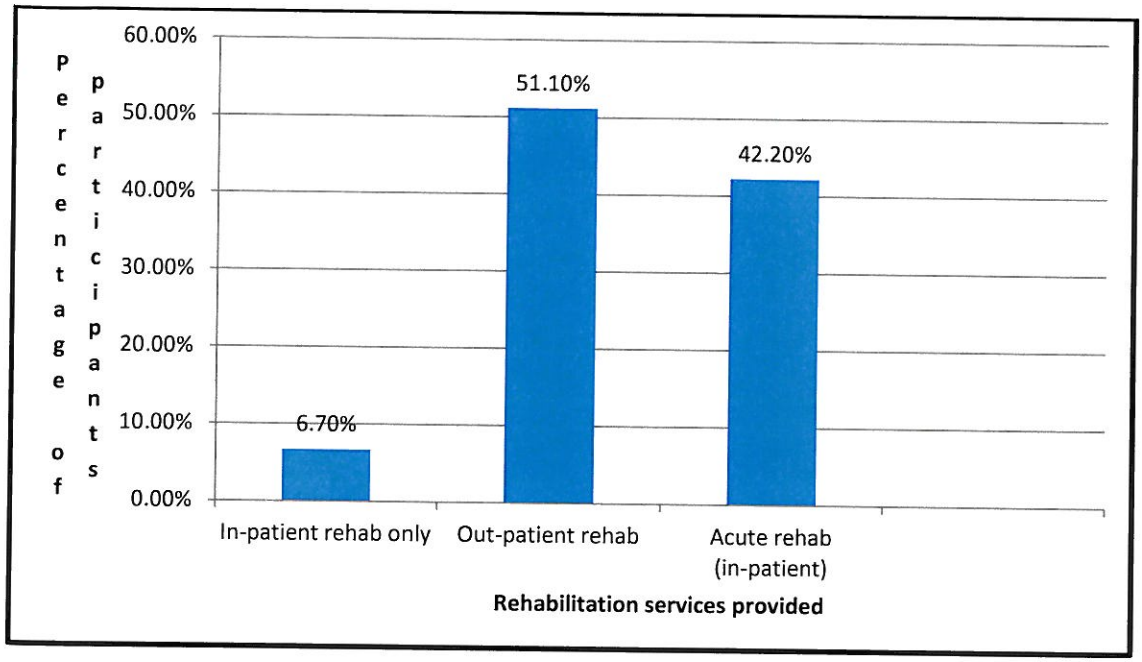


Figure 4.7 In- and out-patient therapy received by participants with SCI (n = 45)

Most of the participants (51.1%) (n=23) received out-patient therapy once they finished their initial acute in-patient therapy and 6.7% (n=3) of participants had no out-patient therapy after their initial in-patient rehabilitation.

Table 4.3 presents the therapy hours received by the participants during their in-patient rehabilitation period.

Table 4.3 Therapy hours per day (n=45)

Therapy hours per day	n(%)
1 hour per day	1(2)
2 hours per day	4(9)
3 hours per day	13(29)
4 hours per day	17(38)
>4 hours per day	10(22)

Participants received varying amounts of therapy input. Majority of the participants (38%) received four hours of therapy per day, and only one participant received one hour of therapy per day.

Table 4.4 presents the results of the length of stay in rehabilitation as an inpatient.

Table 4.4 Participants' length of rehabilitation stay (n=45)

Duration of Rehabilitation hospital stay (Weeks)	n(%)
<2 weeks	0
2-4 weeks	8 (18)
>4-6 weeks	4 (9)
>6-8 weeks	5 (11)
>8-10 weeks	3 (7)
>10 weeks	25 (55)

Majority (55%) of the patients with SCI had a length of stay in rehabilitation of more than ten weeks.

4.4 ENERGY EXPENDITURE

4.4.1 Energy expenditure comparison between SCI and able bodied participants

Table 4.5 presents the results of energy expenditure, distance, velocity and pulse before and after performing the 6MWT for both able bodied and SCI groups.

Table 4.5 Energy expenditure (SCI n=45; Able bodied n=21)

	SCI Mean (±SD)	Able bodied Mean (±SD)	Mean difference between SCI and Able bodied	P-value	95% confidence interval
EE (cal)	19.60 (10.10)	30.80 (9.80)	11.20	<0.001	(-16.50 ; -5.96)
EE/m	0.33 (0.29)	0.08 (0.02)	0.25	<0.001	(0.12 ; 0.37)
Distance (m)	114.10 (104.40)	388.70 (67.20)	274.60	<0.001	(-324.48 ; -224.84)
Velocity (m/s)	0.32 (0.29)	1.10 (0.19)	0.76	<0.001	(-0.90 ; -0.63)
Pulse before walking (bpm)	76.60 (13.60)	77.90 (9.90)	1.30	0.71	(-7.88 ; 5.41)
Pulse after walking (bpm)	106.40 (17.70)	87.70 (11.80)	18.70	<0.001	(10.29 ; 27.27)

**SD: Standard deviation; EE: energy expenditure; cal: calorie; EE/m: Energy expenditure per meter; m: meters; m/s: meters per second; bpm: beats per minute*

There was a statistically significant difference between SCI and able bodied participants for all variables except for pulse before walking which was not statistically different between groups ($p = 0.71$). Energy expenditure for the able bodied participants was higher than SCI participants ($p <0.001$), however energy expenditure per meter was much higher for the SCI participants than able bodied participants ($p<0.001$).

4.4.2 Energy expenditure and age

Table 4.6 presents the mean energy expenditure per meter, velocity and distance for SCI and able bodied participants in a below 50 and above 50 years old group.

Table 4.6 Mean energy expenditure per meter, distance and velocity for SCI and able bodied participants above and below 50 years.

	<50 years	>50 years
EE/m (cal/m)	**Mean EE/m (n)**	**Mean EE/m (n)**
SCI	0.30(35)	0.40(10)
Able bodied	0.10(20)	0.10(1)
Velocity (m/s)	**Mean Velocity (n)**	**Mean Velocity (n)**
SCI	0.30(35)	0.40(10)
Able bodied	1.10(20)	1.20(1)
Distance (m)	**Mean Distance (n)**	**Mean Distance (n)**
SCI	108.60(35)	133.30(10)
Able bodied	385.90(20)	445(1)

Mean energy expenditure per meter was higher for the SCI participants above 50 years of age at 0.40cal/m. Mean velocity was higher for the SCI and able bodied participants older than 50 years with a mean value of 0.40m/s and 1.20m/s respectively. Mean distance was also higher for the SCI and able bodied participants older than 50 years (133.30m and 445m respectively).

4.4.3 Energy expenditure and gender

Table 4.7 presents the results for energy expenditure per meter, velocity and distance walked during the 6MWT for each gender group.

Table 4.7 The mean energy expenditure per meter, velocity and distance walked during the 6MWT for each gender group

	Mean EE/m (cal/m)	Mean Velocity (m/s)	Mean Distance (m)
SCI male (n=36)	0.34	0.34	121.90
SCI female (n=9)	0.27	0.23	82.70
Able bodied male (n=16)	0.08	1.10	395
Able bodied female (n=5)	0.07	1.03	368.50

The males had higher mean energy expenditure than the females in both groups, with the male SCI participants using 0.34cal/m and the able bodied males using 0.08cal/m compared to 0.27cal/m for SCI females and 0.07cal/m for able bodied females. The velocity of walking and the distance walked during the 6MWT was also greater for males for both able bodied and SCI participants.

4.4.4 Energy expenditure and BMI

Table 4.8 presents the results for energy expenditure per meter for each of the WHO BMI categories specified and present in the study population.

Table 4.8 BMI and energy expenditure per meter for SCI and able bodied participants

BMI (kg/m2)	EE/m SCI (cal/m) (n)	EE/m Able (cal/m) (n)
16-16.9	0.15 (3)	0
17-18.49	0.34 (1)	0.04 (1)
18.5-24.9	0.34 (24)	0.07 (14)
25.1-29.9	0.29 (9)	0.10 (5)
30-35	0.39 (8)	0.11 (1)

There was a steady increase in energy expenditure per meter in the able bodied population with 0.04cal/m at the lowest value with a BMI of 17-18.49kg/m2 and reaching 0.11cal/m at a BMI of 30-35. For the SCI sample the energy expenditure also increased with an increase in BMI with

the lowest being 0.15cal/m on a BMI of 16-16.9kg/m2 and reaching 0.39cal/m on a BMI of 30-35kg/m2.

4.4.5 Energy expenditure and ASIA classification

Table 4.9 presents the results for energy expenditure per meter walked for each ASIA category including the mean distances and velocity in each category.

Table 4.9 ASIA classification and mean energy expenditure, -distance and –velocity.

ASIA	A (n = 6)	B (n = 1)	C (n = 12)	D (n = 26)
EE/m	0.71	0.13	0.29	0.26
Distance	19.67	75	114.71	137.04
Velocity	0.05	0.21	0.32	0.38

Mean energy expenditure per meter is highest for ASIA A and reduces in value towards D (with the exception of ASIA B (n=1) which is significantly less than the other values). The mean distance covered by ASIA D is 7 times more than the mean distance covered by ASIA A. Mean velocity in ASIA D is 7.5 times higher than ASIA A.

4.4.6 Energy expenditure while walking using an assistive device

Figure 4.8 presents the different walking aids used by the SCI participants.

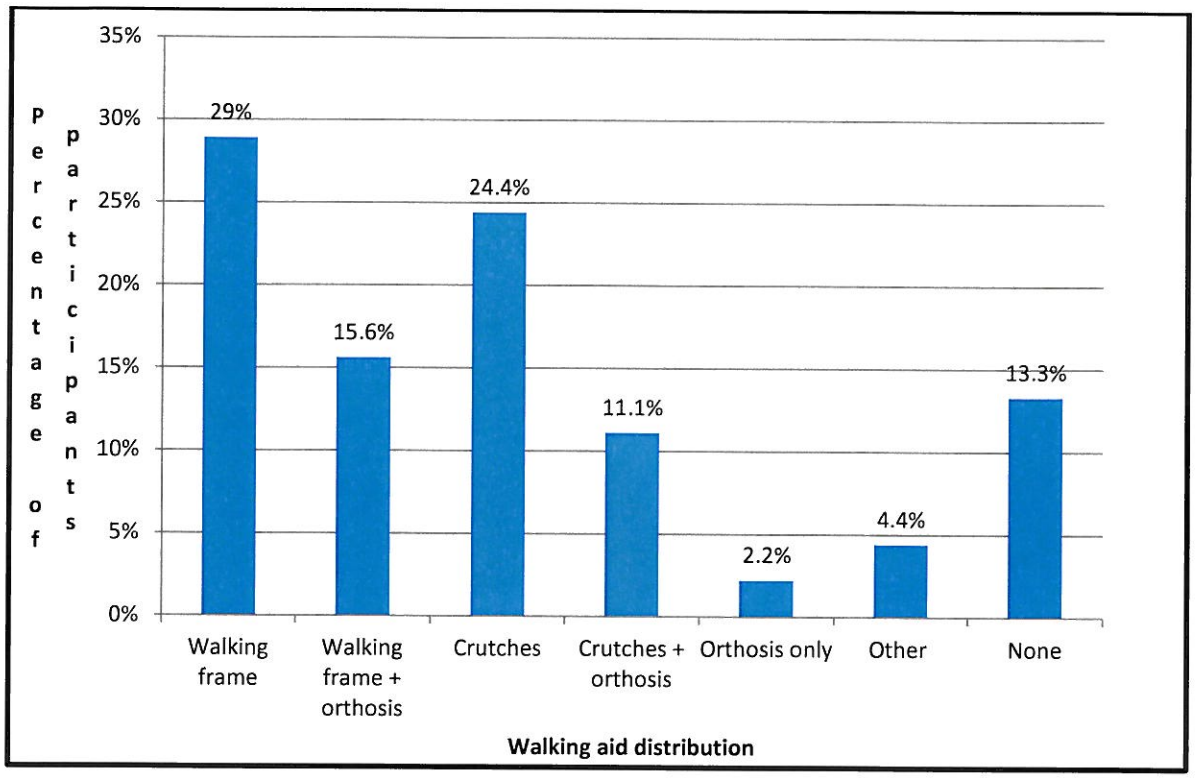


Figure 4.8 Assistive devices used by the SCI participants (n = 45)

Thirteen percent of the participants did not require an assistive device in order to walk. Walking frame was the most commonly used assistive device with 29% using a walking frame only and an additional 15.6% using a walking frame and orthosis.

Table 4.10 indicates the mean energy expenditure while walking with the various assistive devices. For the purpose of this analysis, categories for orthosis only, other and none were combined in one group and named "other" in order to have a comparable group number.

Table 4.10 Mean energy expenditure while walking using an assistive device (n=45)

Assistive device(n)	Mean energy expenditure (calorie/meter)(SD)
Other (9)	0.16 (0.10)
Crutch and orthosis	0.16 (0.02)
Crutches only	0.18 (0.09)
Walking frame only	0.52 (0.36)
Walking frame and orthosis	0.54 (0.32)

The mean energy expenditure was the highest for SCI participants walking with a walking frame and an orthosis (0.54 cal/m) and was the lowest for SCI participants walking without a crutch and orthosis (0.16 cal/m).

Table 4.11 present the results for the comparison of energy expenditure while walking with different assistive devices compared. In Scheffé's comparison, energy expenditure during walking with various assistive devices was compared between different walking devices. These included walking frame, walking frame and orthosis, crutch and crutch with orthosis. The other groups (other, none and orthosis only) were grouped together again as other due to insufficient numbers to be comparable.

Table 4.11 Comparison of energy expenditure per meter used for various assistive devices

	Walking frame EE/m (p)	Walking frame and orthosis EE/m (p)	Crutch EE/m (p)	Crutch and orthosis EE/m (p)
Walking frame and orthosis	0.02 (1.00)			
Crutch	-0.34 (0.03)	-0.36 (0.06)		
Crutch and orthosis	-0.36 (0.11)	-0.38 (0.14)	-0.02 (1.00)	
Others	-0.36 (0.03)	-0.38 (0.06)	-0.02 (1.00)	0.01 (1.00)

Energy expenditure per meter of walking with crutches compared to a walking frame was significantly different (p=0.03) and the difference in energy was 0.34cal/m less for crutches walking.

4.5 FACTORS THAT INFLUENCE ENERGY EXPENDITURE DURING WALKING

Results of the association between energy expenditure and age, gender, BMI, velocity, pulse, sensory score, ASIA, spasticity, length of rehabilitation stay, out-patient rehabilitation and range of movement are presented in this section. Univariate and multivariate analysis results to establish factors that had an influence on energy expenditure are also presented in this section.

4.5.1 The association between age, gender, BMI, velocity, pulse, ASIA, spasticity, length of rehabilitation stay, range of movement and energy expenditure per meter walked.

Table 4.12 indicates the association between age, gender, BMI, velocity, pulse, ASIA, spasticity, length of rehabilitation stay, range of movement and energy expenditure per meter walked.

Table 4.12 The correlation between age, gender, BMI, velocity, pulse, ASIA (motor and sensory scores), spasticity, length of rehabilitation stay, range of movement and energy expenditure per meter.

Variable	Correlation coefficient	p value
Age	0.20	0.30
Gender - Male *	-0.10	0.51
BMI	0.01	0.97
Velocity	-0.60	<0.001
Pulse after	0.20	0.13
Motor score (ASIA)	-0.30	0.08
Sensory score (ASIA)	-0.30	0.02
Spasticity – MAS for hip flexion	-0.02	0.91
Spasticity – MAS for hip extension	-0.02	0.87
Length of rehab stay	-0.10	0.56
Hip flexion ROM	-0.55	<0.001
Hip extension ROM	-0.30	0.04
Knee flexion ROM	-0.30	0.03
Dorsiflexion ROM	-0.01	0.93
Plantarflexion ROM	-0.20	0.23

*Point biserial correlation

Walking velocity and hip flexion ROM had the highest association energy expenditure per meter walked, however the association was negative. The negative association found suggests that as walking velocity and hip flexion ROM decrease the energy expenditure per meter of walking will increase.

4.5.2 Univariate analysis results for factors which had an influence on energy expenditure during walking

Table 4.13 indicate the univariate analysis results for factors which had an influence on energy expenditure during walking

Table 4.13 Univariate analysis results for factors which had an influence on energy expenditure during walking

Variable	*Regression coefficient	Standard error	T	P value	95% confidence interval
Duration since injury:					
6mnths-1yr	-0.13	0.12	-1.16	0.25	(-0.37 ; 0.10)
>1-2years	-0.24	0.13	-1.92	0.06	(-0.50 ; 0.01)
>2<5years	-0.24	0.14	-1.67	0.10	(-0.53 ; 0.05)
>10years	-0.26	0.13	-2.04	0.05	(-0.51 ; -0.003)
Out-patient therapy:					
No out-patient rehab	0.52	0.15	3.36	0.002	(0.21 ; 0.83)
Currently still in acute in-patient stage	0.23	0.08	2.88	0.01	(0.07 ; 0.38)

*effect with reference to baseline

Duration since injury for less than six months was used as a reference point. Therefore participants who had a SCI duration of >10years had 0.26 less energy expenditure than those who had less than six months SCI duration (p = 0.05). SCI participants who did not have out-patient rehabilitation presented with 0.52 more energy expenditure than those who received outpatient therapy (p=0.002). SCI participants who were still in acute in-patient stage had 0.23

more energy expenditure than those who received out-patient therapy after completing acute in-patient therapy.

4.5.3 Multivariate analysis results for factors which had an influence on energy expenditure during walking

Table 4.14 presents the multivariate stepwise regression analysis results for factors which had an influence on energy expenditure during walking.

Table 4.14 Multivariate analysis results for factors which had an influence on energy expenditure during walking

Variable	*Regression coefficient	Standard error	T	P value	95% confidence interval
ROM:					
Hip flexion	-0.003	0.002	-1.67	0.10	(-0.006 ; 0.001)
Knee flexion	0.003	0.001	2.17	0.04	(0.0002 ; 0.005)
Velocity (m/s)	-0.41	0.15	-2.80	0.01	(-0.70 ; -0.11)
ASIA scores:					
ASIA B	-0.55	0.27	-2.07	0.05	(-1.10 ; - 0.01)
ASIA C	-0.38	0.13	-2.87	0.01	(-0.64 ; -0.11)
ASIA D	-0.35	0.13	-2.69	0.01	(-0.61 ; -0.09)

*effect with reference to baseline

The factors which had significant relationships with energy expenditure were included in the stepwise multi-linear regression. As regressions continued factors which did not remain significance were removed. An inverse relationship was identified between energy expenditure per meter walked and several factors – for every decrease in degree of hip flexion ROM there was a 0.003 increase in energy expenditure per meter walked. A unit decrease in velocity resulted in an increase of 0.41 in energy expenditure per meter walked. ASIA A was used as the reference point in this analysis between ASIA classification and energy expenditure per meter while walking. SCI participants with ASIA B had 0.55 less energy expenditure than ASIA A. ASIA C and D had 0.38 and 0.35 less energy expenditure than ASIA A.

CHAPTER 5

5. DISCUSSION

5.1 INTRODUCTION

The objectives for this study were: to establish the energy expenditure of participants with SCI while performing a Six Minute Walk Test (6MWT), the energy expenditure of participants in an able bodied population while performing a Six Minute Walk Test (6MWT), compare the energy expenditure between participants with SCI walking and the able bodied population. The last objective was to identify factors that influence the energy expenditure between participants with SCI and an able bodied population. The findings presented in the results chapter are discussed in this chapter with reference to available literature. The conclusion, limitations of the research and recommendations for future research are also presented in this chapter.

5.2 CHARACTERISTICS OF THE STUDY SAMPLE

5.2.1 Age, Gender and BMI

The mean age of the SCI sample was 38.9 years and ranged from 18 years to 70 years. According to Van den Berg et al. (2010) the international trend amongst the research reviewed showed a bimodal age distribution amongst patients with traumatic SCI. Young adults between the ages of 15 and 29 years presented the first peak and a second peak was in older adults (mostly ≥65 years). Based on the results of this study, far fewer participants were aged older than 50 years (22%). Ackery et al. (2004) indicated that countries with similar economic climates display comparable aetiological trends, age distribution and ratio between male and females acquiring a SCI. Age at the time of injury was found to be higher in developed countries which are attributed to higher life expectancy and socio-economic status.

South Africa is classified as a low to middle income African nation with a small gross domestic product in relation to its population with a reduced life expectancy compared to highly developed countries (World Bank annual report, 2009). Despite a worldwide increase in life expectancy for people living with SCI due to technological and medical advances (Cifu et al., 1999a; Scivoletto et al., 2003) there are no published statistics on the life expectancy for such individuals in South Africa (Mothabeng, 2011). An increase in incidence was observed the last two decades

regarding the development of HIV-related SCI which suggest a further decline in life expectancy with the leading cause of traumatic SCI still being MVA and other violence related behaviour (Mothabeng, 2006). The sample investigated in this study was not as old as the population represented in international studies (Dai, 2001; Kennedy et al., 2003; Scivoletto et al., 2003) which is suggested to be due to South Africa having a lower life expectancy. Furthermore older adults have a lower survival rate following SCI (Kennedy et al., 2003).

The male sample in the participants with SCI constituted 80% of the sample. Based on current literature the male to female ratio of the incidence of SCI was found to be higher in less developed countries than in developed countries. This is suggested to be due to predominantly manual labour work force and greater risk taking behaviour of males in these countries (Ackery et al., 2004; Van den Berg et al., 2010; Draulans et al., 2011). From the results in this study the ratio of male to female SCI participants was 4:1. This is in line with reported statistics of 3.8-4:1 ratio male to female in international statistics (Sekhon & Fehlings, 2001; Wyndaele & Wyndaele 2006).

The SCI participants had a mean BMI of 23.90kg/m2 which ranged from 16.0-34.1kg/m2. This mean BMI score was within normal limits (18.5-24.9kg/m2). A study by Laughton et al. (2009) has shown that the current BMI cut-off fails to identify obese people with SCI, however BMI values greater than 22kg/m2 are considered as high risk for obesity and obesity related chronic diseases in this population (Laughton et al., 2009).

5.2.2 Pain and Spasticity

The prevalence of pain has been widely reported as a frequent complication of SCI. Prevalence has been described from 11-94% of cases (Ehde et al., 2003) although it mostly only affects approximately half (40-65%) of people with SCI (Budh et al., 2003; Siddall et al., 2003; Werhagen et al., 2004; Modirian et al. 2010). Based on the results of the study, the prevalence of pain was reported by 56% of the SCI participants which is similar to that reported in other studies.

Spasticity results from damage to the CNS and is a widely reported phenomenon following SCI (Barnes, 2001; Adams & Hick, 2005; Haisma et al., 2007; Elbasiouny et al., 2010). Looking at the SCI sample only 40% of the study sample presented with spasticity of which only 20%

presented with bilateral symptoms which affected the full ROM. None of the participants presented with spasticity causing rigidity (Modified Ashworth scale greater than three).

5.2.3 ASIA classification, Neurological level and Duration since Spinal Cord Injury

The SCI population observed in this study consisted of 13% ASIA A, 2% ASIA B, 27% ASIA C and 58% ASIA D. The mean sensory and motor score increases from ASIA A to D as predicted in the classification (ASIA, 2003). Functional impairments associated with a SCI are determined by the level and completeness of an injury (ASIA, 2003; Marino et al., 2003; Marino & Graves, 2004). Stuart et al. (2009) and Barbeau et al. (2006) concluded that ASIA classification was the strongest predictor of ambulation potential. People with ASIA D are more likely to walk than ASIA C, and both the latter are more likely to walk than ASIA A or B (Scivoletto et al., 2003; Kay et al., 2007; Stuart et al., 2009). Based on the majority of participants (58%) in the ASIA D classification it would be expected that ambulatory parameters for velocity, distance and energy expenditure would be closer to able bodied parameters within this group. Higher motor scores in the lower extremity expected in ASIA D produced a high correlation coefficient with the 6MWT in terms of gait speed and distance walked due to the relationship of muscle strength with ambulatory capacity in SCI (Kim et al., 2004).

The neurological levels of injury within the sample were distributed to have 26.7% of participants with thoracic level lesions including or below T10. Lumbar level lesions were observed in 26.7% of the study sample. None of the participants had sacral level lesions. The remaining 46.7% of participants had neurological level of injuries higher than T10 but incomplete in nature to still allow motor and sensory function below the level. A large proportion (46.7%) of the participants presented with high level lesions. The energy expenditure is expected to be higher for this group when walking. Kawashima et al. (2005) found that higher level lesions resulted in higher energy expenditure in order to ambulate. Slower gait speed as a result of higher lesions contributed to limited hip motion and presumed excess load on the upper limb, making the gait less efficient (Kawashima et al., 2005).

Most of the SCI participants (39%) had a duration of less than six months since SCI and 22.2% (n=10) had their injury between six months and a year. Only one individual had more than 10 years duration post SCI. Motor recovery has been reported to mainly take place during the first six months post injury and the most rapid recovery takes place within the first three months post SCI (Kirshblum et al., 2004). However, improvements in neurological recovery have also been

reported to take place up to five to twelve years post SCI with reported increased physical capacity and muscle strength (McDonald et al., 2003; Kirshblum et al., 2004; Dvorak et al., 2005; Hicks et al., 2011). Significant balance and walking ability improvements including distance and velocity have been reported for individuals with lesions more than three years post SCI (Harkema et al., 2012). Based on the sample distribution, 60% of participants had their SCI less than a year ago. This would suggest that poorer mobility would be expected due to the limited recovery time based on the duration since injury.

5.2.4 Extent of treatment

Most of the participants (51.1%) (n=23) received out-patient therapy once they finished their initial acute in-patient therapy and only 6.7% (n=3) of participants had no out-patient therapy after their initial in-patient rehabilitation. A large portion of the sample (42.2%) was still in the in-patient rehabilitation phase. Neurological recovery, including functional improvement in motor scores, balance and walking ability due to ongoing therapeutic intervention has been widely reported during the first and second year post injury (Marino et al., 1999; Patrick, 2003; Burns et al., 2012). This would imply that once in-patient therapy has been concluded further recovery is still possible which could be impeded by a lack of out-patient rehabilitation.

Participants received varying amounts of therapy input. Majority of the participants (38%) received four hours of therapy per day, and only one participant received one hour of therapy per day for the duration of in-patient rehabilitation. Functional and motor score improvement are widely reported due to therapeutic intervention (Rimaud et al., 2005; Valent et al., 2007; Hicks et al., 2011). However the literature is very unspecific regarding length and extent of therapeutic intervention in order to produce clinically significant effects (Rimaud et al., 2005).

Majority (55%) of the patients with SCI had a length of stay in rehabilitation of more than ten weeks. In ideal circumstances the length of stay is determined by degree of motor recovery and potential for ambulation as well as patient goals. Patients with incomplete injuries often only get discharged from in-patient rehabilitation once independent ambulation is recovered (Roth et al., 1990; Burns et al 1997), however limited funding and resources (availability of beds in rehabilitation units) is largely the determining factor of length of stay (Mothabeng, 2011).

5.3 ENERGY EXPENDITURE

Based on the results of the Two-sample t-test, relationship between energy expenditure and significant variables will be discussed.

5.3.1 Energy expenditure per meter

Mean energy expenditure per meter values yielded by the SCI samples was four times higher than the able bodied sample (p=<0.001). This is lower than the results reported by Kawashima et al. (2006) who found energy expenditure to be approximately six times higher for SCI participants who walk with orthotic assisted gait compared to able bodied participants. However in Kawashima's study the SCI sample used the reciprocating gait orthosis and had complete paraplegia between T5 to T12. In this study sample incomplete SCI lesions were included and a variety of assistive devices used to aid walking. Only 13% of the study sample did not require an assistive device. The higher energy expenditure for the SCI sample is attributed to greater upper limb and trunk involvement during walking compared to able bodied individuals in order to swing their paralysed lower limbs and maintain balance (Ijzerman et al., 1999; Kawashima et al. 2006). Based on this study's results and various reports from other studies, energy expenditure is significantly greater for people with SCI than able bodied during walking at a self selected pace (Waters & Mulroy, 1999; Dobkin et al., 2003; Ulkar et al., 2003; Kawashima et al., 2006).

5.3.2 Distance

The mean distance covered during the 6MWT for the SCI sample was more than three times less than the able bodied sample. This is similar to the findings of Stuart et al. (2009) who reported that SCI distances during the 6MWT was less than a third of the reported normal scores and suggested to be insufficient to allow safe community ambulation. The mean distance covered within the 6MWT for the SCI sample in this study was 114.10m (SD+/-104.40) compared to 338.70 (SD+/-67.20) for the able bodied sample (p<0.001). Able bodied distance is usually calculated at 60-100 meters/minute (Waters & Mulroy, 1999) which is similar to the mean obtained by the able bodied population. In the study by Stuart et al. (2009) SCI participants yielded distances between 129m on admission to 220m at discharge (SD+/-94). Buehner et al. (2012) reported mean distance of 164m (SD+/-159.82) using the 6MWT. Harkema et al. (2012) reported a range between 91m (SD=+/- 116) to 154m (SD=+/-148m) in a chronic SCI sample.

Participants in this study were in different stages of the rehabilitation process which may explain the distances achieved in Stuart's and Beuhner's study exceeding this study's results.

Ambulation for routine activities of daily living and community integration would require people with SCI to cover distances greater than 250m and on average spend at least 10min ambulating (Ulkar et al, 2003). Based on this study results, on average the SCI participants will only walk 190m in 10minutes.

5.3.3 Velocity

SCI participants walked at a mean velocity (0.32m/s, SD±0.29) three times less than that of the able bodied participants ($p<0.001$). Lapointe et al. (2001) reported that comfortable walking speed for able bodied people was twice that of incomplete SCI participants. Similar results were reported by Buehner et al. (2012) with a mean velocity of 0.46 (SD=0.44) in their study using the 6MWT, which is almost two and a half times less than that of the able bodied optimal speed. Stuart et al. (2009) found that gait speeds for people with SCI at discharge from rehabilitation was significantly less than that of able bodied individuals at a reported one fifth to one quarter of normal scores. Van Hedel et al. (2009) reported that gait speeds within different categories of SCI mobility levels were between 0.1 to 0.88m/sec for participants who required orthotic or physical assistance and up to 1.46m/sec for participants who could walk without aid. Walking speeds reported by Harkema et al. (2012) ranged between 0.31-0.51m/sec which is less than 50% of the reported optimal speed of 1.1m/sec.

Proximal lower extremity muscle strength, in particular hip flexors, hip extensors and hip abductors have been reported key in functional performance in walking, measured by the 6MWT, 10MWT and TUG (Kim et al., 2004). With increased strength greater stride length and gait speed was observed. It can therefore be assumed that with greater lower extremity strength producing higher walking velocity, energy expenditure would be reduced compared to SCI participants with poorer lower limb strength in the hip.

5.3.4 Pulse rate after walking test

The mean pulse rate before the walk test was similar for both SCI and able bodied participants ($p=0.71$). However, pulse rate (106.40bpm, SD±17.70) for the SCI group was 21% greater than the able bodied group after completion of the 6MWT at the preferred walking speed ($p<001$). Lapointe et al. (2001) found that pulse rate in SCI participants walking at a preferred rate is 32% higher than able bodied. Waters & Mulroy (1999) reported pulse rate between 108-130bpm depending on lower extremity motor score (ASIA) while walking at a self selected pace. The increased pulse rate can be related to tachycardia being closely associated with strenuous

exercise and in the absence of cardiac pathology. There is a linear relationship between heart (pulse) rate and oxygen uptake, the greater the demand for oxygen due to exercise the higher the pulse rate. The SCI population is considered one of the most inactive of all segments of society (Hicks & Ginis, 2008). Therefore a greater cardiovascular response is expected during exercise compared to an able bodied population (Phillips et al., 1998; Lapointe et al., 2001).

Cardiovascular function depends on arteries readily expanding and recoiling with changes in pressure in other words, healthy vascular endothelium. This process is controlled by the autonomic nervous system which can be significantly affected in people with SCI (Phillips et al., 1998; Wecht et al., 2004). A reduced compliance (increase in arterial stiffness) has been indicated as the number one factor associated with progression in cardiovascular disease (DeLoach & Townsend, 2008). Increased femoral artery stiffness and associated endothelial dysfunction have been observed in the SCI population (Hopman et al., 2002; De Groot et al., 2003). The situation is further complicated in the SCI population because of poor venous return. This is a result of a lack of sympathetic tone which causes blood pooling in the lower limb and a diminished or absent venous "muscle pump" in the legs. This latter mechanism perhaps contributes the greatest diminution in the potential for aerobic performance in the SCI population (Phillips et al., 1998). Lower limb exercises increase heart rate more than upper limb exercises and are more efficient in developing and maintaining both central and peripheral aspects of cardiovascular fitness (Phillips et al., 1998; Waters & Mulroy, 1999). Therefore, walking is expected to increase pulse rate more in people with SCI than able bodied participants, due to laborious lower limb involvement and lack of autonomic control in the SCI population.

5.4 FACTORS THAT HAD AN EFFECT ON ENERGY EXPENDITURE WHILE WALKING IN THE SCI POPULATION

5.4.1 Age

Based on the Pearson's correlation results, no significant relationship exists between age and energy expenditure per meter walked ($p=0.30$). Energy expenditure per meter walked was 25% higher for the above 50 year old group than used by the younger group. However the older than 50 year group walked a mean distance of 24.7meters further than the under 50 year old SCI participants. Furthermore the velocity for the participants older than 50 years was found to be 25% higher than those below 50 years of age. The higher energy expenditure per meter is

therefore related to the higher velocity and increased distance covered in the participants older than 50 years.

Based on current literature poorer functional recovery and a decline in walking speed with an increase in age is expected (Newey et al., 2000; Dai et al., 2001; Samson et al., 2001; Malatesa et al., 2003; Malatesa et al., 2004; Dvorak et al., 2005; Mian et al., 2006; Fiser et al. 2010; Schrack et al., 2012). This was attributed to a decline in physical function with age as well as poorer biomechanical efficiency. Fiser et al. (2010) and Schrack et al. (2012) also linked the reduction in velocity of walking and inability to walk at a self-selected pace with an increase in energy expenditure. Based on research by Penrod et al. (1990) and Scivoletto et al. (2003) walking ability of individuals with an SCI is greater for individuals below 50 years of age compared to above 50 years of age. Scivoletto et al. (2008) also found that with an advance in age the distance walked during a 6MWT was negatively correlated and noted that long distance walking requiring endurance particularly affects the elderly people with SCI and attributed it to energy expenditure and muscle fatigue. Kay et al. (2007) made similar reports based on their findings that walking recovery was affected by age and those individuals >50years were less likely to regain an efficient walking pattern.

Non-traumatic injuries are more commonly the cause of SCI in older participants (Scivoletto et al. 2003; Hagen et al., 2005). Younger participants are likely to suffered more extensive injuries due to the nature of the SCI being most likely traumatic in nature such as MVA and other violence related activities (Harrop et al., 2001; Becker et al., 2003; Ackery et al., 2004; Van den Berg et al., 2010; Draulans et al., 2011). There is a higher incidence of secondary injuries and subsequent medical precautions in younger SCI patients as a result of the trauma. This may result in delayed walking onset during rehabilitation (Kay et al., 2007).
Injuries in younger patients are more commonly complete in nature than the hyperextension and age related degenerative SCI more likely to occur in the older group (Cifu et al., 1999a; Marino et al., 1999; Dai, 2001; Ehara & Shimamura, 2001; Scivoletto et al., 2003; Hagen et al., 2005; Gulati et al., 2011). Kirshblum et al., (1998) found that recovery is more favourable in persons with incomplete lesions than complete with significantly more becoming ambulatory. It can therefore be inferred that age related cause of injury and subsequent extent of injury may have an influence on the results of this study. The ratio of 3.5:1 younger than 50 years to older than 50 years would imply that more of the participants in the sample included may have suffered more extensive injuries.

A large portion of the participants (42.20%) in this study were also still in the acute in-patient part of their rehabilitation which would again imply greater numbers of participants of a younger than 50 years may be in the more initial stages of rehabilitation where gait efficiency would be worse than in sub-acute or chronic ambulators. The mean age of the above 50 group was higher in the studies who reported more efficient gait below 50 years (Newey et al., 2000; Scivoletto et al., 2003; Kay et al., 2007). This may contribute to the results not indicating a similar picture as reported.

5.4.2 Gender

Both SCI and able bodied men had higher energy expenditure per meter walked during the 6MWT than the females however in both cases the velocity was higher for the males and resultant distance which could explain the higher energy expenditure per meter. From the Pearson's correlation analysis between gender and energy expenditure no significant relationship was identified between gender and energy expenditure per meter ($p=0.43$). This is similar to Morio et al's (1997) finding. They investigated the effect gender would have on energy expenditure while walking in a able bodied population and found that once variables such as speed of walking, step length and body weight were controlled for, there was no difference between able bodied male and female participants' energy expenditure. Current literature illustrates some controversy regarding whether there is a difference in functional recovery and performance in relation to gender for people with spinal cord injuries. It has been reported that there is no significant difference in ASIA motor scores, length of hospital stay, FIM scores, Barthel index, Rivermead mobility index and Walking Index for Spinal Cord Injury between male and female patients with SCI during recovery (Greenwald et al., 2001; Scivoletto et al., 2003; Catz et al., 2004; New et al., 2007).

5.4.3 BMI

In the Pearson's correlation between BMI and energy expenditure per meter no significant relationship was found ($p=0.97$). However, when analysing each classification of BMI in the study sample as stipulated by the WHO (2000), the energy expenditure per meter of the able bodied participants presented a steady increase as BMI increased. The same was observed with the SCI sample (with some irregularity with the 25.1-29.9kg/m2 category) although the energy expenditure per meter in the latter category was still higher than the lower range BMI scores observed for this group. The SCI sample yielded energy expenditure per meter values 3-8.5 times higher than the able bodied sample for the same BMI category. This could be

attributed to the fact that an increase in BMI relates to a decrease in functional ambulation (Yamakawa et al., 2004). An inverse relationship has been observed between BMI and walking velocity as well as ambulation measured in steps/day and distance walked (Yamakawa et al., 2004). Poor caloric expenditure leads to obesity which makes ambulation more energy intensive and uncomfortable which results in increased obesity (Yamakawa et al., 2004). High BMI scores in able bodied individuals have yielded significantly higher energy expenditure scores during walking and jogging for males and females (Mattson-Prince et al., 1997; Melanson et al., 2003; Browning et al., 2005; LeCheminant et al., 2009).

5.4.4 Pain

No significant relationship was found in a univariate regression analysis between energy expenditure and the presence of pain for any of the reported pain frequencies. A decline in physical activity, including performance of activities of daily living, and self-care, mobility and exercise, work and outdoor activities, sleep disturbance and poor community integration have been widely reported in the SCI population with the presence of pain. (Modirian et al., 2010; Dijkers et al., 2009; Krause et al., 2007; Donnelly & Eng, 2005; Jensen et al., 2005; Putzke et al., 2002; Siddall & Loeser, 2001; Widerstrom-Noga et al., 2001). Pain has also been described as one of the worst disabling consequences of a SCI (Kennedy et al., 2006; Budh et al., 2007). Although no direct link could be found in the literature linking energy expenditure increases to pain experienced, walking speed, stride length and walking distance improve in the absence of pain for people with SCI with reduced levels of mobility due to pain (Buchser et al., 2005). Literature has also illustrated that distance, speed and stride length during walking is associated with more efficient energy expenditure during walking (Fiser et al., 2010; O'Connor et al., 2012; Schrack et al., 2012).

Although the presence of pain as a common complication for people with SCI is undisputed, according to the data analysis it does not contribute to higher energy expenditure during walking for people with SCI.

5.4.5 Spasticity

The Pearson's correlation results between the Modified Ashworth Score and energy expenditure per meter revealed no significant relationship with energy expenditure while walking. A small inverse correlation was found indicating that with an increase in hip flexion spasticity or extension spasticity there will be a decrease in energy expenditure per meter walked. In a study

by Scivoletto et al. (2008) spasticity was also found to have a negative correlation with 6MWT performance. They concluded that walking performance was negatively affected by spasticity due to increased muscle tone causing movements to be more difficult while trying to overcome spasticity in order to allow an activity such as leg swing during walking (Ditunno & Scivoletto, 2009).

Spasticity has also been reported to increase with the effort of physical work which just accentuates the resistance to movement (Scivoletto et al., 2008). Dvorak et al. (2005) also reported an inverse effect between spasticity and functional capacity. Spasticity causing an abnormal gait pattern has been reported to increase energy expenditure during walking (Rodrigo et al., 2010a) and cause a reduction in distances walked before fatigue (Scivoletto et al., 2008). Norman et al. (1998) reported that the use of anti-spasmodic treatment for people with spasticity post SCI has produced improved gait speed and reduced need for assistance with walking. Similar findings were reported by Barbeau & Norman (2003).

Based on this study's findings, the above literature is not supported. This may be attributed to only 20% of the sample observed had bilateral symptom with a MAS score greater than two. Further consideration can also be given to a large proportion of the sample (42.20%) was still in the acute rehabilitation stage of their recovery and could still have been suffering from spinal shock. Spinal shock has been reported to last for several weeks post SCI (Wolpaw & Tennissen, 2001; Hiersemenzel et al 2000). The resolution of spinal shock may coincide with an increase in spasticity (Sköld et al., 1999; Adams & Hick, 2005). Although no clear relationship has been described between presence of spasticity and duration since injury, 65-78% of people with SCI have been reported to have symptoms of spasticity one year down the line (Sköld et al., 1999). Therefore only a small proportion of the sample in our study presented with spasticity which explains the lack of correlation with energy expenditure while walking.

5.4.6 Duration since injury, length of stay in rehabilitation, extent of treatment and rehabilitation services received

Participants who had a SCI duration of >10years had 0.26 less energy expenditure than those who had less than six months SCI duration ($p = 0.05$). This can be explained by the duration since injury and ongoing rehabilitation facilitating ongoing recovery. Neurological recovery for the SCI population has been widely reported during the first and second year post injury with an emphasis on the first three to six months (Marino et al., 1999; Patrick, 2003; Kirshblum et al.,

2004; Burns et al., 2012). Functional improvement in motor scores, balance and walking ability have more recently also been reported in the chronic SCI population (McDonald et al.,2003; Kirshblum et al., 2004; Dvorak et al., 2005; Hicks et al., 2011; Harkema et al., 2012; Schrack et al., 2012). This implies that with ongoing treatment there will be ongoing improvements in gait parameters which is will continue to improve. Greater time since injury is therefore linked to better performance. Based on improvements in gait speed, balance and endurance (Harkema et al., 2012; Schrack et al., 2012) energy expenditure while walking was also suggested to decrease as people with SCI improve in their walking abilities with the lapse of time since injury.

The current trend in rehabilitation is to have reduced length of stay in hospital (Ditunno & Formal, 1994; Kay et al., 2007). This is to contain high costs involved in medical care of this population (Ditunno & Formal,1994; Kennedy et al., 2006; Hammel, 2007). In our study the largest proportion of the SCI sample (55%) had more than 10 weeks of in-patient rehabilitation. The second biggest category was 2 to 4 weeks (18%). The smaller groups were 6 to 8 weeks with 11%, 4 to 6 weeks with 9% and lastly 8 to 10 weeks with 7%. Even though the association between length of stay and energy expenditure while walking was not statistically significant, the increase in length of stay was associated with a decrease in energy expenditure. The impacts of the timing, intensity, and duration of inpatient rehabilitation programs on rehabilitation outcomes have been widely researched. Participation in inpatient rehabilitation for SCI has been found to result in functional gains (Eastwood et al., 1999; Sumida et al., 2001; Van der Putten et al., 2001; Pagliacci et al., 2003; Scivoletto et al., 2004; Scivoletto et al., 2005;). It can therefore be assumed that the longer the participation period for in-patient treatment they are exposed to, the greater the functional gains. This would explain why there was an association between increased length of stay and decreased energy expenditure.

For the univariate analysis of energy expenditure while walking and out-patient rehabilitation received, significant relationships were observed for not receiving out-patient treatment ($p=0.002$) and still in in-patient rehabilitation ($p=0.01$). An increase of 52% and 23% was yielded respectively for not receiving out-patient- and being in inpatients treatments. It has been widely reported that ongoing treatment is associated with increase in functional improvement, balance, gait parameters and motor strength in the chronic SCI population with ongoing therapy (McDonald et al.,2003; Kirshblum et al., 2004; Dvorak et al., 2005; Hicks et al., 2011; Harkema et al., 2012; Schrack et al., 2012). This is indicated in this current study results – greater energy efficiency with out-patient therapy attendance. For the individuals still in the in-patient

rehabilitation process the higher energy expenditure can be explained by not being as efficient yet due to motor weakness post injury still being severe.

5.4.7 Energy expenditure and Assistive devices

Based on the study results, the use of different assistive devices appears to influence energy expenditure to a larger or lesser extent depending on the device.

In the Scheffé comparison the energy expenditure yielded during the walking assessment using different assistive devices were compared for differences. A significant difference was observed between energy expenditure during crutch use compared to walking frame use ($p=0.03$) with a difference of 0.34cal/m in favor of the crutch. Similar to the results reported by Ulkar et al. (2003), that crutches were found to be more energy efficient than walkers. They concluded that different walking aids affect walking speed which causes walking more or less energy efficient. In Ulkar's study the participants walked with both assistive devices in turn to control for differences in the two groups which in our study were not the case. Walking with a walking frame and an orthotic (in this case mostly backslabs to achieve knee extension) yields the highest energy expenditure value of all the assistive devices in this study with a mean of 0.54cal/m. In comparison with able bodied participants who yielded an energy expenditure per meter of 0.08cal/m the walking frame and orthotic group requires 6.75 times the energy the able bodied group does. Similar results were reported in a study by Kawashima et al. (2006) who reported that energy expenditure in orthotic assisted SCI gait compared to able bodied required six times the energy cost during walking. The high energy expenditure cost of walking frame ambulation has been reported to be due to slow walking speed, step-to-gait pattern and the repeated lifting of the frame necessary for forward motion (Priebe & Kram, 2011). Many people with SCI discontinue the use of their orthotics and assistive devices due to a reported high demand for the energy expenditure and mechanical work during orthotic gait (Ulkar et al., 2003; Karimi, 2011).

5.4.8 Energy expenditure and ROM

In the correlation analysis between ROM and energy expenditure per meter an overall inverse relationship was observed. Hip flexion had a significant relationship with energy expenditure per meter ($p= <0.001$) and with a decrease in hip flexion the energy expenditure per meter would increase by 0.50. Hip extension was also significant ($p= 0.04$), with a decrease in hip extension there would be an increase of 0.30 in energy expenditure per meter. In a study by

Kawashima et al. (2006) observations were made about the lesion level on the orthotic gait performance in complete thoracic SCI. Kawashima et al. concluded that hip ROM does affect the energy expenditure while walking. Higher thoracic lesions and resultant increased paralysis in the trunk and hip musculature produce smaller ROM at the hips during walking than lower thoracic lesions. Insufficient leg swing is therefore produced due to greater relative paralysis which leads to slower gait speed, shorter distances and higher energy expenditure.

A decrease in knee flexion resulted in the energy expenditure increases of 0.30. Knee flexion has been reported in literature to contribute to a reduction in energy consumption during walking compared to an absence of knee flexion (Edwards & Bataweel, 1996; Yang et al., 1996; Baardman et al., 2002). Impaired ROM has been reported to potentiate spasticity which increases energy expenditure to overcome in order to allow movement to walk (Skold et al., 1999; Scivoletto et al., 2008). ROM therefore indirectly also influences energy expenditure during walking.

5.4.9 Energy expenditure and ASIA classification

As illustrated in the data from this study, lower extremity scores for motor and sensory categories increased progressively from ASIA A to D. Velocity and distance also increased in the same direction indicating faster walking and greater speeds in ASIA D and C (D being the greatest). This was also reported in a study by Kim et al. (2004) who that reported ASIA motor scores correlate with gait speed and ambulatory capacity both in acute and chronic SCI (Kim et al., 2004).

Energy expenditure per meter decreases from ASIA A to ASIA D indicating that less energy is expended in order to walk one meter for a person with ASIA D than A, More specifically, ASIA A required 2.5 times more energy to walk one meter than D. ASIA B had lower energy expenditure per meter than any of the other categories however; the sample consisted of one individual which could be the reason for the skewed data. Participants with ASIA D could walk seven times the distance walked by those with ASIA A and had walking speed 7.6 times greater than those with ASIA A. Similar findings were reported by Kim et al. (2004) who reported that ASIA lower extremity motor scores have been found to have a high correlation coefficient with the 6MWT in terms of gait speed and distance walked in a study investigating the relationship of muscle strength with ambulatory capacity in SCI.

In the multivariate regression significant correlations were identified between ASIA classification and energy expenditure. ASIA B, C and D in relation to ASIA A yielded p=0.05, 0.01 and 0.01 respectively. Classification for ASIA B, C and D are inversely correlated with ASIA A, therefore energy expenditure per meter in these categories will have a 0.55, 0.38 and 0.35 less energy expenditure per meter walked. This can be explained by the fact that walking function regained after a SCI depends strongly on the level of injury and completeness of the injury (Van Hedel & Dietz, 2010). ASIA C and D have been reported to achieve leisurely velocities of walking and distance to successfully allow community activities by six months post SCI (Dobkin et al., 2007). However, ambulatory function very rarely reaches the level of able bodied subjects (Consortium for Spinal Cord Medicine, 1999). In general, walking velocity for people with spinal cord injury is slower and gait requires assistive devices (Van Hedel et al., 2007; Van Hedel et al., 2009; Ditunno et al., 2007). Slower gait velocity has been linked with an increase in energy expenditure required to ambulate (Fiser et al., 2010; Schrack et al., 2012). This is clearly illustrated in the results with ASIA A participants producing reduced walking velocity in comparison with ASIA D and categories progressive increasing velocity towards ASIA D.

5.4.10 Energy expenditure and Sensory score

In the Pearson's correlation analysis of sensory score and energy expenditure per meter of walking a significant inverse relationship was noted (p=0.02). With a decrease in sensory score the energy expenditure would increase by 0.30. The mean sensory score for SCI participants with an ASIA A was 147.30 and the energy expenditure per meter was 0.71cal/m. By definition there would be no sensory sparing below the level of the lesion which could explain the reason for the high energy expenditure. ASIA B's sensory score was 175 and energy expenditure per meter 0.13cal/m. ASIA B would have sensory sparing below the level of lesion as per definition. ASIA C and D had mean sensory scores of 179.50 and 183.80 respectively and energy expenditure of 0.29 and 0.26 cal/m respectively. Sensory and motor sparing is present in C and D as per definition. It is clear from the data that there is an increase in sensory scores from ASIA A towards ASIA D as well as a decrease in energy expenditure per meter walked from D towards A. ASIA B is lower than the other categories however this may be due to only one participant fell in this category. The maximum sensory score is 224 and therefore ASIA D and C mean values were 82% and 80% of the normal sensation. ASIA A was 66% and ASIA B 78% of normal values. Burns et al (2012) reported that 20-50% of people with SCI who present with a motor complete lesion but have an incomplete sensory impairment will walk in some capacity by

one year post-injury. Both pin prick and light touch scores have been found to be predictors of motor recovery (Curt & Dietz, 1997; Oleson et al., 2005; Van Middendorp et al., 2009).

This suggests that sensory preservation is linked to motor performance during walking.
On the contrary, Beuhner et al. (2012) reported that based on their study, below level sensation was found to have no relationship with locomotor recovery and performance including gait speed, endurance and balance. However participants who performed well in their study with locomotor tasks did have a wide range of pin prick and light touch scores. No literature could be found which directly link energy expenditure with sensory preservation.

5.4.11 Energy expenditure and walking velocity

From the Pearson's correlation analysis of velocity and energy expenditure during walking yielded a significant ($p<0.001$) inverse relationship – with a decrease in velocity the energy expenditure increases by 0.06. Walking velocity ranged between 0.03 to 0.78m/sec for the participants who used walking aids. The mean velocity for the participants who walked without an assistive device was 0.91m/sec. In the multivariate stepwise regression velocity had a p value of 0.01 with the inverse relationship to energy expenditure of 0.41 for every meter walked.

Similar results were reported by by Harkema et al. (2012) with walking velocity ranging between 0.31-0.51m/sec which is less than 50% of the reported optimal speed of 1.1m/sec.
Van Hedel et al. (2009) reported that gait speeds within different categories of SCI mobility levels were between 0.1 to 0.88m/sec for participants who required orthotic or physical assistance and up to 1.46m/sec for participants who could walk without aid.

It is widely reported that walking velocity in people with SCI is slower than the able bodied population and that gait often requires assistive devices (Waters & Mulroy, 1999; Ulkar et al., 2003; Kawashima et al., 2006; Van Hedel et al., 2007; Van Hedel et al., 2009; Ditunno et al., 2007). ASIA motor scores have been found to correlate with gait speed and ambulatory capacity both in acute and chronic SCI (Kim et al., 2004). Functional ability or extent of weakness will affect velocity and energy expenditure while walking in the SCI population. SCI participants with an ASIA A walked at a mean velocity of 0.05m/s and utilised 0.71cal/m while walking. Participants with an ASIA D classification walked at 0.38m/s and their energy expenditure was 0.26cal/m indicating the faster walking speed was more energy efficient but was depended on function (ASIA classification). Higher functional ability as presented in ASIA D

participants will yield faster walking speed and more efficient energy expenditure while performing the walking task.

5.5 Study limitations

For a few of the factors in question to potentially affect the energy expenditure per meter while walking there was an uneven distribution within the sub-categories of the respective groups.
For example:

- Age – there were too few participants over 50 years of age to effectively investigate if age does play a role in energy expenditure.
- Rehabilitation services provided – 42% of the sample was still in rehabilitation and could therefore not utilise out-patient therapy services yet. Therefore the benefit of out-patient therapy could not be investigated fully.
- Duration since injury – 73% of the study sample was below two years post injury when recovery is still expected. The chronic SCI population and improvements in the later years could therefore not be investigated.

The walking aids and orthotics used during the assessment were that which the participant usually uses for walking. However there is quite a difference in resourcefulness between the rehabilitation units. Where knee extension was absent, some participants had callipers to compensate where as some from poorly resourced rehabilitation units only had backslabs and bandages to secure to the participant leg. Furthermore, a lack of ankle dorsiflexion to achieve swing through is compensated by an AFO (carbon or plastic) which was not available for some of the participants from poorly resourced rehabilitation units. This causes circumduction during gait with potential balance, trunk and upper limb loading which may increase energy expenditure.

CHAPTER 6

6. Conclusions and Recommendations

6.1 Conclusions

- The mean energy expenditure per meter values yielded by the SCI samples was four times higher than the able bodied sample. The difference in energy expenditure between the able bodied individuals and the SCI participants is lower than reported by literature.
- The mean distance covered during the 6MWT for the SCI sample was more than three times less than the able bodied sample. The results are similar to what is reported in literature.
- SCI participants walked at a mean velocity three times less than that of the able bodied participants. The results are in line with what is reported in the literature.
- The pulse rate for the SCI group is 21% greater than the able bodied group after completion of the 6MWT at their preferred walking pace. This is again similar to what is reported in literature.
- Energy expenditure while walking was significantly lower for participants who received out-patient therapy after acute in-patient therapy was completed than for participants not receiving or currently still in acute in-patient rehabilitation.
- A duration since injury >10 years was observed to have a significantly lower energy expenditure while walking compared to <6months since injury.
- Crutch walking utilised significantly less energy than walking frame ambulation.
- ROM of hip flexion, hip extension and knee flexion inversely correlate with energy expenditure – the smaller the range, the greater the energy expenditure.
- Energy expenditure per meter for ASIA D category proved to be the most efficient gait, followed by ASIA C and then ASIA B.
- A significant inverse relationship was observed between sensory score (ASIA) and energy expenditure with an increase in energy expenditure as sensory score decreases.
- Velocity of walking also yielded a significant inverse relationship with energy expenditure ($p<.0.001$). As walking velocity increases, there is a decrease in energy expenditure per meter walked.

6.2 Recommendations

- Ongoing therapy after acute in-patient treatment has been found to facilitate more efficient energy expenditure while walking. Where possible patients should be encouraged to continue with therapy upon return to home as well as appropriate referrals for patients who may not be able to continue out-patient treatment at the same facility.
- On the basis that it is a long road to recovery, gait re-education should start at the earliest point during in-patient rehabilitation to enable the patient to achieve the maximum gait recovery at the earliest point. Out-patient funding is often limited.
- Walking speed not only has a significant impact on energy expenditure but also determine to a large extent if community mobility will be safe and accessible to a patient. Emphasis should be made during in-patient and ongoing out-patient treatment to achieve acceptable walking speeds, efficient energy expenditure and distances to allow independence in the community.
- Range of motion has been indicated as a factor which would increase energy expenditure if a loss of ROM occurs. All attempts should be made to ensure maximum active ROM (especially for hip flexion, hip extension and knee flexion) and prevent contracture formation to ensure efficient gait.
- Crutches have been identified as being more energy efficient than walking frames. Where possible patients should be encouraged to achieve safe crutch walking rather than walking frame. This places an emphasis on balance training as part of gait re-education from the onset.
- In the rehabilitation setting often funding is limited due to the length of time patients require therapeutic intervention. It would be a recommendation to funders to assist patients to continue with ongoing therapy upon rehabilitation discharge from hospital to enable achievement of community ambulation independence.

References

Ackery A, Tator C, Krassioukov A. 2004. A Global Perspective on Spinal Cord Injury Epidemiology Journal of Neurotrauma 21: 1355-1370.

Adams MM, Hick AL. 2005. Spasticity after spinal cord injury. Spinal cord 43:577-586.

Adams MM, Martin Ginis KA, Hicks AL. 2007. The spinal cord injury spasticity evalutation tool: development and evaluation. Archives of physical medicine and rehabilitation 88:1185-1192.

American Thoracic Society. 2002. ATS Statement: Guideline for the Six-Minute Walk Test. American Journal of Respiratory and Critical Care Medicine166:111-117.

American Spinal Injury Association. Reference manual for the International Standards for Neurological Classification of Spinal Cord Injury. Chicago: American Spinal Injury Association; 2003.

Anderson KD. 2004. Targeting recovery: priorities of the spinal cord-injured population. Journal of Neurotrauma 21:1371-1383.

Ansari NN, Naghdi S, Arab TK, Jalaie S. 2008. The interrater and intrarater reliability of the Modified Ashworth Scale in the assessment of muscle spasticity: limb and muscle group effect. NeuroRehabilitation 23:231-237.

Arazpour M, Bani MA, Hutchins SW, Jones RK. 2012. The physiological cost index of walking with mechanical and powered gait orthosis in patients with spinal cord injury. Spinal Cord doi: 10.1038/sc.2012.162. [Epub ahead of print].

Baardman G, Ijzerman J, Hermens H, Veltink P, Boom HBK, Zilvold G. 2002. Knee flexion during the swing phase of orthotic gait: influence on kinematics, kinetics and energy consuption in two paraplegic cases. Saudi Journal of Disability Rehabilitation 8:20-32.

Barbeau H, Norman KE. 2003. The effect of noradrenergic drugs on the recovery of walking after spinal cord injury. Spinal Cord 41:137-43.

Barbeau H, Nadeau S, Garneau C. 2006. Physical determinants, emerging concepts, and training approaches in gait of individuals with spinal cord injury. Journal of Neurotrauma 23:571-585.

Barnes MP. 2001. Upper motor neurone syndrome and spasticity. Cambridge: Cambridge University Press p1-14.

Becker D, Sadowsky CL, McDonald JW. 2003. Restoring function after spinal cord injury. Neurologist 9:1-15. Review.

Biering-Sørensen F, Hansen RB, Biering-Sørensen J. 2004. Mobility aids and transport possibilities 10-45 years after spinal cord injury. Spinal Cord 42:699-706.

Buchholz AC, McGillivray CF, Pencharz PB. 2003. Differences in resting metabolic rate between paraplegic and able-bodied subjects are explained by differences in body composition. The American Journal of Clinical Nutrition 77:371-378.

Bohannon RW, Smith MB. 1987. Interrater reliability of a modified Ashworth scale of muscle spasticity. Physical Therapy 67:206-207.

Brosseau L, Balmer S, Tousignant M, O'Sullivan JP, Goudreault C, Goudreault M, Gringras S. 2001. Intra- and intertester reliability and criterion validity of the parallelogram and universal goniometers for measuring maximum active knee flexion and extension of patients with knee restrictions. Archives of Physical Medicine and Rehabilitation 82:396-402.

Browning RC, Baker EA, Herron JA, Kram R. 2005. Effects of obesity and sex on the energetic cost and preferred speed of walking. Journal of Applied Physiology 100:390-398. Epub 2005 Oct 6.

Buchser E, Paraschiv-Ionescu A, Durrer A, Depierraz B, Aminian K, Najafi B, Rutschmann B. 2005. Improved Physical Activity in Patients Treated for Chronic Pain by Spinal Cord Stimulation. Neuromodulation 8:40-48.

Budh NC, Lund I, Ertzgaard P, Holtz A, Hultling C, Levi R, Werhagen L, Lundeberg T. 2003. Pain in a Swedish spinal cord injury population. Clinical Rehabilitation 17:685-690

Budh CN, Osteråker AL. 2007. Life satisfaction in individuals with a spinal cord injury and pain. Clinical Rehabilitation 21:89-96

Budh NC, Lundeberg T. 2005. Use of analgesic drugs in individuals with spinal cord injury. Journal of Rehabilitation Medicine 37:87-94.

Buehner JJ, Forrest GF, Schmidt-Read M, White S, Tansey K, Basso DM. 2012. Relationship between ASIA examination and functional outcomes in the NeuroRecovery Network Locomotor Training Program. Archives of Physical Medicine and Rehabilitation 93:1530-1540.

Burns SP, Golding DG, Rolle WA Jr, Graziani V, Ditunno JF Jr. 1997. Recovery of ambulation in motor-incomplete tetraplegia. Archives of Physical Medicine and Rehabilitation 78:1169-1172.

Burns AS, Marino RJ, Flanders AE, Flett H. 2012. Clinical diagnosis and prognosis following spinal cord injury. Handbook of Clinical Neurology 109:47-62.

Cardenas DD, Turner JA, Warms CA, Marshall HM. 2002. Classification of chronic pain associated with spinal cord injuries. Archives of Physical Medicine and Rehabilitation 83:1708-1714.

Cardenas DD, Bryce TN, Shem K, Richards JS, Elhefni H. 2004. Gender and minority differences in the pain experience of people with spinal cord injury. Archives of Physical Medicine and Rehabilitation 85:1774-1781.

Catz A, Goldin D, Fishel B, Ronen J, Bluvshtein V, Gelernter I. 2004. Recovery of neurologic function following nontraumatic spinal cord lesions in Israel. Spine 29:2278-2282.

Cahil SE. 1998. Towards a sociology of the person. Sociological Theory 16:131 – 148.

Cifu DX, Huang ME, Kolakowsky-Hayner SA, Seel RT. 1999a. Age, outcome, and rehabilitation costs after paraplegia caused by traumatic injury of the thoracic spinal cord, conus medullaris, and cauda equina. Journal of Neurotrauma. 16:805-815.

Cifu DX, Seel RT, Kreutzer JS, McKinley WO. 1999b. A multicenter investigation of age-related differences in lengths of stay, hospitalization charges, and outcomes for a matched tetraplegia sample. Archives of Physical Medicine and Rehabilitation 80:733-740.

Clifton GL, Donovan WH. 1996. Omental transposition in chronic spinal cord injury. Spinal Cord 34:193-203.

Consortium for Spinal Cord Medicine. Outcomes Following Traumatic Spinal Cord Injury: Clinical Practice Guidelines for Health-Care Professionals. Washington, DC: Paralyzed Veterans of America; 1999. (Scientific evidence–Guideline).

Craven BC, Morris AR. 2010. Modified Ashworth scale reliability for measurement of lower extremity spasticity among patients with SCI. Spinal Cord 48:207-213.

Cripps RA, Lee BB, Wing P, Weerts E, Mackay J, Brown D. 2011. A global map for traumatic spinal cord injury epidemiology: towards a living data repository for injury prevention. Spinal Cord 49:493-501.

Cruz-Almeida Y, Martinez-Arizala A, Widerström-Noga EG. 2005. Journal of Rehabilitation Research and Development 42:585-594. Chronicity of pain associated with spinal cord injury: A longitudinal analysis.

Curt A, Dietz V. 1997. Ambulatory capacity in spinal cord injury: significance of somatosensory evoked potentials and ASIA protocol in predicting outcome. Archives of Physical Medicine and Rehabilitation 78: 39-43.

Dai LY. 2001. Acute central cervical cord injury: the effect of age upon prognosis. Injury 32:195-199.

De Groot PC, Van Kuppevelt DH, Pons C, Snoek G, Van Der Woude LH, Hopman MT. 2003. Time course of arterial vascular adaptations to inactivity and paralyses in humans. Medicine and Science in Sports and Exercise 35:1977-1985.

DeLoach SS, Townsend RR. 2008. Vascular stiffness: its measurement and significance for epidemiologic and outcome studies. Clinical Journal of the American Society of Nephrology 3:184-192. Review.

Den Hoed M, Westerterp KR. 2008. Body composition is associated with physical activity in daily life as measured using a triaxial accelerometer in both men and women. International Journal of Obesity 32:1264-1270.

Devillard X, Rimaud D, Roche F, Calmels P. 2007. Effects of training programs for spinal cord injury. Annales de Readaptation et de Medecine Physique 50:490-498.

Dijkers M. 1999. Measuring quality of life: methodological issues. American Journal of Physical Medicine and Rehabilitation 78:286 – 300.

Dijkers M, Bryce T, Zanca J. 2009. Prevalence of chronic pain after traumatic spinal cord injury: a systematic review. Journal of Rehabilitation Research and Development 46:13-29.

Ditunno JF Jr, Formal CS. 1994. Chronic spinal cord injury. New England Journal of Medicine 330:550-556.

Ditunno JF Jr, Graziani V, Tessler A. 1997. Neurological assessment in spinal cord injury. Advances in Neurology 72:325-333.

Ditunno JF, Barbeau H, Dobkin BH, Elashoff R, Harkema S, Marino RJ. 2007. Validity of the walking scale for spinal cord injury and other domains of function in a multicenter clinical trial. Neurorehabilitation and Neural Repair 21:539-550.

Ditunno PL, Patrick M, Stineman M, Ditunno JF. 2008. Who wants to walk? Preferences for recovery after spinal cord injury: a longitudinal and cross-sectional study. Spinal Cord 47:500-506.

Ditunno J, Scivoletto G. 2009. Clinical relevance of gait research applied to clinical trials in spinal cord injury. Brain Research Bulletin 78:35-42.

Dobkin BH, Apple D, Barbeau H, Basso M, Behrman A, Deforge D, Ditunno J, Dudley G, Elashoff R, Fugate L, Harkema S, Saulino M, Scott M. 2003. Methods for a randomized trial of weight-supported treadmill training versus conventional training for walking during inpatient rehabilitation after incomplete traumatic spinal cord injury. Neurorehabilitation and Neural Repair 17:153-167.

Dobkin B, Barbeau H, Deforge D, Ditunno J, Elashoff R, Apple D, Basso M, Behrman A, Harkema S, Saulino M, Scott M; Spinal Cord Injury Locomotor Trial Group. 2007. The evolution of walking-related outcomes over the first 12 weeks of rehabilitation for incomplete traumatic spinal cord injury: the multicenter randomized Spinal Cord Injury Locomotor Trial. Neurorehabil Neural Repair. 2007 Jan-Feb; 21(1):25-35.

Domingo A, Al-Yahya AA, Asiri Y, Eng JJ, Lam T; Spinal Cord Injury Rehabilitation Evidence Research Team. 2012. A systematic review of the effects of pharmacological agents on walking function in people with spinal cord injury. Journal of Neurotrauma 29:865-79. Epub 2012 Feb 29

Donnelly C, Eng JJ. 2005. Pain following spinal cord injury: the impact on community reintegration. Spinal Cord 43:278-782.

Draulans N, Kiekens C, Roels E, Peers K. 2011. Etiology of spinal cord injuries in Sub-Saharan Africa. Spinal Cord. 49:1148-54

Dvorak MF, Fisher CG, Hoekema J, Boyd M, Noonan V, Wing PC, Kwon BK. 2005. Factors predicting motor recovery and functional outcome after traumatic central cord syndrome: a long-term follow-up. Spine 30:2303-2311.

Eastwood EA, Hagglund K, Ragnarsson K, Gordon W, Marino R. 1999. Medical rehabilitation length of stay and outcomes for persons with traumatic spinal cord injury–1990–1997. Archives of Physical Medicine and Rehabilitation 80:1457–1463.

Ehde DM, Jensen M P, Engel JM, Turner JA, Hoffman AJ, Cardenas, DD. 2003. Chronic pain secondary to disability: A review. Clinical Journal of Pain19:3–17.

Edwards J, Bataweel AOP. 1996. Hybrid system for upright mobility with unlockable orthotic knee for knee bending during swing phase. In: Pedotti, Ferrarin, Quintern and Riener (Eds.) Neuroprosthetics – from basic research to clinical applications. Springer-Verlag, Berlin/Heidelberg pp 493-502.

Ehara S, Shimamura T. 2001. Cervical spine injury in the elderly: imaging features. Skeletal Radiology 30:1-7.

Eriks-Hoogland IE, de Groot S, Post MW, van der Woude LH. 2011 Correlation of shoulder range of motion limitations at discharge with limitations in activities and participation one year later in persons with spinal cord injury. Journal of Rehabilitation Medicine 43:210-215.

Elbasiouny SM, Moroz D, Bakr MM, Mushahwar VK. 2010 Management of spasticity after spinal cord injury: current techniques and future directions. Neurorehabilitation and Neural Repair 24:23-33. Epub 2009 Sep 1.

Field-Fote EC, Fluet GG. 2001. The spinal cord injury functional ambulation inventory (SCI-FAI). Journal of Rehabilitation Medicine 33:177-181.

Finnerup NB, Johannesen IL, Sindrup SH, Bach FW, Jensen TS. 2001. Pain and dysesthesia in patients with spinal cord injury: A postal survey. Spinal Cord 39:256-62.

Fiser WM, Hays NP, Rogers SC, Kajkenova O, Williams AE, Evans CM, Evans WJ. 2010. Energetics of walking in elderly people: factors related to gait speed. The Journal of Gerontology, Series A 65:1332-7. Epub 2010 Aug 1.

Frielingsdorf K, Dunn RN. 2007. Cervical spine injury outcome – a review of 101 cases treated in a tertiary referral unit. South African Medical Journal 97:203-207.

Greenwald BD, Seel RT, Cifu DX, Shah AN. 2001. Gender-related differences in acute rehabilitation lengths of stay, charges, and functional outcomes for a matched sample with spinal cord injury: a multicenter investigation. Archives of Physical Medicine and Rehabilitation 82:1181-1187.

Gittler MS, McKinley WO, Stiens SA, Groah SL, Kirshblum SC. 2002. Spinal cord injury medicine. 3. Rehabilitation outcomes. Archives of Physical Medicine and Rehabilitation 83:S65-71, S90-8.

Gregson JM, Leathley M, Moore AP, Sharma AK, Smith TL, Watkins CL. 1999. Reliability of the Tone Assessment Scale and the modified Ashworth scale as clinical tools for assessing poststroke spasticity. Archives of Physical Medicine and Rehabilitation 80:1013-1016.

Gulati A, Yeo CJ, Cooney AD, McLean AN, Fraser MH, Allan DB. 2011. Functional outcome and discharge destination in elderly patients with spinal cord injuries. Spinal Cord. 49:215-218. Epub 2010 Aug 10.

Gupta N, White KT, Sandford PR. 2006. Body Mass Index in spinal cord injury - a retrospective study. Spinal Cord 44:92-94.

Hagen EM, Aarli JA, Gronning M. 2005. The clinical significance of spinal cord injuries in patients older than 60 years of age. Acta Neurologica Scandinavico 112:42-47.

Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, Post MW, Bussmann JB. 2007. Complications following spinal cord injury: occurrence and risk factors in a longitudinal study during and after inpatient rehabilitation. Journal of Rehabilitation Medicine 39:393-398.

Hale L, Williams K, Ashton C, Connole T, McDowell H, Taylor C. 2007. Reliability of RT3 accelerometer for measuring mobility in people with multiple sclerosis: Pilot study. Journal of Rehabilitation Research and Development 44:619-628.

Hammell KW. 2007. Quality of life after spinal cord injury: A meta-synthesis of qualitative findings. Spinal Cord 45(2):124-139.

Harkema SJ, Schmidt-Read M, Lorenz DJ, Edgerton VR, Behrman AL. 2012. Balance and ambulation improvements in individuals with chronic incomplete spinal cord injury using locomotor training-based rehabilitation. Archives of Physical Medicine and Rehabilitation 93:1508-1517.

Harrop JS, Sharan AD, Vaccaro AR, Przybylski GJ. 2001. The cause of neurologic deterioration after acute cervical spinal cord injury. Spine 26:340-346.

Hart C, Williams E. 1994. Epidemiology of spinal cord injuries: a reflection of changes in South African society Paraplegia 32:709–714.

Hayes AM, Myers JN, Ho M, Lee MY, Perkash I, Kiratli BJ. 2005. Heart rate as a predictor of energy expenditure in people with spinal cord injury. Journal of Rehabilitation Research & Development 42:617-624.

Hendrick P, Boyd T, Low O, Takarangi K, Paterson M, Claydon L, Milsavljevic S. 2010. Construct validity or RT3 accelerometer: A comparison of level-ground and treadmill walking at self selected speeds. Journal of Rehabilitation Research and Development 47:147-168.

Hermanus FJ, Draper CE, Noakes TD. 2010. Spinal cord injuries in South African Rugby Union (1980 - 2007). South African Medical Journal 100:230-234.

Hicks AL, Ginis KA. 2008. Treadmill training after spinal cord injury: it's not just about the walking. Journal of Rehabilitation Research and Development 45:241-248. Review.

Hicks AL, Martin Ginis KA, Pelletier CA, Ditor DS, Foulon B, Wolfe DL. 2011. The effects of exercise training on physical capacity, strength, body composition and functional performance among adults with spinal cord injury: a systematic review. Spinal Cord 49:1103-1127.

Hiersemenzel LP, Curt A, Dietz V. 2000. From spinal shock to spasticity: neuronal adaptations to a spinal cord injury. Neurology 54: 1574–1582.

Hopman MT, Groothuis JT, Flendrie M, Gerrits KH, Houtman S. 2002. Increased vascular resistance in paralyzed legs after spinal cord injury is reversible by training. Journal of Applied Physiology 93:1966-1972.

Hsu AL, Tang PF, Jan MH. 2003. Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. Archives of Physical Medicine and Rehabilitation 84: 1185-1193

Ijzerman MJ, Baardman G, van 't Hof MA, Boom HBK, Hermens HJ, Veltink PH. 1999. Validity and reproducibility of crutch force and heart rate measurements to assess energy expenditure of paraplegic gait. Archives of physical medicine and rehabilitation 80:1017-1023.

Jackson AB, Carnel CT, Ditunno JF, Read M, Boninger ML, Schmeler MR, Williams SR, Donovan WH. 2008. Outcome measures for gait and ambulation in the spinal cord population. Journal of Spinal Cord Medicine 31:487-499.

Jensen MP, Hoffman AJ, Cardenas DD. 2005. Chronic pain in individuals with spinal cord injury: a survey and longitudinal study. Spinal Cord 43:704-712.

Jensen TS, Baron R, Haanpää M, Kalso E, Loeser JD, Rice AS, Treede RD. 2011. A new definition of neuropathic pain. Pain 152:2204-5. Epub 2011 Jul 18.

Jones LM, Legge M, Goulding A. 2003. Healthy body mass index values often underestimate body fat in men with spinal cord injury. Archives of Physical Medicine and Rehabilitation 84:1068-1071.

Kakebeeke TH, Lechner H, Baumberger M, Denoth J, Michel D, Knecht H. 2002. The importance of posture on the isokinetic assessment of spasticity. Spinal Cord 40:236-243.

Kannus P, Niemi S, Palvanen M, Parkkari J. 2000. Continuously increasing number and incidence of fall-induced, fracture-associated, spinal cord injuries in elderly persons. Archives of Internal Medicine 160:2145-2149.

Karimi MT. 2011. Evidence-based evaluation of physiological effects of standing and walking in individuals with spinal cord injury. Iranian Journal of Medical Science 36:242-53.

Kawashima N, Nozaki D, Abe MO, Akai M, Nakazawa K. 2005. Alternate Leg Movement Amplifies Locomotor-Like Muscle Activity in Spinal Cord Injured Persons. Journal of Neurophysiology 93: 777–785.

Kawashima N, Taguchi D, Nakazawa K, Akai M. 2006. Effect of lesion level on the orthotic gait performance in individuals with complete paraplegia. Spinal Cord 44: 487-494.

Kay ED, Deutsch A, Wuermser LA. 2007. Predicting walking at discharge from inpatient rehabilitation after a traumatic spinal cord injury. Archives of Physical Medicine and Rehabilitation 88:745-750.

Kay E, Deutsch A, Chen D, Semik P, Rowles D. 2010. Effects of gender on inpatient rehabilitation outcomes in the elderly with incomplete paraplegia from nontraumatic spinal cord injury. Journal of Spinal Cord Medicine 33:379-386.

Kennedy P, Evans MJ, Berry C, Mullin J. 2003. Comparative analysis of goal achievement during rehabilitation for older and younger adults with spinal cord injury. Spinal Cord 41:44-52.

Kennedy P, Lude P, Taylor N. 2006. Quality of life, social participation, appraisals and coping post spinal cord injury: a review of four community samples. Spinal Cord 44:95-105.

Kim CM, Eng JJ, Whittaker MW. 2004. Level walking and ambulatory capacity in persons with incomplete spinal cord injury: relationship with muscle strength. Spinal Cord 42:156-162.

Kirshblum SC, O'Connor KC. 1998. Predicting neurologic recovery in traumatic cervical spinal cord injury. Archives of Physical Medicine and Rehabilitation 79:1456-1466

Kirshblum S, Millis S, McKinley W, Tulsky D. 2004. Late neurologic recovery after traumatic spinal cord injury. Archives of Physical Medicine and Rehabilitation 85:1811-1817.

Kohan AH, Abootalebi S, Khoshnevisan A, Rahgozar M. 2010. Comparison of modified Ashworth scale and Hoffmann reflex in study of spasticity. Acta Medica Iranica 48:154-157.

Krause, James S.; Brotherton, Sandra S.; Morrisette, David C.; Newman, Susan D.; Karakostas, Tasos E. 2007. Does pain interference mediate the relationship of independence in ambulation with depressive symptoms after spinal cord injury? Rehabilitation Psychology 52:162-169.

Lam T, Noonan VK, Eng JJ. 2008. A Systematic review of functional ambulation outcomes in spinal cord injury. Spinal Cord 46:246-254.

Lammertse D,Tuszynski MH, Steeves JD, Curt A, Fawcett JW, Rask C, Ditunno JF, Fehlings MG, Guest JD, Ellaway PH, Kleitman N, Blight AR, Dobkin BH, Grossman R, Katoh H, Privat A, Kalichman M. 2007. Guidelines for the conduct of clinical trials for spinal cord injury as developed by the ICCP panel: clinical trial design. Spinal Cord 45, 232–242.

Lance JW. 1980. Spasticity: disorder of motor control. Chicago: Year Book Medical Publishers.

Lapointe R, Lajoie Y, Serresse O, Barbeau H. 2001. Functional community ambulation requirements in incomplete spinal cord injured subjects. Spinal Cord 39:327-335.

Laughton GE, Buchholz AC, Ginis KAM, Goy RE. 2009. Lowering body mass index cutoffs better identifies obese persons with spinal cord injury. The SHAPE SCI Research Group Spinal Cord (2009) 47, 757–762.

LeCheminant JD, Heden T, Smith J, Covington NK. 2009. Comparison of energy expenditure, economy, and pedometer counts between normal weight and overweight or obese women during a walking and jogging activity. European Journal of Applied Physiology 106:675-682.

Lehmann M, Fournier A, Selles-Navarro I, Dergham Selles-Navarro, Sebok A, Leclerc N, Tigyi G, McKerracher L. 1999. Inactivation of Rho signaling pathway promotes CNS axon regeneration. Journal of Neuroscience19:7537–7547.

Mahoney JS, Engebretson JC, Cook KF, Hart KA, Robinson -Whelen S, Sherwood AM. 2007. Spasticity experience domains in persons with spinal cord injury. Achives of Physical Medicine and Rehabilitation 88:287-294.

Magee D. 2006. Orthopedic Physical Assessment. 4th edition. Elsevier Sciences. http://www.gobookee.net/magee-orthopedic-physical-assessment-4th-ed/

Malatesta D, Simar D, Dauvilliers Y, Candau R, Borrani F, Prefaut C, Caillaud C. 2003. Energy cost of walking and gait instability in healthy 65- and 80-yr-olds. Journal of Applied Physiology 95:2248-2256. Epub 2003 Jul 25.

Malatesta D, Simar D, Dauvilliers Y, Candau R, Ben Saad H, Préfaut C, Caillaud C. 2004. Aerobic determinants of the decline in preferred walking speed in healthy, active 65- and 80-year-olds. Pflugers Archiv: European Journal of Physiology.447:915-921. Epub 2003 Dec 10

Marino RJ, Ditunno JF Jr, Donovan WH, Maynard F Jr. 1999. Neurologic recovery after traumatic spinal cord injury: data from the Model Spinal Cord Injury Systems. Archives of Physical Medicine and Rehabilitation 80:1391-1396.

Marino R. 2003. International standard for neurological classification of spinal cord injury. Journal of spinal cord medicine 26:49-56.

Marino RJ, Graves DE. 2004. Metric properties of the ASIA motor score: subscales improve correlation with functional activities. Archives of Physical Medicine and Rehabilitation 85:1804-1810.

Mattson-Prince J. 1997. A rational approach to long-term care: comparing the independent living model with agency-based care for persons with high spinal cord injuries. Spinal Cord 35:326-331.

McDonald JW, Becker D. 2003. Spinal cord injury: promising interventions and realistic goals. American Journal of Physical Medicine and Rehabilitation 82:S38-49

Mehrholz J, Kugler J, Pohl M. 2008. Locomotor training for walking after spinal cord injury. Spine 33:E768-777.

Melanson EL, Bell ML, Knoll JR, Coelho LB, Donahoo WT, Peters JC, and Hill JO. 2003. Body mass index and sex influence the energy cost of walking at self-selected speeds. Medicine and Science in Sports and Exercercise 35:S183.

Merati G, Sarchi P, Ferrarin M, Pedotti A, Veicsteinas A. 2000. Paraplegic adaptation to assisted-walking: energy expenditure during wheelchair versus orthosis use. Spinal Cord 38:37-44.

Mian OS, Thom JM, Ardigò LP, Narici MV, Minetti AE. 2006. Metabolic cost, mechanical work, and efficiency during walking in young and older men. Acta Physiologica 186:127-39.

Modirian E, Pirouzi P, Soroush M, Karbalaei-Esmaeili S, Shojaei H, Zamani H. 2010. Chronic pain after spinal cord injury: results of a long-term study. Pain Medicine 11:1037-1043. Epub 2010 May 19.

Morio B, Beaufrère B, Montaurier C, Verdier E, Ritz P, Fellmann N, Boirie Y, Vermorel M. 1997. Gender differences in energy expended during activities and in daily energy expenditure of elderly people. The American Journal of Physiology 273:E321-7.

Mothabeng DJ. 2006. Changing profiles in the epidemiology of spinal cord injuries. Presented at the 5th congress of the Africa region of the world confederation for physical therapy. Dar es Salaam. Tanzania, 12-16 August 2006.

Mothabeng DJ. 2007. A perspective on disability and rehabilitation. South African Journal of Physiotherapy 63:32-34.

Mothabeng DJ. 2011. Participation for people living with spinal cord injury in the Tshwane metropolitan area. Thesis submission to the Department of Physiotherapy, University of Pretoria p1-237.
http://upetd.up.ac.za/thesis/available/etd-07212011-132739/unrestricted/00front.pdf

Munakata M, Kameyama J, Kanazawa M, Nunokawa T, Moriai N, Yoshinaga K. 1997. Circadian blood pressure rhythm in patients with higher and lower spinal cord injury: simultaneous evaluation of autonomic nervous activity and physical activity. Journal of Hypertension 15:1745-1749.

New PW. 2007. The Influence of Age and Gender on Rehabilitation Outcomes in Nontraumatic Spinal Cord Injury. Journal of Spinal Cord Medicine 30: 225–237.

Newey ML, Sen PK, Fraser RD. 2000. The long-term outcome after central cord syndrome: a study of the natural history. The Journal of Bone and Joint Surgery. British volume 82:851-855.

Norman KE, Pépin A, Barbeau H. 1998. Effects of drugs on walking after spinal cord injury. Spinal Cord 36:699-715.

Nunan D, Donovan G, Jakovljevic DG, Hodges LD, Sandercock GR, Brodie DA. 2009. Validity and reliability of short-term heart-rate variability from the Polar S810. Medicine and Science in Sports and Exercise 41:243-250. doi: 10.1249/MSS.0b013e318184a4b1.

O'Connor SM, Xu HZ, Kuo AD. 2012. Energetic cost of walking with increased step variability. Gait Posture 36:102-107. Epub 2012 Mar 28.

Ohta Y, Yano H, Suzuki R, Yoshida M, Kawashima N, Nakazawa K. 2007. A two-degree-of-freedom motor-powered gait orthosis for spinal cord injury patients. Proceedings of the Institute of Mechanical Enginering, Part H 221(6):629-39.

Oleson CV, Burns AS, Ditunno JF, Geisler FH, Coleman WP. 2005. Prognostic value of pinprick preservation in motor complete, sensory incomplete spinal cord injury. Archives of Physical Medicine and Rehabilitation 86:988-992.

Olmos LE, Freixes O, Gatti MA, Cozzo DA, Fernandez SA, Vila CJ, Agrati PE, Rubel IF. 2008. Comparison of gait performance on different environmental settings for patients with chronic spinal cord injury. Spinal Cord 46:331-334.

Pagliacci MC, Celani MG, Zampolini M, Spizzichino L, Franceschini M, Baratta S. 2003. An Italian survey of traumatic spinal cord injury. The Gruppo Italiano studio epidemiologico Mielolesioni study. Archives of Physical Medicine and Rehabilitation 84:1266–1275.

Pandyan AD, Johnson GR, Price CI, Curless RH, Barnes MP, Rodgers H. 1999. A review of the properties and limitations of the Ashworth and modified Ashworth Scales as measures of spasticity. Clinical Rehabilitation 13:373-83.

Patrick JH. 2003. Case for gait analysis as part of the management of incomplete spinal cord injury. Spinal Cord 41:479-82.

Penrod LE, Hegde SK, Ditunno JF Jr. 1990. Age effect on prognosis for functional recovery in acute, traumatic central cord syndrome. Archives of Physical Medicine and Rehabilitation 71:963-968.

Phillips WT, Kiratli BJ, Sarkarati M, Weraarchakul G, Myers J, Franklin BA, Parkash I, Froelicher V. 1998. Effect of spinal cord injury on the heart and cardiovascular fitness. Current Problems in Cardiology 23:641-716. Review.

Post M, Noreau L. 2005. Quality of Life after spinal cord injury. Journal of Neurolic Physical Therapy 29:139 – 146.

Price MJ. 2009. The effects of absolute exercise intensity on core temperature responses of athletes with a spinal cord injury. In: Cisneros AB, Goins BL, editors. Body temperature regulation. New York: Nova Biomedical Books Inc., 2009: 227-41.

Price M. 2010. Energy expenditure and metabolism during exercise in spinal cord injuries. Sports Medicine 40 (8): 682-696.

Priebe JR, Kram R. 2011. Why is walker-assisted gait metabolically expensive? Gait Posture 34:265-269.

Putzke JD, Richards JS, Hicken BL, DeVivo MJ. 2002. Interference due to pain following spinal cord injury: important predictors and impact on quality of life. Pain 100:231-242.

Ravenscroft AYS, Burnside IG. 2000. Chronic pain after spinal cord injury. A patient survey. Spinal Cord 38:611-614

Richards JS, Waites K, Chen YY, Kogus S, Schmitt MM. 2004. The epidemiology of secondary conditions following spinal cord injury. Topics in spinal cord injury rehabilitation 10:15-29.

Rimaud D, Calmels P, Devillard X. 2005. Training programs in spinal cord injury. Annales de Readaptation et de Medecine Physique 48:259-269.

Rintala DH, Loubser PG, Castro J, Hart KA, Fuhrer MJ. 1998. Chronic pain in a community-based sample of men with spinal cord injury: prevalence, severity, and relationship with impairment, disability, handicap, and subjective well-being. Archives of Physical Medicine and Rehabilitation 79:604-614.

Rodrigo S, Garcia I, Franco M, Alonso-Vazquez A, Ambrosio J. 2010a. Energy expenditure during human gait. I - An optimized model. Conference Proceedings - IEEE Engineering in Medicine and Biology Society 2010:4254-7. doi: 10.1109/IEMBS.2010.5627174.

Rodrigo S, Garcia I, Franco M, Alonso-Vazquez A, Ambrosio J. 2010b. Energy expenditure during human gait. II - Role of muscle groups. Conference Proceedings - IEEE Engineering in Medicine and Biology Society 2010: 4858-4861. doi: 10.1109/IEMBS.2010.5627427.

Roth EJ, Lawler MH, Yarkony GM. 1990. Traumatic central cord syndrome: clinical features and functional outcomes. Archives of Physical Medicine and Rehabilitation 71:18-23.

Roy RR, Edgerton VR. 2012. Neurobiological perspective of spasticity as occurs after a spinal cord injury. Experimental Neurology 235:116-122. Epub 2012 Jan 27.

Samson MM, Crowe A, de Vreede PL, Dessens JA, Duursma SA, Verhaar HJ. 2001. Differences in gait parameters at a preferred walking speed in healthy subjects due to age, height and body weight. Aging (Milano). 13:16-21.

Schrack JA, Simonsick EM, Chaves PH, Ferrucci L. 2012. The role of energetic cost in the age-related slowing of gait speed. Journal of the American Geriatric Society 60:1811-1816. Epub 2012 Oct 4.

Scivoletto G, Morganti B, Ditunno P, Ditunno JF, Molinari M. 2003. Effects on age on spinal cord lesion patients' rehabilitation. Spinal Cord 41:457–464.

Scivoletto G, Morganti B, Molinari M. 2004. Neurologic recovery of spinal cord injury patients in Italy. Archives of Physical Medicine and Rehabilitation 85:485–489.

Scivoletto G, Morganti B, Molinari M. 2005. Early vs. delayed inpatient spinal cord injury rehabilitation: an Italian study. Archives of Physical Medicine and Rehabilitation 86:512–516.

Scivoletto G, Romanelli A, Mariotti A, Marinucci D, Tamburella F, Mammone A, Cosentino E, Sterzi S, Molinari M. 2008. Clinical factors that affect walking level and performance in chronic spinal cord lesion patients. Spine 33:259-264.

Sekhon LH, Fehlings MG. 2001. Epidemiology, demographics, and pathophysiology of acute spinal cord injury. Spine 26:S2-12.

Sheean G. 2002. Botulinum toxin for the treatment of musculoskeletal pain and spasm. Current Pain and Headache Reports 6:460-469Siddall PJ, Loeser JD 2001 Pain following spinal cord injury. Spinal Cord 39:63-73.

Siddall PJ, Loeser JD. 2001. Pain following spinal cord injury. Spinal Cord 39:63-73. Review.

Siddall PJ, McClelland JM, Rutkowski SB, Cousins MJ. 2003. A longitudinal study of the prevalence and characteristics of pain in the first 5 years following spinal cord injury. Pain 103:249-257.

Sipski ML, Jackson AB, Gómez-Marín O, Estores I, Stein A. 2004. Effects of gender on neurologic and functional recovery after spinal cord injury. Archives of Physical Medicine and Rehabilitation 85:1826-36.

Sköld C, Levi R, Seiger A. 1999. Spasticity after traumatic spinal cord injury: nature, severity, and location. Archives of Physical Medicine and Rehabilitation 80:1548-1557.

Sköld C. 2000. Spasticity in spinal cord injury: Self - and clinically rated intrinsic fluctuation and intervention-induced changes. Archives of Physical Medicine and Rehabilitation 81:144-149.

Solomonow M, Baratta R, D'Ambrosia R. 2000. Standing and Walking After Spinal Cord Injury: Experience with the Reciprocating Gait Orthosis Powered by Electrical Muscle Stimulation. Topics in Spinal Cord Injury Rehabilitation 5:29–53.

Spungen AM, Adkins RH, Stewart CA, Wang J, Pierson RN Jr, Waters RL, Bauman WA. 2003. Factors influencing body composition in persons with spinal cord injury: a cross-sectional study. Journal of Applied Physiology 95:2398-2407.

Stuart RN, Holland AE, New PW. 2009. Walking ability at discharge from inpatient rehabilitation in a cohort of non-traumatic spinal cord injury patients. Spinal Cord 47:763-768.

Sumida M, Fujimoto M, Tokuhiro A, Tominaga T, Magara A, Uchida R. 2001. Early rehabilitation effect for traumatic spinal cord injury. Archives of Physical Medicine and Rehabilitation 82:391–395.

Taylor-Schroeder S, LaBarbera J, McDowell S, Zanca JM, Natale A, Mumma S, Gassaway J, Backus D. 2011. The SCIRehab project: treatment time spent in SCI rehabilitation. Physical therapy treatment time during inpatient spinal cord injury rehabilitation. The Journal of Spinal Cord Medicine 34:149-61.

Tasiemski T, Bergström E, Savic G, Gardner BP. 2000. Sports, recreation and employment following spinal cord injury--a pilot study. Spinal Cord 38:173-84.

Tasiemski T, Kennedy P, Gardner BP, Taylor N. 2005. The association of sports and physical recreation with life satisfaction in a community sample of people with spinal cord injuries. NeuroRehabilitation 20(4):253-65.

The World Bank Annual report 2009 http://siteresources.worldbank.org/EXTAR2009/Resources/6223977125295083187 3/AR09_Complete.pdf. Accessed 25 September 2012.

Tilton AH, Bernard LM. 2001. Consensus statement on Pharmacotherapy for spasticity. Journal of Child Neurology 16:66-67.

Tow AM, Kong KH. 1998. Central cord syndrome: functional outcome after rehabilitation. Spinal Cord 36:156-160.

Turner JA, Cardenas DD, Warms CA, McClellan CB. 2001. Chronic pain associated with spinal cord injuries: a community survey. Archives of Physical Medicine and Rehabilitation 82:501-509.

Ulkar B, Yavuzer G, Guner R, Ergin S. 2003. Energy expenditure of the paraplegic gait: comparison between different walking aids and normal subjects. International Journal or Rehabilitation Research 26:213-217.

Ullrich PM, Jensen MP, Loeser JD, Cardenas DD, Weaver FM. 2008. Pain among veterans with spinal cord injury. Journal of Rehabilitation Research and Development 45:793-800.

Valent L, Dallmeijer A, Houdijk H, Talsma E, van der Woude L. 2007. The effects of upper body exercise on the physical capacity of people with a spinal cord injury: a systematic review. Clinical Rehabilitation 21:315-330.

Van Cauwenberghe E, Gubbels J, De Bourdeaudhuij I, Cardon G. 2011. Feasibility and validity of accelerometer measurements to assess physical activity in toddlers. International Journal of Behavioral Nutrition and Physical Activity 2011, 8:67-78.

Van den Berg ME, Castellote JM, Mahillo-Fernandez I, de Pedro-Cuesta J. 2010. Incidence of spinal cord injury worldwide: a systematic review. Neuroepidemiology 34:184-192. Epub 2010 Feb 2.

Van der Putten J, Stevenson V, Playford E, Thompson A. 2001. Factors affecting functional outcome in patients with nontraumatic spinal cord lesions after inpatient rehabilitation. Neurorehabilitation and Neural Repair 15:99–104.

Van Hedel HJ, Wirz M, Dietz V. 2006. Improving walking assessment in subjects with an incomplete spinal cord injury: responsiveness. Spinal Cord 44:352-356.

Van Hedel HJ, Dietz V, Curt A. 2007. Assessment of walking speed and distance in subjects with an incomplete spinal cord injury. Neurorehabilitation and Neural Repair 21:295-301.

Van Hedel HJ; EMSCI Study Group. 2009. Gait speed in relation to categories of functional ambulation after spinal cord injury. Neurorehabilitation and Neural Repair 23:343-350.

Van Hedel HJ, Dietz V. 2010. Rehabilitation of locomotion after spinal cord injury. Restorative Neurology Neuroscience 28:123-34.

Van Middendorp JJ, Hosman AJ, Pouw MH; EM-SCI Study Group, Van de Meent H. 2009. ASIA impairment scale conversion in traumatic SCI: is it related with the ability to walk? A descriptive comparison with functional ambulation outcome measures in 273 patients. Spinal Cord 47:555-560.

Velmahos GC, Degiannis E, Hart K, Souter I, Saadia R. 1995. Changing profiles in spinal cord injuries and risk factors influencing recovery after penetrating injuries. The Journal of Trauma 38:334-337.

Vlok AJ, Petersen J, Dunn RN, Stander J. 2010. Shallow-water spinal injuries--devastating but preventable. South African Medical Journal100:682-684.

Waninge A, Rook RA, Dijkhuizen A, Gielen E, van der Schans CP. 2011. Feasibility, test-retest reliability, and interrater reliability of the Modified Ashworth Scale and Modified Tardieu Scale in persons with profound intellectual and multiple disabilities. Research in Developmental Disability 32:613-620.

Waters RL, Yakura JS, Adkins R, Barnes G. 1989. Determinants of gait performance following spinal cord injury. Archives of Physical Medicine and Rehabilitation 70:811–818.

Waters RL, Yakura SJ, Adkins RH. 1993. Gait performance after a spinal cord injury. Clinical Orthopedics 288:87-96.

Waters RL and Mulroy S. 1999. The energy expenditure of normal and pathologic gait. Gait & Posture, 9:207-231.

Weaver FM, Collins EG, Kurichi J, Miskevics, SBA; Smith B, Rajan S, Gater, David MD. 2007. Prevalence of Obesity and High Blood Pressure in Veterans with Spinal Cord Injuries and Disorders: A Retrospective Review. American Journal of Physical Medicine & Rehabilitation 86: 22-29.

Wecht JM, Weir JP, DeMeersman RE, Spungen AM, Bauman WA. 2004. Arterial stiffness in persons with paraplegia. Journal of Spinal Cord Medicine 27:255-259.

Welk GJ. 2005. Principles of design and analyses for the calibration of accelerometry-based activity monitors. Medicine and Science in Sport and Exercise 37:501-511.

Welmer AK, Von Arbin M, Widen Holmqvist L, Sommerfield DK. 2006. Spasticity and its association with functioning and health related quality of life 18 months after stroke. Cerebrovascular Disease 21:247-253.

Werhagen L, Budh CN, Hultling C, Molander C. 2004. Neuropathic pain after traumatic spinal cord injury--relations to gender, spinal level, completeness, and age at the time of injury. Spinal Cord 42:665-673.

Whiteneck G, Gassaway J, Dijkers M, Backus D, Charlifue S, Chen D, Hammond F, Hsieh CH, Smout RJ. 2010. The SCIRehab project: treatment time spent in SCI rehabilitation Inpatient treatment time across disciplines in spinal cord injury rehabilitation.The Journal of Spinal Cord Medicine 34:133-145.

Widerström-Noga EG, Felipe-Cuervo E, Yezierski RP. 2001. Chronic pain after spinal injury: interference with sleep and daily activities. Archives of Physical Medicine and Rehabilitation 82:1571-1577.

Widerström-Noga EG, Turk DC. 2003. Types and effectiveness of treatments used by people with chronic pain associated with spinal cord injuries: influence of pain and psychosocial characteristics. Spinal Cord 41:600-609.

Wolpaw JR, Tennissen AM. 2001. Activity-dependent spinal cord plasticity in health and disease. Annual Review of Neuroscience 24: 807–843.

World Health Organization. 1995. Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. WHO Technical Report Series 854. Geneva: World Health Organization.

World Health Organization. 2000. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. World Health Organization Tech Rep Ser; 894: i–xii, 1–253.

World Health Organization. 2001. International Classification of Functioning, Disability and Health (ICF). Geneva: WHO Publications.

Wyndaele M, Wyndaele JJ. 2006. Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey? Spinal Cord 44:523-529. Epub 2006 Jan 3.

Yamakawa K, Tsai CK, Haig AJ, Miner JA, Harris MJ. 2004. Relationship between ambulation and obesity in older persons with and without low back pain. International Journal of Obesity 28:137–143.

Yang L, Condie DN, Granat MH, Paul JP, Rowley DI. 1996. Effect of joint motion constraints on the gait of normal subjects and their implications on the further development of hybrid FES orthosis for paraplegic persons, Journal of Biomechanics 29:217-226.

Young RR. 1994. Spasticity: a review. Neurology 44:S12-20.

Zelik KE, Kuo AD. 2012. Mechanical work as an indirect measure of subjective costs influencing human movement. PLoS One 7:e31143. Epub 2012 Feb 24.

Participant Code: ☐

The energy expenditure of people with spinal cord injury while walking compared to a matched able bodied population.

Demographic Questionnaire

Age: _____

Gender: Male ☐ 0 Female ☐ 1

Date of onset of injury: <6mnth ☐ 0 6mnth-1yr ☐ 1 1-2yrs ☐ 2
<5yrs ☐ 3 <10yr ☐ 4 >10yrs ☐ 5

Level of lesion: T10 ☐ 0 T11 ☐ 1 T12 ☐ 2 L1 ☐ 3
Incomplete ☐ 12 L2 ☐ 4 L3 ☐ 5 L4 ☐ 6 L5 ☐ 7
Incomplete Level:_____ S1 ☐ 8 S2 ☐ 9 S3 ☐ 10 S4/5 ☐ 11

Assistive device use:

Ankle-foot-orthosis (AFO)	☐ 0	Crutches	☐ 4
Calipers	☐ 1	Walking frame	☐ 5
FES	☐ 2	Botox	☐ 6
Four wheel walker	☐ 3	Other	☐ 7

Mobility around the home environment:

Do you only walk therapeutically?	No ☐ 0	Yes ☐ 1			
Do you walk indoors?	No ☐ 0	Yes ☐ 1			
Do you walk outdoors?	No ☐ 0	Yes ☐ 1			
Do you walk at work?	No ☐ 0	Yes ☐ 1	N/A ☐ 2		
Do you walk in the community?	No ☐ 0	Yes ☐ 1			

Length of stay in Rehab after injury: <2 wks ☐ 0 2-4wks ☐ 1 4-6wks ☐ 2
6-8 wks ☐ 3 8-10wks ☐ 4 >10wks ☐ 5

Amount of therapy per day in rehab: _____hrs

Therapy after hospital discharge: No ☐ 0 Yes ☐ 1 N/A ☐ 2

Pain:

None ☐ 0 Occasional ☐ 1 Frequent ☐ 3 Constant ☐ 4

Height_____

Weight_____

Calculated BMI_____

Pulse rate: Baseline_____ End of 6MWT_____

Energy expenditure_____

Distance during 6MWT_____

Velocity during 6MWT_____

Energy expenditure/m _____

Comments:_____

_____

_____

_____

_____

_____

Patient Name _____

Examiner Name _____ Date/Time of Exam _____

STANDARD NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

ISCOS

MOTOR

KEY MUSCLES (scoring on reverse side)

	R	L	
C5	☐	☐	Elbow flexors
C6	☐	☐	Wrist extensors
C7	☐	☐	Elbow extensors
C8	☐	☐	Finger flexors (distal phalanx of middle finger)
T1	☐	☐	Finger abductors (little finger)

UPPER LIMB TOTAL (MAXIMUM) ☐ (25) + ☐ (25) = ☐ (50)

Comments:

L2	☐	☐	Hip flexors
L3	☐	☐	Knee extensors
L4	☐	☐	Ankle dorsiflexors
L5	☐	☐	Long toe extensors
S1	☐	☐	Ankle plantar flexors

Voluntary anal contraction (Yes/No) ☐

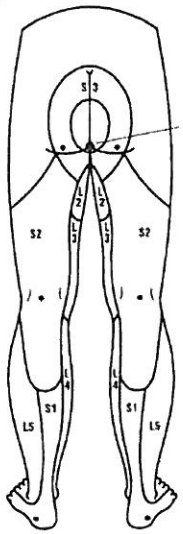
LOWER LIMB TOTAL (MAXIMUM) ☐ (25) + ☐ (25) = ☐ (50)

SENSORY

KEY SENSORY POINTS

	LIGHT TOUCH R	LIGHT TOUCH L	PIN PRICK R	PIN PRICK L
C2				
C3				
C4				
C5				
C6				
C7				
C8				
T1				
T2				
T3				
T4				
T5				
T6				
T7				
T8				
T9				
T10				
T11				
T12				
L1				
L2				
L3				
L4				
L5				
S1				
S2				
S3				
S4-5				
TOTALS (MAXIMUM)	☐ (56)	☐ (56)	☐ (56)	☐ (56)

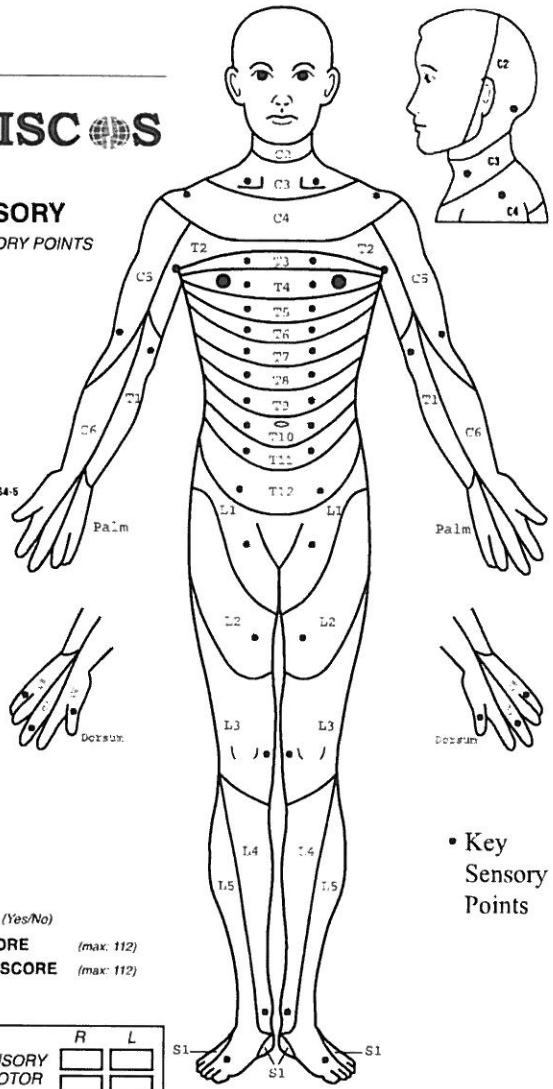
0 = absent
1 = impaired
2 = normal
NT = not testable



☐ Any anal sensation (Yes/No)

☐ + ☐ = ☐ PIN PRICK SCORE (max: 112)

☐ LIGHT TOUCH SCORE (max: 112)



• Key Sensory Points

NEUROLOGICAL LEVEL (The most caudal segment with normal function)	SENSORY R ☐ L ☐ / MOTOR R ☐ L ☐	COMPLETE OR INCOMPLETE? ☐ (Incomplete = Any sensory or motor function in S4-S5)	ZONE OF PARTIAL PRESERVATION (Caudal extent of partially innervated segments)	SENSORY R ☐ L ☐ / MOTOR R ☐ L ☐
		ASIA IMPAIRMENT SCALE ☐		

This form may be copied freely but should not be altered without permission from the American Spinal Injury Association.

REV 03/06

Appendix C

Modified Ashworth Scale Testing Form

Name:_____ Date:_____

Muscle Tested	Score
_____	____
_____	____
_____	____
_____	____
_____	____
_____	____
_____	____
_____	____
_____	____

Downloaded from www.rehabmeasures.org
Test instructions provided courtesy of Richard Bohannon PT, PhD and Melissa Smith, PT

Appendix D

Range of Motion Testing

ROM	Left	Right
Hip		
• Flexion		
• Extension		
Knee		
• Flexion		
• Extension		
Ankle		
• Dorsiflexion		
• Plantarflexion		

Appendix E

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Miss Jana Vosloo

CLEARANCE CERTIFICATE	M110944
PROJECT	The Energy Expenditure of People with Spinal Cord Injury While Walking Using Elbow Crutches Compared to a Matched Able Bodied Population
INVESTIGATORS	Miss Jana Vosloo.
DEPARTMENT	Department of Physiotherapy
DATE CONSIDERED	30/09/2011
M1109440DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 19/12/2011 **CHAIRPERSON** .....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Ms Veronica Ntsiea

DECLARATION OF INVESTIGATOR(S)
To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**
PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

Appendix F

Letter requesting permission from the hospital CEO

To: The hospital CEO

Re: Post graduate study in physiotherapy involving participants in government hospitals.

I am a physiotherapist currently doing a Masters degree in Physiotherapy specialising in Adult Neurology. As part of the requirements for the degree we have to complete a research report which involves assessments of a large sample size of appropriate spinal cord injured patients for the study. The topic of my study is: **The energy expenditure of people with spinal cord injury while walking compared to an able bodied population.**

In order to complete this study I need at least 28 participants who have sustained a spinal cord injury but are now able to walk ten meters. They will be compared to an age, body-mass index and gender comparable group of able bodied participants.

At present there is very little literature available on the energy expenditure in spinal cord injured gait. Although functional walking is suggested to be one of the most important patient goals in the SCI population, there is limited guidance in the research to assist the therapist in relation to structuring the rehabilitation program to attain this. By having factual information on how taxing the walking pattern is in terms of energy expenditure compared to normal gait, I will suggest some guidelines to aim for within the rehabilitation program. This will hopefully optimize higher levels of independent mobilization within this population and lead to higher levels of physical activity. This study will also look at the factors that possibly contribute to the difference in energy expenditure between individuals in this study.

This letter serves to ask for permission for me to access patients in your facilities in order to perform the assessments necessary to complete a research report. This research project will involve the following hospitals: Muelmed Medi-Clinic, Netcare Rehabilitation Hospital, Life New Kensington, Life Riverfield Lodge, Life Eugene Marais, Rehab matters, Natalspruit Hospital and Tshwane Rehabilitation unit.

The hospitals will be contacted to establish if there are suitable participants for the study on a regular basis with your permission. All the patients will then be consulted in person with an explanation of what the study aims are and consent requested to participate.

The patients who are willing to participate will have to complete a consent form as well as a demographic questionnaire. The information will be treated with strict confidentiality.

For the assessments of patients, an American Spinal Cord Injury Impairment Scale (ASIA) will be performed on each participant to establish the severity of their spinal cord injury. A Modified Ashworth scale will be used to measure the intensity of their spasticity if applicable. A goniometer will be used to measure their range of motion (ROM) in particular joints and their height and weight will be measured, A pulse rate measure will also be used to establish their base line and after assessment pulse rate which will be repeated once the walking has been completed. This will be followed by the main testing procedure, a six minute walk test (6MWT) using the walking aid they generally use if applicable. While performing this test the patient's energy expenditure will be measured by a small accelerometer which is fixed to the patient. Every precaution will be taken to keep participants safe at all times during the time they are involved in the study and rest periods will be provided if needed.
In the case where a patient does not want to participate no effort will be exerted to persuade them in their choice.

If there are any further queries regarding the study please do not hesitate to contact me. If you have any complaints regarding how the research is conducted, you may contact the chairperson of the University of the Witwatersrand, Human Research Ethics Committee established to help protect the rights of research participants at 011 717 2301.

Thank you for taking the time to read my introduction letter.

Kind regards

Jana Vosloo
BSc Physiotherapy
0712527953
jaa_ns@yahoo.com

Appendix G

Letter requesting permission from Private Practices/Head of department

Dear Rehabilitation private practice manager/Head of department

Re: Recruiting participants for a research project

I am a physiotherapist currently doing a Masters degree in Physiotherapy specialising in Adult Neurology. As part of the requirements for the degree we have to complete a research report which involves assessments of a large sample size of appropriate spinal cord injured patients for the study. The topic of my study is: **The energy expenditure of people with spinal cord injury while walking compared to an able bodied population.**

In order to complete this study I need at least 28 participants who have sustained a spinal cord injury at the level of T10 or below or have an incomplete spinal cord injury and are now able to walk ten meters with the use of an assistive device where applicable. They will be compared to an age, body-mass index and gender comparable group of able bodied participants.

At present there is very little literature available on the energy expenditure in spinal cord injured gait. Although functional walking is suggested to be one of the most important patient goals in the SCI population, there is limited guidance in the research to assist the therapist in relation to structuring the rehabilitation program to attain this. By having factual information on how taxing the walking pattern is in terms of energy expenditure compared to normal gait, I will suggest some guidelines to aim for within the rehabilitation program. This will hopefully optimize higher levels of independent mobilization within this population and lead to higher levels of physical activity. This study will look at the energy expenditure of spinal cord injured walking compared to the normal population as well as the factors possibly contributing to the difference in energy expenditure between individuals in this study.

This letter serves to ask for permission for me to access your patients in order to perform the assessments necessary to complete a research report. All the patients will then be contacted in person with an explanation of what the study aims are and consent requested to participate.

The patients who are willing to participate will have to complete a consent form as well as a demographic questionnaire of which the information will be treated with strict confidentiality. The participants will have the following assessments: an American Spinal Cord Injury Impairment Scale (ASIA) will be performed on each participant to establish the severity of their

spinal cord injury. A Modified Ashworth scale will be used to measure the intensity of their spasticity if applicable. A goniometer will be used to measure their range of motion (ROM) in particular joints and their height and weight will be measured, A pulse rate measure will also be used to establish their base line and after assessment pulse rate which will be repeated after walking is completed. This will be followed by the main testing procedure, a six minute walk test (6MWT). While performing this test the patient's energy expenditure will be measured by a small accelerometer which is fixed to the patient. Every precaution will be taken to keep participants safe at all times during the time they are involved in the study and rest periods will be provided if needed.

In the case where a patient does not want to participate no effort will be exerted to persuade them in their choice.

If there are any further queries regarding the study please do not hesitate to contact me. If you have any complaints regarding how the research is conducted, you may contact the chairperson of the University of the Witwatersrand, Human Research Ethics Committee established to help protect the rights of research participants at 011 717 2301.

Thank you for taking the time to read my introduction letter.

Kind regards

Jana Vosloo
BSc Physiotherapy
0712527953
jaa_ns@yahoo.com

Appendix H

MEDICLINIC

MEDICLINIC OFFICES
STRAND ROAD
STELLENBOSCH
7600

PO BOX 456
STELLENBOSCH
7599

T +27 21 809 6500
F +27 21 809 6756
ETHICS LINE 0800 005 316

www.mediclinic.co.za

17 February 2012

Miss J Vosloo
PO Box 1462
Tzaneen
0850

E-mail: jaa_nee@yahoo.com

cc: Mr Johan Verwey
Hospital Manager: Mediclinic Muelmed
johan.verwey@mediclinic.co.za

Dear Jana

THE ENERGY EXPENDITURE OF PEOPLE WITH SPINAL CORD INJURY WHILE WALKING USING ELBOW CRUTCHES COMPARED TO A MATCHED ABLE BODIED POPULATION

Please be advised that Mediclinic hereby approves the application for the above-mentioned research, on condition that the treating doctor in the rehabilitation team obtains the patients' permission to provide you with their details in order for you to contact them.

Yours sincerely,

DR M S SMUTS
CHIEF CLINICAL OFFICER

MEDICLINIC LTD
REG. NO. 1983/009218/06

Appendix I

Netcare Limited

Tel: + 27 (0)11 301 0000
Fax: Corporate +27 (0)11 301 0499
76 Maude Street, Corner West Street, Sandton, South Africa
Private Bag X34, Benmore, 2010, South Africa

RESEARCH COMMITTEE FINAL APPROVAL OF RESEARCH

Approval number: UNIV-2012-0005

Ms Jana Vosloo

E mail: jaa_ns@yahoo.com

Dear Ms Vosloo

RE: THE ENERGY EXPENDITURE OF PEOPLE WITH SPINAL CORD INJURY WHILE WALKING USING ELBOW CRUTCHES COMPARED TO A MATCHABLE ABLE BODIED POPULATION

The above-mentioned research was reviewed by the Research Committee's delegated members and it is with pleasure that we inform you that your application to conduct this research at Netcare Rehabilitation Hospital, has been approved, subject to the following:

i) Research may now commence with this FINAL APPROVAL from the Academic Board of Netcare (Research Committee).

ii) All information with regards to Netcare will be treated as confidential.

iii) Netcare's name will not be mentioned without written consent from the Academic Board of Netcare (Research Committee).

iv) All legal requirements with regards to patient rights and confidentiality will be complied with.

v) Insurance will be provided and maintained for the duration of the research. This cover provided to the researcher must also protect both the staff and the hospital facility from potential liability

vi) In accordance with MCC approval, that medicine will be administered by or under direction of the authorised Trialist

vii) The research will be conducted in compliance with the GUIDELINES FOR GOOD PRACTICE IN THE CONDUCT OF CLINICAL TRIALS IN HUMAN PARTICIPANTS IN SOUTH AFRICA (2000)

viii) Netcare must be furnished with a STATUS REPORT on the progress of the study at least annually on 30th September irrespective of the date of approval from Academic Board of Netcare (Research Committee) as well as a FINAL REPORT with reference

Executive Directors: R H Friedland *(CEO)*, V E Firman *(CFO)*, V L J Litlhakanyane

Non-Executive Directors: S J Vilakazi *(Chairman)*, T Brewer, A P H Jammine, J M Kahn, M J Kuscus, H R Levin, K D Moroka, M I Sacks, N Weltman

Company Secretary: L Bagwandeen **Reg. No.** 1996/008242/06

to intention to publish and probable journals for publication, on completion of the study.

ix) A copy of the research report will be provided to Netcare once it is finally approved by the tertiary institution, or once complete.

x) Netcare has the right to implement any Best Practice recommendations from the research.

xi) Netcare reserves the right to withdraw the approval for research at any time during the process, should the research prove to be detrimental to the subjects/Netcare or should the researcher not comply with the conditions of approval.

We wish you success in your research.

Yours faithfully

Prof Dion du Plessis
Full member: Research Committee & Medical Practitioner evaluating research applications as per Management and Governance Policy
Date:

Shannon Nell
Chairperson: Research Committee
Network Healthcare Holdings Limited (Netcare)
Date: 23/4/2012.

Appendix J

Life Rehabilitation

Oxford Manor, 21 Chaplin Road, Illovo 2196
Private Bag X13, Northlands 2116, South Africa
Telephone: +27 11 219 9000
Telefax: +27 11 219 9001
www.lifehealthcare.co.za

3 February 2012

Ms Jana Vosloo
Life Riverfield Lodge, Life New Kensington and Life Eugene Marais
Approval Number 120203

Request for permission to conduct research: The energy expenditure of people with spinal cord injury while walking using elbow crutches compared to a matched able bodied population.

Life Healthcare supports the furthering of knowledge and the development of the field of Rehabilitation, and I am pleased to grant permission to conduct research at Life New Kensington Clinic and Life Riverfield Lodge under the following conditions:

- Contact with the therapy unit managers to discuss time lines and logistics, including access to patients
- Permission obtained from patients
- The research conducted will not interfere with the patient's rehabilitation routine
- Feedback on your research and presentation of the results to the units where the study was undertaken

I wish you success with your research, and be assured that we will assist where possible.

Sincerely

Nina Strydom
Support Specialist
Mental Health and Physical Rehabilitation
Life Healthcare
Tel: + 27 312041426
Fax: + 27 866781450
Mobile: + 27 84 5661281
Email: nina.strydom@lifehealthcare.co.za
Website: www.lifehealthcare.co.za

Life Healthcare Group (Proprietary) Limited
Reg. no. 2003/024367/07 Registered address Oxford Manor, 21 Chaplin Road, Illovo 2196, Private Bag X13, Northlands 2116
Directors: Prof GJ Gerwel (Chairman), CMD Flemming (Managing Director), RJ Hogarth (Financial Director),
MA Brey, Dr MP Ngatane, GC Solomon

Appendix K

health and social development
Department: Health and Social Development
GAUTENG PROVINCE

BANK OF LISBON BUILDING
37 SAUER STREET JHB
PRIVATE BAG X085
MARSHALLTOWN
Tel: (011) 355 3310 / 3831 / 2467
Fax: (011) 355 3505

GAUTENG DEPARTMENT OF HEALTH AND SOCIAL DEVELOPMENT

RESEARCH PROPOSAL EVALUATION FORM

Researcher Name	Vosloo Jana
Researcher's contact details	Tel: 0712527953 Email: jaa_ns@yahoo.com
Institution	University of the Witwatersrand
Research Topic	The energy expenditure of people with spinal cord injury while walking using elbow crutches compared to a matched able bodied population.
Date Received by the Directorate PPR	2012/01/26
Date Received Reviewer	2012/02/20
Final Review Date	2012/02/20
Date Submitted to Director of PPR	2012/02/21
Research Site(s)	Muelmed Medi-Clinic, Netcare Rehabilitation Hospital, Life New Kensington, Life Riverfield, Natalspruit Hospital and Tshwane Rehabilitation
Type of research	Descriptive

CRITERIA	YES	NO	COMMENTS
1. Is this research project within the scope of the Department of Health key policy priorities/directives?	X		
2. Content of Research:			
▪ Original work	X		
▪ New facts, ideas	X		
▪ Confirmation of uncertain data	X		
▪ Repetition of known data and consequently of limited importance		X	
▪ Insufficient research information		X	
▪ Confusion of topics/questions		X	
3. Is the title of the research project suitable?	X		
4. Are the objectives of the research project adequate?	X		
5. Could the objectives be limited to better focus on the project's main objective?		X	
6. Writing style			
▪ The text of the proposal is clear	X		
▪ The nomenclature used is correct	X		

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CRITERIA	YES	NO	COMMENTS
▪ The references used are relevant, comprehensive and accurate	X		
▪ The spelling and grammar are correct	X		
▪ The language needs improvement		X	
▪ The research proposal needs re-styling and re-writing		X	
7. Are the research methods appropriate to the study?	X		
8. Is data collection method in line with the study design?	X		
9. Does the study have ethical approval? If yes, name the ethics committee.	X		Wits: M110944
10. Is the definition and measurement of variables consistent with the scope of the proposal?	X		
11. Is the time frame of the proposal adequate to meet the objectives?	X		
12. Is the method of dissemination of the results of the research project stated?		X	It is recommended that the researchers specify how the results will be shared / disseminated
13. Is any possible conflict of interests clarified?	n/a		
14. Are financial implications and financial support transparent?	x		

SUMMARY OF PROPOSAL

Background

There is very little literature available on the walking energy expenditure in spinal cord injured patients. Although functional walking is suggested to be one of the most important patient goals in the SCI population, there is limited guidance in the research to assist the therapist in relation to structuring the rehabilitation program to attain this. It is therefore the aim of this study to assess the energy expenditure of people with an incomplete SCI while performing mobility assessment using elbow crutches and comparing it to a matched able bodied population.

Objectives

- To establish the energy expenditure of participants with SCI while performing a six minute walk test (6MWT) using elbow crutches.
- To establish the energy expenditure of able bodied matched population while performing a Six Minute Walk Test (6MWT).
- To compare the energy expenditure between patients with SCI walking with crutches and the matched able bodied population.
- To establish factors that influence the differences in energy expenditure of patients with SCI while using elbow crutches compared to that of the matched able bodied population.

METHODS

Demographic questionnaire will be used to interview seventy participants selected from Muelmed Medi-Clinic, Netcare Rehabilitation Hospital, Life New Kensington, Life Riverfield, Natalspruit Hospital and Tshwane Rehabilitation. The questionnaire will include the participant's age, date of onset of spinal cord injury, level of the lesion, level of mobility, use of assistive devices and extent of rehabilitation received. The matched able bodied participants will only fill in the applicable parts of the questionnaire. A height and weight measurement will be performed and the BMI calculated. An American Spinal Cord Injury Association Impairment Scale (ASIA) assessment will determine the severity of the spinal cord injury. An accelerometer assessment will establish the energy expenditure during the walking assessment.

REVIEWER'S FINAL CONCLUSION

The proposed study will assist therapists in relation to structuring the rehabilitation program and is therefore recommended for approval.

Reviewed and Recommended by

B.D Ikakafeng

Dr B Ikakafeng

Date: 2012/02/21

Approved by

S. le Roux

S. le Roux: Director PPR

Date: 24/02/2012

Appendix L

Participant information letter

Dear Participant

My name is Jana Vosloo and I am a physiotherapist currently doing a Masters degree in Physiotherapy specialising in Adult Neurology. As part of the requirements for the degree we have to complete a study which involves assessments of walking for people with a spinal cord injury compared to people not having a spinal cord injury. The topic of my study is: '**The energy expenditure of people with spinal cord injury while walking compared to an able bodied population'.**

In order to complete this study I need at least 28 participants who have sustained a spinal cord injury but are now able to walk at least ten meters. This will be compared to an age, body-mass index and gender matched able bodied group of participants.

The aim of my study is to assess the energy expenditure of people following SCI while performing a mobility assessment and comparing it to a normal population.

The objectives are:

- To establish the energy used while performing a six minute walk test (6MWT) if you have a spinal cord injury.
- To establish the energy used while performing a Six Minute Walk Test (6MWT) if you are part of the able bodied population.
- To compare the energy used while walking between the spinal cord injury and the able bodied groups.
- To establish factors that influence the differences in energy used while walking between the spinal cord injured and able bodied population.

If you are willing to participate, you will have to complete a consent form as well as a demographic questionnaire. The information will be treated with strict confidentiality in other words I won't share the information with anybody, except for what is anonymously relevant to the study. A questionnaire code will be used instead of your name.

For the assessments, an American Spinal Cord Injury Impairment Scale (ASIA) will be performed which just means I will test the muscles and feeling to establish the severity of your spinal cord injury. A Modified Ashworth Scale (MAS) will be done to determine the severity of

your spasticity if applicable. A range of motion (ROM) assessment will be done to determine if the joints still move as much as they should and your height and weight will be measured. A pulse measurement will also be done before and after the walk test. This will be followed by the main assessment, a six minute walk test (6MWT) using the assistive devices you would normally use if any. While doing this test your energy use will be measured by a small accelerometer which is fixed to you prior to starting the walk test. Every precaution will be taken to keep you safe at all times during the time you are involved in the study and rest periods will be provided if and when needed. Nothing during the assessment will cause any pain or harm to you.

If you initially agree to participate in the study and change your mind you are entitled to do so and you will just be excluded from any further involvement and this will not have an effect on your ongoing therapy.

I would greatly appreciate your willingness to be part of the study. There will be no direct benefit to you but the opportunity to assist in a study that may help others with spinal cord injuries in future. You are under no obligation to participate and if you choose not to I will understand. If you have any questions before or during the procedure you are welcome to stop and ask me.

Thank you

Jana Vosloo
0712527953
jaa_ns@yahoo.com

Appendix M

Participant consent form

Before the study begins you will be asked to complete a demographic questionnaire. The information will be treated with strict confidentiality. The assessor will perform the following assessments:

- An ASIA impairment scale assessment to determine the severity of the spinal cord injury (SCI). This is only applicable to the participants who have a spinal cord injury.
- A Modified Ashworth Scale (MAS) assessment will be done to determine the severity of you spasticity if applicable.
- A range of motion (ROM) assessment will be done to determine if all the joints that could be affected, still move as much as they should.
- A height and Weight measurement in order to calculate your body-mass index (BMI).
- A pulse measurement will be done before and after the walking test to measure your pulse rate.
- Position a small device on your pants to measure the energy you require to perform six minutes of walking. It is called an accelerometer.

I have read the participant information letter, understand the aims and requirements of the study and give my consent to participate and for information collected to be used for the purposes of this study. I understand that it is not a must that I take part in the study and offer to participate voluntarily.

_____ _____

Signature Date