Quantifying Physical Activity in Community Dwelling Spinal Cord Injured Individuals

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Abstract

Purpose: To characterize physical activity of people using manual wheelchairs with spinal cord injury in Manitoba.

Methods: An observational study of manual wheelchairs users with spinal cord injury. Participants completed surveys related to self-efficacy for exercise, physical activity participation, and shoulder pain. Accelerometers were worn for 7 days on the wrist and trunk (GT3X, 100 Hz, 5 s epochs) and completed an activity log concurrently. Individual specific thresholds were determined for moderate intensity during a pace graded wheeling trial. Physical activity and sedentary time were characterized using various derived variables.

Results: Twenty five participants (12 tetra:13 para, 21M:4F) demonstrated excellent accelerometer adherence achieving an average of 6.2 days worn for over 13 hours per day. A total of 74.6 min (all activity) and 115 min (contiguous bouts of activity) were achieved over time worn (6.2 days), corresponding to 11.8 and 18.5 min/day respectively. The participants substantially exceeded the published SCI guidelines (40 min/week, $P<0.01$) but were under the able bodied threshold of 150 min/week ($P<0.01$). No relationships were observed between surveys and objectively measured PA. Characterization of PA bouts revealed few participants (n=7) exhibiting single bout durations greater than 10 minutes, with an average contiguous bout duration of 30 s. A new functional classification scheme revealed positive correlations to PA variables and wheeling performance. Sedentary times ranged from 6.25 to 8.4 hours per day depending upon accelerometer placement.

Conclusion: Arm based accelerometry can be used to determine PA and sedentary characteristics of manual wheelchair users with individual specific moderate intensity thresholds. Participants exceeded the SCI specific activity guidelines in terms of time per week, and failed to reach bout durations of 20 min. This study supports the use of able-bodied PA guidelines as a target. A new functional classification scheme was derived based upon wheeling dependent muscle innervation that had enhanced prediction of PA relative to standard anatomical classification.

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Introduction

Individuals with spinal cord injury (SCI) have among the lowest levels of physical activity (PA) compared to other populations (Fernhall, Heffernan, Jae, & Hedrick, 2008) Low PA levels, are especially common for those who are wheelchair dependent after SCI (Dearwater et al., 1986; Monroe et al., 1998). Loss of volitional movement, pain, fatigue, altered muscle tone, compromised bone and joint health, psychosocial and accessibility barriers (including snow cover in certain climates) are a number of obstacles hindering participation in both planned exercise and that derived from daily living. Ironically, many of these barriers including those of a psychosocial nature are positively influenced by physical activity (Tawashy, Eng, Lin, Tang, & Hung, 2009). PA levels and sedentarism are considered two separate entities. One might intuitively closely relate the two, however, despite substantiated low PA levels in this population, far less is known about the characteristics of their sedentary behaviors. Low levels of PA and high levels of sedentarism, collectively or independently are considered a health risk (Garber et al., 2011).

The low levels of physical activity in the able- bodied population is a well-established and a significant health concern (Colley et al., 2011). The problem is amplified in those with disabilities (Fernhall et al., 2008). Even further compounding the problem in some of those with SCI is the denervation of the autonomic nervous system. In people with tetraplegia and high level paraplegia (T6 and above), this can limit the ability to increase heart rate beyond 130 beats/minute (Jacobs & Nash, 2004). This, in addition to limitations in movement and muscle innervation creates a milieu that restricts the stimulus to evoke a normal cardiovascular response in most wheelchair users with tetraplegia and many with paraplegia. PA driven adaptations of the cardiovascular system over time and many of the health benefits associated with PA are likely altered for these individuals.

Reports indicate that participation in physical activity and sport decreases dramatically after spinal cord injury (Tasiemski, Bergström, Savic, & Gardner, 2000). Only 13% of individuals with quadriplegia and 16% of individuals with paraplegia self -report regular physical activity. Nearly 60% of persons with paraplegia and nearly 70% of persons with quadriplegia report being significantly less active than their aged related able-bodied counterparts, many likely participating in virtually no physical activity beyond that required for basic living (Washburn & Hedrick, 1997). Similarly, it has been reported that people with SCI spend less than 2% of their waking hours engaged in leisure time physical activity (Martin Ginis et al., 2008). It is important to note that this information is based on self-reporting methods, and if these are similar to able-bodied (Troiano et al., 2008) then this would represent an overestimation. Also, these estimations are distinct from time spent moving or sedentary during daily routines outside of leisure activity or planned exercise, the characteristics of which very little is known.

Mortality rates for individuals with SCI have improved over the last 3 decades with a 40% decline in mortality after the first 2 years post- injury (Strauss, Devivo, Paculdo, & Shavelle, 2006). Medical management during the acute and sub- acute phases after a SCI may explain this marked decline in short term mortality. Interestingly, Strauss and coworkers also describe a potentially overstated presumption that lifespan beyond the acute phase of injury has increased dramatically in recent decades. Conversely, a systematic review of survival following traumatic and non-traumatic SCI worldwide by Van Den Berg and coworkers (Maayken E L van den Berg, Castellote, de Pedro-Cuesta, & Mahillo-Fernandez, 2010) suggests there is evidence that lifespan is improving in the SCI population and that mortality rates of persons with long-standing SCI stems from secondary complications such as diminished pulmonary function and cardiovascular disease. This is in contrast to increased mortality in years past due to renal failure and urinary tract complications (DeVivo, Krause, & Lammertse, 1999). In spite of modern treatments and presumably improving outcomes of such ailments, overall mortality in SCI is still up to 3 times higher than the general population (Maayken E L van den Berg et al., 2010). The causes of premature death and morbidity however, as suggested by Van Den Berg, may be shifting towards those seen in the general population including early cardiovascular disease and metabolic disease including Type 2 diabetes (DeVivo et al., 1999; Garshick et al., 2005; Maayken E L van den Berg et al., 2010) some of which can be attributable to lifestyle factors including low PA.

There is a unique mobility and weight-bearing demand placed on the upper extremities in this population that evolutionarily is not a primary role of the upper limbs. As such, pain has been shown to be prevalent in wheelchair users. Thirty-70% of people with SCI using manual wheelchairs report pain and dysfunction about the shoulder (Middaugh, Thomas, Smith, McFall, & Klingmueller, 2013). Wheelchair propulsion, transferring to various seating surfaces, mobilizing outside of a chair, and manipulating the environment from a disadvantageous seated position are daily activities for wheelchair users. SCI level dependent muscle innervations in the shoulders and trunk have a significant role in dynamic shoulder stability and posture, affecting shoulder and spine mechanics. The etiologies of pain are not perfectly clear but certainly secondary to upper limb activity, or perhaps due to limitations in rehabilitation approaches post SCI. The existence of an upper limb injury/pain and possibly the fear of these injuries can hamper the activity levels in SCI wheelchair users. However, upper limb exercise has been shown to decrease shoulder pain by 63% and 71% in two separate 16 week programs (Middaugh et al., 2013, Kemp et al., 2011) so it appears that the absence of activity may be promoting the pain, rather than overuse. It is possible that the numerous health care encounters common to many of these individuals with physiatrists and alike are promoting decreased activity by inducing this fear, thereby enabling disability.

So what depicts an adequate physical activity level and sedentary time for the SCI population? Two camps of thought exist in relation to appropriate PA benchmarks. Until recently there have been no evidence-based guidelines specific to people with spinal cord injury. However, in 2011, exercise guidelines were established through a systematic review of the available, albeit limited, literature on the impact of exercise on the physical fitness of people with SCI. An expert panel (Ginis et al., 2011) recommended a minimum of 40 minutes of moderate to vigorous physical activity (MVPA) per week of cardiovascular exercise gathered in two bouts of 20 minutes. These guidelines have created some controversy given their sharp contrast to the 150 minutes of MVPA per week recommended for able-bodied adults, which continues to be the recommendation for SCI individuals by many (Jacobs & Nash, 2004; R. A. Tanhoffer, Tanhoffer, Raymond, Hills, & Davis, 2014), including the ACSM's current guidelines indicating 20-60 minutes 3-5 times per week (Durstine, Moore, Painter, & Roberts, 2009).

There are a multitude of reasons that PA objective measures are crucial to the study of health implications in those with SCI. With a population paradoxically trending towards longer life expectancy paralleled by increasing rates of cardiovascular and metabolic disease, the significance of studying and understanding the role of fitness and physical activity on health and aging after SCI has become an increasingly relevant topic. Objective measures of PA will also serve as a vital component to further refinement of PA guidelines and to better explain the association of PA with key health outcomes including associations with cardiovascular, shoulder pain, self-efficacy, and quality of life amongst many others, after SCI.

This study, including the review of literature below will explore the use of accelerometers as an objective measure of physical activity in the SCI population. Literature regarding the use of accelerometry applications as well as health implications, and current guidelines for PA in those with SCI will be reviewed and discussed.

Literature Review

Accelerometers for Assessment of PA after SCI

Energy Expenditure Assessment

Hiremath and Ding (2011) evaluated two kinds of accelerometers to measure their ability to accurately estimate energy expenditure (EE) in 24 individuals with paraplegia. 19 males and 5 females with an average age of 41.4 years participated. The participants wore a Sensewear Armband (wrist) and an RT3 tri-axial accelerometer (trunk). The RT3 used a sampling rate of 10 Hz, grouping acceleration based activity counts derived during 60 second epochs. The Sensewear used a sampling rate of 32 Hz at an unspecified epoch. A portable metabolic cart and heart rate monitor were used to measure metabolic costs and heart rate while performing various PA tasks. Participants were asked to propel manual wheelchairs at speeds of 2 and 3 mph on an unspecified stationary dynamometer and 3 mph on a level tiled floor. They then propelled an arm ergometer at three different combinations of resistance and speed, and lastly performed relatively sedentary deskwork including retrieving books, reading and typing. Rest periods between activities were also captured. As compared to the metabolic costs measured by the metabolic cart, the RT3 (worn on the trunk) both under and overestimated the energy expenditure for the various tasks. The wrist worn Sensewear sensor frequently overestimated energy expenditure. For propulsion tasks, the energy estimation errors ranged from 24.4 to 125.8% for the Sensewear and 22.0 to 52.8% for the RT3. Both devices demonstrated an ability to detect variance in activity intensity. They did not use the two devices in any combinational way to determine energy expenditure, and a major limitation is that they used able-bodied algorithms for deriving energy expenditure.

Hiremath and Ding (2011) performed a second investigation in 2011 to develop and evaluate new energy expenditure predictive equations for the RT3 accelerometers (as opposed to proprietary able bodied algorithms). In this study RT3 accelerometers were used on both upper arm and waist in 23 participants. 19 participants were used to develop the equations and 4 were used to validate them. The participants were again asked to wheel their manual chair on a stationary dynamometer at various speeds, wheel over ground, use an arm ergometer, perform deskwork and sit quietly. Accelerometry, demographic variables, metabolic and heart rate data were combined and analyzed to develop general and activity specific regression equations for the SCI population. Results demonstrated that the accelerometer worn on the arm performed better than that on the waist and similar to combined waist and arm. EE estimation errors with the new prediction equations varied from 12.2%-38.1% compared to 21.3-55.2% from the default RT3 equations. This study demonstrated an improved but still flawed ability to predict EE based on accelerometry data. As the previous study, the low sampling rate (ability to capture movement features) and prolonged epoch durations (1 minute can contain activity/non-activity in one epoch) with the RT3 is problematic. Furthermore, this study measured only 1 speed of over ground movement. From a single speed it is difficult to assess the accuracy of the energy estimation method for the primary form of physical activity of a manual wheelchair user. Further, energy expenditure is only one aspect of PA characterization; others include time spent in light, moderate or vigorous activity.

Tanhoffer and associates (Tanhoffer, Raymond, Hills, & Davis, 2012), compared multiple ways to assess energy expenditure and physical activity in spinal cord injured manual wheelchair users. 14 subjects, 18-65 years old with SCI participated. Included were 10 people with paraplegia and 4 with tetraplegia. A doubly labeled water technique (DLW) was employed to determine total daily energy expenditure (TDEE) over 14 days, and used as the reference standard. Heart rate (Polar) and accelerometry (Sensewear Arm Band, right upper arm, proprietary able bodied algorithms) was recorded for two days. Two recall questionnaires (Physical activity

Recall Assessment for People with Spinal Cord Injury: PARA-SCI; Physical Activity Scale for Individuals with Physical disabilities: PASIPD) were given to participants to self assess their physical activity over a 3 day period. Results indicated that of the four methods used, the PARA-SCI questionnaire best estimated TDEE (r=0.74) and physical activity EE (r= 0.50) when compared to DLW. PASIPD was correlated less well TDEE (r= 0.53) and physical activity EE (r= 0.13). There was a moderate association between Sensewear Arm-band and DLW for TDEE (r=0.65). Interestingly and possibly not surprising, there was a poor association between arm band energy expenditure from physical activity derived from 2 days to the DLW estimate from 14 days (r=0.16). The reason for only assessing two days of PA using accelerometry and comparing to 14 days of DLW was not provided, but clearly is a methodological error. Association with heart rate for TDEE was (r=0.68) and (r= 0.30) for physical activity EE, but once again comparing 14 days (DLW) to 2 days (HR). Lastly, limitations were again noted in this study as they employed able-bodied algorithms for energy expenditure with the accelerometers.

Washburn and Copay (1999) studied participants with mixed diagnoses with locomotor impairment. Participants wore accelerometers (CSA) on both wrists. They were asked to propel manual wheelchairs at three different speeds on an indoor course. Heart rate and oxygen consumption were measured. Results indicated that wheeling speed, heart rate, and oxygen consumption increased over the three conditions and associations ($p < 0.01$) based on both accelerometers. The correlation of energy expenditure to accelerometer data for individual devices was r= 0.52 for the right and r= 0.66 for the left. The study concluded that their results showed that the CSA accelerometer worn on the wrist may provide a useful measure of physical activity in persons who use wheelchairs as their primary mode of locomotion. The measure derived from the accelerometer was not described. This study demonstrated a moderate association with the accelerometer data and energy expenditure. Subjects had a variety of conditions and thus the results cannot be extrapolated to any particular manual wheelchairs users (or single arm tasks). Further the CSA accelerometers are only uni-axial designed for able-bodied motion detection, thus sensing only vertical accelerations. This may have limited the ability to detect physical activity.

Physical Activity Characteristics

Warms and Belza (2004a) evaluated the suitability of accelerometry as a measure of free living physical activity in the SCI population. Three phases of monitoring were performed. 6 subjects participated in the first two phases and 16 in the third. In phases one and two, 4 men and 2 women participated aged 30-53. Phase three was comprised of 13 men and 3 women. Injury levels were evenly distributed between groups. Actiwatch activity monitor accelerometers were used. Epoch length was 15 seconds, sampling rates were undisclosed. Phase one consisted of 6 participants performing controlled activities including wheelchair propulsion, range of motion exercises and periods of inactivity including sitting quietly and desk work for 5 minute intervals. Results showed a significant difference in activity counts between periods of activity and sedentarism. In phase two, 22 participants were asked to wear the accelerometer and maintain an activity log for 4 days. Participants were asked to complete a self-rating activity record with intensity log. Correlated self-report to activity intensity was r= 0.3 to 0.7 with a mean coefficient of 0.6. The magnitudes of activity counts from the Actiwatch were also consistent with varying intensity ratings in the self- report. Phase three results were reported in a second study by Warms and coworkers (C. Warms & Belza, 2004b). This phase included incorporating use of the Actigraph monitors to assess activity in a multidimensional program aimed to increase physical activity among people living with SCI. Warms and Belza were able to demonstrate the capability of accelerometry units to capture motion as well as time spent active and sedentary among community dwelling individuals with SCI. The use of the accelerometers had a low burden rating and a high compliance, which was another positive outcome. Positive correlations between increased activity counts and activity intensity are favorable albeit arguably less conclusive because of the associated weaknesses of using a self-report to validate an objective measure. Lastly, not all acceleration sampling and processing methods were specified and therefore quality of the data received is somewhat unknown.

Postma and coworkers (Postma et al., 2005) studied the ability of an activity monitor to validly predict wheelchair propulsion and distinguish propulsion and other activities of daily living in individuals with SCI. 10 inpatient participants were selected in a rehabilitation setting. Included were individuals 19 to 63 years old, with both paraplegia and tetraplegia. Subgroupings were established between the ten participants to analyze differences in detection of propulsion between individuals with strong or weak triceps. Six ADXL202 piezo-resistive accelerometer sensors were attached to each wrist, each thigh and two on the sternum. A portable data recorder was carried on the waist with a belt. A sampling frequency of 32 Hz was used. Participants were asked to perform a series of consecutive activities including wheelchair propulsion, transfers, cooking, and opening doors. Video was used as a reference method for detection of activity. Proprietary software was utilized to analyze the data from the activity monitors to determine if movement patterns were consistent with wheelchair propulsion or other upper extremity related activities. The activity monitors and the video were synchronized and then analyzed. The overall agreement between the two measures was 92%. Sensitivity to detection of wheelchair propulsion specifically was less in the subgroup with poor triceps strength then in the subgroup with good triceps strength (81 and 95% respectively, $P< 0.01$). The overall duration of wheelchair propulsion was over-estimated by only 3.9%. A larger overestimation was seen in the group with stronger triceps. This study concluded, "wheelchair propulsion can be validly detected with by activity monitors in patients with SCI, both with poor and good triceps strength. Therefore, activity monitors offer the possibility to obtain objective information (duration of activity) on all major mobility related activities performed by patients with SCI. The ability to use a six accelerometer system in free living situations is somewhat suspect.

Gendle and coworkers (Gendle et al., 2012) used wheelchair-mounted accelerometers to evaluate the validity of measuring PA in athletic wheelchair users. Ten women and 2 men participated. Five participants had acquired spinal cord injuries, 3 had spina bifida, 2 had lower body amputations, and 2 had lower body structural issues. All were wheelchair athletes at a collegiate level. RT3 accelerometers (tri-axial) were attached underneath the participants seat. A sampling rate of 1 Hz with and 60 second epochs were used. A heart rate monitor was attached on the subjects' chests. Testing of each participant was performed over 2 days. Each day was comprised of two 7 minute blocks of wheeling. Subjects were asked to wheel on a rectangular course at various intensities (effort measured by BORG perceived exertion = light 10-11 vs moderate 13-14) and mode (continuous versus "stop and go"). Strong correlations were observed between accelerometry activity counts, and heart rate and distance travelled (r values ranging from 0.72 to 0.96).

Coulter and coworkers (Coulter, Dall, Rochester, Hasler, & Granat, 2011) studied the use of wheelchair-mounted accelerometers (ActivePAL) on 14 individuals with SCI (9 male, 5 female). Participants ranged from inpatients to 1 year post injury. The tri-axial accelerometer was positioned on the rear wheel. Sampling rate was 10 Hz. Accelerometer data was used to calculate the angle of the wheel and then converted to wheel revolutions and duration of movement from which distance and speed could be calculated. A circular indoor track was used to assess wheeling at a self-selected speed. Forward and backward propelling and obstacles such as ramps and curbs were performed outdoors. Video analysis of the rear wheel revolutions and angles during the above tasks was used to validate the data and calculations derived from the accelerometers. Intraclass correlation coefficients and Bland-Altman plots were used to demonstrate very high concurrent validity in determining wheeling speed, distance and duration. This study demonstrated the use of accelerometers as "wheelometers", akin to pedometers for able-bodied individuals. Clearly a limitation of this study is that full time wheelchair users still move outside of their chairs, or perform movement that does not include wheelchair motion. Secondly, these accelerometers cannot distinguish between a self- propelled or pushed wheelchair.

Kooijmans and associates (Kooijmans, Horemans, Stam, & Bussmann, 2014) studied the ability to distinguish wheelchair propulsion from other activities in full time wheelchair users. One accelerometer was placed on the wrist and a second on the chair wheel. Actigraph GT3X+ accelerometers were used with a sample rate of 30 Hz and 1 second epochs. 10 participants, all male, levels C5-T12 performed a series of representative daily activities in a lab setting. The researchers were able to detect wheeling from the accelerometer readings with 88% sensitivity and 83% specificity. The conclusion was that valid detection of self-propelled wheelchair driving and task duration can be provided using these procedures.

Accelerometry Usability

Warms and Belza (2004a) studied the perceived burden of wrist born accelerometer use with a series of numerical scaling questions. Participants rated burden low with a mean 95% compliance to wearing the devices indicating minimal interference with activity.

Bussmann and colleagues (Bussmann et al., 2010) conducted a study to assess the burden of accelerometers in a SCI population. 10 individuals participated (8 male, 2 female) of which 5 had paraplegia, and 5 had tetraplegia. All had motor complete injuries and were full time wheelchair users with a median age of 51 years. A rotation counter was used on the individual's manual wheelchairs and was used to assess activity in the wheelchair over a 7 day period. Participants were then asked to wear an activity monitor in the form of a portable data recorder worn via a belt on the waist and 6 piezo-resistive accelerometers for a single day. Experienced burden was measured with a visual analogue scale style questionnaire where 0 = no burden and 10 = maximal burden. It consisted of 8 questions, 3 regarding equipment, 5 regarding activity. Results revealed a low to moderate burden with the accelerometer unit. Burden was not different between sub groups. The results are favorable for use of activity monitors, especially considering that 6 accelerometer units were employed in this study. Participants however were only asked to wear the device for a single day where as six days are the standard for adequate PA characterization (Colley et al., 2011).

Physical Fitness and Exercise Guidelines

Ginis and coworkers (Ginis et al., 2011), developed exercise guidelines for people living with spinal cord injury. A systematic review of literature, an expert panel, and a trial with stakeholders (practitioners working with SCI and individuals with SCI) was conducted to determine the intensity, duration, and type of training required to generate fitness benefits among people with SCI (ages 18-64). 82 articles on PA in individuals SCI were chosen from 160 potentially eligible papers. Between the systematic review and expert consensus it was determined there was enough evidence to produce guidelines aimed to improve muscle strength, and physical capacity in people with chronic SCI.

The guidelines state that 40 minutes per week of moderate to high intensity physical activity, consisting of two bouts of 20 minute durations. Resistance training is recommended 2 times per week for all major muscle groups. The review alleges high quality randomized controlled trial evidence showing effectiveness of a 2 days per week frequency to increase aerobic and muscular strength over 9 months. Interestingly, most of the reviewed studies used 3 days per week training protocols. The recommendation of moderate to high intensity for 20 minute durations was based on RCTs coupled with lower quality studies.

For strength training, the guidelines recommend an intensity of 70-80% of 1 rep maximum, prompting 3 sets of 8-10 repetitions, where the exerciser can “barely but safely finish 8-10 reps of the last set”. Again, the point is made that frequency was often 3 times per week in the reviewed studies, but it was indicated that a lower intensities were still found to be effective.

The panel made clear distinctions regarding its guideline's purposes. The systematic review yielded no evidence that exercise can decrease body weight and mixed evidence regarding effects of exercise on muscle mass and adipose tissue. Despite consistent but lower quality (not RCT) studies indicating that exercise can improve wheelchair propulsion, the report states that there was insufficient evidence for development of guidelines to improve functional performance. Lastly, the study concluded an ability of the guidelines to render improved fitness in beginner exercisers, but unable to conclude that the recommended amount of activity is sufficient for health benefits.

In 2014, Pelletier and colleagues (Pelletier, Totosy de Zepetnek, MacDonald, & Hicks, 2015) completed a 16 week RCT to evaluate the above guidelines. 23 people with SCI were split into an exercise group following SCI exercise guidelines and another a 'recreational activity group'. The group found that after the 16 week trial, peak aerobic capacity, aerobic endurance and muscle strength all improved significantly as compared to those in the control group. They concluded that while objective measures of strength and CV fitness improved, health benefits and reduction of cardiovascular co-morbidities couldn't be assumed with this dose of physical activity.

The ACSM current guideline for individuals with SCI mirrors those for able-bodied individuals. In a brochure released in 2013, ACSM endorses the use of circuit training for individuals with SCI stating "resistance training improves aerobic fitness in persons with SCI as much as, if not more than, aerobic exercise" (Vincent, 2013). When combined with circuit training, resistance exercise is an excellent training modality to improve health-related physical fitness, reduce secondary disease risk and slow typical age-related declines in function thereby enhancing independence and reducing risk of inactivity." Three circuits of 6 low intensity resistance exercises (40-60% 1RM) separated by 2 minutes of aerobic training was recommended as a protocol with 30 second rest periods between sets.

Interestingly, using ACSM's guidelines for weight management in healthy individuals, Tanhoffer (R. A. Tanhoffer et al., 2014) used doubly labeled water energy assessment of two groups with SCI (sedentary, n=7 and those meeting 150 min/week, n=6). The results of this study provide evidence that regular exercise at this level will improve body composition, total daily energy expenditure and basal metabolic rate. They also suggested that increased volume or intensity, more than those proposed for able-bodied individuals might be needed for people with SCI.

Koury and associates (Koury, Passos, Figueiredo, Chain, & Franco, 2013) compared a physically active group of individuals with tetraplegia to a non-active group of individuals with tetraplegia. The active group was defined as individuals who practiced physical activity for longer than 3 months, at a rate of 3 times per week for a minimum of 150 minutes per week. The active group exhibited decreased total body mass, decreased fat mass compared to the non-active group, and an inverse relationship of insulin resistance to length of time exercising (r= -0.59, p=0.033) at or above the 150 minute per week benchmark. Similarly, D'Oliveira and associates (D'Oliveira et al., 2014) showed findings, indicating that individuals with tetraplegia (C5-C7) who practiced 150 minutes of exercise per week demonstrated decreased insulin resistance and lower fat mass, including regional abdominal fat.

Jacobs and Nash (Jacobs & Nash, 2004) completed a review of the literature regarding exercise for persons with spinal cord injury. Pertaining to endurance training, arm conditioning has consistently shown to increase V02 peak in persons with paraplegia and tetraplegia, with the magnitude of increase being inversely proportional to injury level. The physiological adaptations responsible for the improvements are less clear. The ratio of central (HR, SV, CO), to peripheral (oxygen extraction, mitochondrial numbers) adaptations is likely different depending on injury levels. Altered sympathetic function in higher injuries and decreased stroke volume from diminished cardiac preload with all levels of injury make the SCI population different from any other. The recommendation was made to follow the general population guidelines of 150 minutes in 3-5 sessions per week with bouts of 20-60 minutes in length. Caution is suggested with beginners in this population. Erring on the conservative side with exercise durations and intensities is more important than in the able bodied population.

Fernhall et al (2008) also completed a literary review of the health implications of physical activity in individuals with SCI. The group looked at the research pertaining to unique challenges faced by those with SCI when engaging in physical activity. Altered physiology, secondary medical complications and social roles were among the most significant (Weaver, Hammond, Guihan, & Hendricks, 2000) Physiological changes included decreased regional and whole body muscle mass, decreased bone mass and density, increased adiposity, altered lipid profiles, increased insulin resistance with increased risk of type 2 diabetes, increased abdominal obesity and decreased resting basal metabolic rates.

Summary

Overall there is a limited amount of research available on the monitoring or quantifying of physical activity among wheelchair users. In the available literature however, two primary objectives are evident. Studies attempting to use accelerometry technology to estimate individual energy expenditure of wheelchair users, and others aiming to capture and quantify individuals' mobility characteristics such as time spent active versus sedentary, distances and speeds travelled during a day.

The energy expenditure studies indicate a promising future for the use of accelerometry to estimate energy expenditure in wheelchair users, but have failed to coordinate or adapt the technology to capture the varying abilities and movement characteristics of wheelchair users seen within the spinal cord injury spectrum.

Studies were commonly thwarted by the use of regression equations for energy expenditure based on software intended for able-bodied users. Those having investigated the ability of accelerometers to assess movement characteristics have shown promising results in terms of validity and reliability. Evidence from these studies has demonstrated the ability of accelerometers to detect changes in intensity, duration of activity and wheelchair propulsion speeds effectively (Gendle et al., 2012; Postma et al., 2005; C. A. Warms & Belza, 2004). Studies in both streams have focused on validation of accelerometers as tools for PA measurement, and have yet to take the next logical step of clinical or practical application of the tools to examine the free-living PA characteristics of SCI.

The accelerometers used to date in SCI participants have largely been older technology (low sampling rates, long epochs, uniaxial) potentially contributing to inaccuracies. Current technology uses higher sampling rates, triaxial sensors, and stores data in shorter time frames (epochs), thereby increasing the accuracy of the movement captured and the ability to analyze its characteristics in detail.

The accelerometers themselves have been well received by participants with indications from studies of high compliance rates, low burden and minimal reactive changes in activity patterns when wearing an activity-monitoring device.

Etiology of widespread shoulder pain in this population is also unclear. This study hopes to shed light on the relationships between activity levels, shoulder dysfunction and pain complaints.

The health benefits attributed to exercise in the general population are to date still largely unsubstantiated in the SCI population. Despite providing generalized exercise guidelines for the SCI population as a whole, Ginis and associates (Ginis et al., 2011) were unable to conclude that following these guidelines would result in any health benefits. Multiple sources have indicated need for higher levels of physical activity to ascertain health benefits in the SCI population (Jacobs & Nash, 2004; Koury, Passos, Figueiredo, Chain, & Franco, 2013; D'Oliveira, 2013; Rosety-Rodriguez et al., 2013; A. I. P. Tanhoffer et al., 2013). Certainly, health implications of physical activity in the SCI population require a significant amount of ongoing research. With a multitude of physiological differences from the able bodied population and without longitudinal studies available, we are unable to conclude that physical activity infers a similar amount of disease risk reduction in persons with SCI. It is difficult to study the SCI population given the heterogeneous nature of different injury levels and completeness of injuries. It is likely that physical activity confers different impacts on health to individuals with injuries at different levels and of varying degrees of completeness. Despite the relative lack of conclusive research, some pieces of promising evidence are starting to accumulate. Within the literature, there is evidence to suggest that exercise increases fitness, increases muscular strength (Hicks et al., 2011; Hoffman, 1986; Jacobs & Nash, 2004), increases work capacity (Hoffman, 1986) increases high density lipoprotein (associated with decreased cardiovascular and metabolic risk), increases insulin sensitivity (D'Oliveira et al., 2014; Koury et al., 2013; Nooijen et al., 2012), decreases total body mass and fat mass (D'Oliveira et al., 2014; Koury et al., 2013; R. A. Tanhoffer et al., 2014), decreases arterial stiffness (Fernhall et al., 2008), increases perceived quality of life and self-efficacy (Manns & Chad, 1999; C. A. Warms, Belza, Whitney, Mitchell, & Stiens, 2004; Zemper et al., 2003) and decreased pressure sores (Stotts, 1986). Decreased muscular strength also leads to decreased independence and consequently decreased quality of life ratings (Rimmer, Graves, & Franklin, 2001). It should be noted that many of the above health benefits have only been noted in individuals meeting the weekly 150 minute exercise guidelines (D'Oliveira et al., 2014; Jacobs & Nash, 2004; Koury et al., 2013; Rosety-Rodriguez et al., 2013; R. A. Tanhoffer et al., 2014).

Indications for the proposed study

Accelerometry has been shown to effectively capture both temporal and intensity characteristics of wheelchair user's physical activity behaviors (Postma et al., 2005; C. Warms & Belza, 2004a) and correlate strongly with varying heart rates (when applicable) and 02 consumption (Gendle et al., 2012; Washburn & Copay, 1999). Given the literature and the ongoing technological advances, it is our opinion that accelerometers are efficient tools for activity monitoring with the appropriate application and strategies. Currently, there is little information on physical activity levels and patterns beyond self-reports in the SCI community. An objective physical activity measure is required to properly characterize the levels of activity so as to improve the quality of life of individuals with SCI, and to evaluate exercise guidelines. Relationships between actual physical activity levels and areas such as shoulder pain, self-efficacy, and reliability of physical activity self-reports cannot be properly assessed without a reliable objective physical activity measure. This may also have implications in a rehabilitation setting when prescribing and evaluating exercise treatments as well as encouraging client compliancy and behavioral changes through tangible feedback on PA and sedentary levels.

Purpose

The purpose was to characterize physical activity patterns of people using manual wheelchairs with spinal cord injury in Manitoba.

Objectives

1. Develop and assess a practical technique to assess physical activity characteristics of people using manual wheelchairs using individualized participant thresholds for identification of moderate PA intensity.

2. Characterize physical activity in terms of:
    a. Daily duration at normal and moderate intensities of all epochs
    b. Daily duration and number of contiguous bouts of epochs
    c. Duration of sedentary behavior

3. Compare physical activity characteristics to PA guidelines (SCI and able-bodied) and sedentary normative data.

4. Relate physical activity and sedentary behavior levels to
    a. Injury characteristics & classifications
    b. Self-report of physical activity levels, shoulder pain and self-efficacy.

5. Characterize participants based on their PA patterns

6. Document the inventory of physical activities performed.

Methods

Design

This is an observational, cross-sectional study of manual wheelchair users with spinal cord injury in Manitoba.

Participants

Inclusion and Exclusion Criteria

Participants are individuals with a chronic spinal cord injury (> 3 months) residing in Manitoba. Participants with paraplegia and tetraplegia were included. All participants must use a manual wheelchair as their primary means of mobility. The age range will be 18 to 60 with no substantial co-morbidities or major musculoskeletal injury that will diminish physical functioning.

This study was approved by the HREB at the University of Manitoba (H2009:085). A grant from the Canadian Paraplegic Association (Manitoba) was the source of support for this project.

Recruitment

Participants were recruited through the Canadian paraplegic association database, through advertisement in ParaTracks newsletter, posters, and word of mouth.

Sample Size

This study used a sample of convenience with a minimum of 20 people equally distributed between paraplegia and tetraplegia.

Participant Classification

Participants were classified using the standard paraplegia and tetraplegia method. This was termed the Anatomical Level in this study. Participants were also classified with a new method, also based on anatomical levels but specific to motor levels related to functional wheeling capacity. This was termed the Functional Level in this study. The following criteria were used:

i. no tricep or trunk stability (NTNT) (C6 and above)
ii. tricep function but poor trunk stability (TNT) (C7-T9)
iii. tricep function and trunk stability (TT) (T10 and below)

Also, participants were ranked using a newly designed SCI Lifestyle Scale (SCILS). This preliminary trial version, which was completed by a physiotherapist based upon experience with the participants as well as the study's intake interview findings. Lifestyle rank was given without knowledge of objective PA assessment outcomes or answers to questionnaires. The scale was designed to provide an assessment of general activity level present in the participants lifestyle and the presence of a plan or framework for implementation of PA. A framework for PA was assessed with the following categories:

- Amount of support available to the individual to aid in facilitation of PA for such purposes as transportation to a facility or assistance with setting up exercise equipment if required.
- Availability of equipment or facility resources to the individual
- General knowledge of PA and PA guidelines
- Participation in recreational or social circles such as sports teams that encourage regular PA
- Personal priority placed on physical activity

The following criteria were used:

5- Consistent, above average activity level implemented with very high priority placed on PA. Excellent availability of required resources and knowledge of exercise. Frequency or duration of exercise is not dependent on others.

4- Consistent, adequate activity level implemented with high priority placed on PA. Good availability of required resources. Minimal or no support required but consistently available if necessary.

3- Variable PA levels and adherence due to lack of consistent resources, support, knowledge or priority placed on PA.

2- Low PA levels with minimal support and resources available or sought after. Dependency on others to help facilitate implementation PA may be a factor. Self-aware of low PA levels and may be interested in increasing PA levels but currently places low priority on PA.

1- Very low PA level with minimal support or resources available or sought after. Poor PA knowledge and no plans to change behavior.

As an initial validation of the scale, it will be compared to the objectively measured sedentary and PA levels.

Protocol

The protocol consists of the completion of the following;

1. Participant information and consent
2. Surveys
    a. Wheelchair Users Shoulder Pain Index
    b. Spinal Cord Injury Self Efficacy Scale
    c. Physical Activity for Individuals with Physical Disabilities
3. Physical Activity Assessment
    a. Assessment of individual specific intensity threshold during free wheeling
    b. 7 day PA assessment concurrent with activity log.

Physical Activity Assessment

The miniature triaxial accelerometers (GT3X, Actigraph, Pensacola, FL.) were set to record acceleration continuously at 100 Hz. The accelerometer data was downloaded via manufacturer's software (Actilife™ software, version 5.6.1). The acceleration data was then post-processed into 5 second epochs. Each epoch of accelerometer data is time stamped and contains the acceleration for each of the three axes, the orientation of the accelerometer, and the light intensity near the devices. The accelerometer data was exported in comma separated text files, which were imported into a spreadsheet for additional post-processing. The resultant acceleration magnitude was derived from the three axes using the Pythagorean theorem.

The participants wore two accelerometers, one on their dominant arm located at the wrist, and one strapped to the trunk. Studies have indicated placement on either dominant or non-dominant are equally effective in determination of activity levels (Learmonth, Kinnett-Hopkins, Rice, Dysterheft, & Motl, 2015).

Individual Specific Intensity Threshold Determination

Participants were asked to wheel around a 51.7 m (190 foot) track provided with the following instructions.

a. Perform one lap at a ‘slower than their normal’ wheeling pace. Then rest for 30 seconds (SLOW - SPA).
b. Perform one lap at ‘their normal’ wheeling pace. Then rest for 30 seconds (NORMAL- NPA).
c. Perform continuous laps at a wheeling pace aiming to reach a moderate intensity of 13 as perceived on a 20 point Borg perceived exertion (BPE) scale (MODERATE - MPA).

The BPE scale was used to allow for a relative threshold for each person dependent upon his or her wheeling capacity or fitness, rather than an absolute threshold. The BPE scale (6-20) was affixed where the participant could visualize it upon completion of each lap. The participant was instructed to stop at the end of the lap in which he or she had reached the desired BPE rating indicating a moderate exertion level. The time to complete each lap was recorded. The speed for each lap was then computed. Average trunk and wrist accelerations were computed for each wheeling pace.

Free Living Physical Activity Assessment

Participants were asked to wear the accelerometers for 7 days during waking hours for up to a maximum of 9 days to allow for incidentally missed days, and to account for partial days due to donning and doffing the accelerometers for study purposes. Participants were asked to keep an hourly log of their daily activities throughout the course of the week, as well as indicate when they performed transfers. Participants were asked not to waiver from their regular routines. The participants wore the accelerometers during the spring, summer and fall seasons where there was no snow cover, and temperatures were above zero.

Wear time was determined using the Actilife software algorithms. This algorithm effectively differentiates periods of inactivity (sedentary time) from non-wear time. A minimum of 8 hours wear time was used to identify a valid day for subsequent analysis based upon standard methods for population physical activity assessments (Colley et al, 2011). The average daily sedentary time was also calculated which did not include non-wear time or sleep time.

In this study, physical activity was operationally defined as the duration of time spent above normal (NPA) and moderate (MPA) thresholds as determined by perceived exertion levels achieved during the individual specific threshold trials. PA levels were determined through two separate acceleration processing approaches. The first used all epochs (5s duration) that exceeded the normal and moderate thresholds (ALL Activity). The second used a contiguous bout approach, which concatenated bouts to provide a description of "sustained" physical activity (CONTIGUOUS Activity). The contiguous method allowed for intermittent lapses below moderate threshold using a 30 second grace period (6 epochs). This duration was chosen based upon the ability of the cardiovascular system to remain in "steady state" despite a momentary lapse in activity. For example, during a 10 minute wheeling exercise session at moderate intensity, there may be a decrease in intensity below threshold for 20 seconds at the 4 and 8 minute marks. Given the intensity resumed to above threshold levels before over 30 seconds elapsed, using the contiguous method, the participant would be credited with 1 MPA bout of 10 minutes in length. In the *all activity* method the participant would be credited with 9 minutes and 20 seconds of MPA as 40 seconds (20 seconds x 2) was below the intensity threshold.

All Activity

The following parameters were derived from all epoch data;

1. Number of epochs that exceeded the normal PA threshold (NPA) and the number that exceeded the moderate threshold (MPA).

2. The total time spent at or above each threshold was calculated (min).

3. The daily activity time (min/day) above each threshold was derived as total time (min) divided by the number of valid days per person.

Contiguous Activity

The following parameters were derived for contiguous activity;

1. Number of contiguous bouts
2. The total duration of contiguous bouts (min)
3. The average duration of contiguous bouts (min)
4. The average daily contiguous activity (min/day)
5. The total number of bouts that were within the following durations;
   a. 5 to 30 s
   b. 30 s to 2 min
   c. 2 to 10 min
   d. 10 min or over

Activity Log

Key words from the activity log were extracted and coded into a spreadsheet to derive word count frequencies, as well as to import into visual text frequency graphic (wordle diagram). Further, the participants also logged transfers to allow a daily tally of transfers.

Sedentary Behavior

The method for determining sedentary time was to look for periods of low to no activity during the wear time period using fixed thresholds for the trunk (15) and wrist (100). The thresholds were selected after inspection of the activity data in association with the activity logs. This allowed known periods of sedentary behavior to be associated with the magnitude of acceleration at the wrist and trunk. Total sedentary time was computed for the wrist, trunk and combined wrist and trunk.

Questionnaires

Wheelchair Users Shoulder Pain Index (WUSPI)

The Wheelchair Users Shoulder Pain Index was developed by Curtis et al (1995). It is a 15 item, self report questionnaire measuring the functional cost of shoulder pain in wheelchair users on a visual analog scale. The anchors for the items range from 0 “no interference due to pain” to 10 “completely interferes due to shoulder pain”. The questionnaire covers 4 subsections, which include transfers, wheelchair mobility, self-care, and general activities.

Spinal Cord Injury Exercise Self Efficacy Scale (SCI ESES)

The Spinal Cord Injury Exercise Self Efficacy Scale was developed by Thilo Kroll, (Kroll, Kehn, Ho, & Groah, 2007). It is a 10 item self-report questionnaire requiring respondents to answer questions intended to measure perceived exercise self-efficacy in individuals with SCI. The scale requires individuals to indicate their confidence in performing physical activities and exercise on a 4-point Likert scale (1-not at all true, 4-always true). The scale is SCI-specific and measures perceived self-efficacy for various types of physical exercise.

Physical Activity Scale for Individual's With a Physical Disability (PASIPD)

The Physical Activity Scale for Individuals With a Physical Disability is a self-report questionnaire that captures information about leisure, household and work related physical activity over the preceding 7 days. Individuals respond to 2 ordinal ranked responses; a frequency response from 1 (never) to 4 (often) and a duration response from 1 (less than 1 hour) to 4 (greater than 4 hours). The average hours per day for each item is multiplied by a metabolic equivalent value associated with each activity. Scores range from 0 to >100 METS hr/day. (Miller & Chan, 2013)

Statistical Analysis

Statistical analysis performed included descriptive statistics, inferential statistics independent t tests, single sample t test, and ANOVA where indicated. An alpha level of 0.05 was employed.

Correlation was used to relate self-reports of disability, self-efficacy, shoulder pain, and classification schemes to physical activity/sedentary parameters using Pearson or Spearman correlations as appropriate.

Results

Participant Description

Table 1 illustrates the basic characteristics of the participants. Participants were all full time manual wheelchair users with ASIA scores ranging from A to C. There were no significant differences between classification groupings regarding age, injury age, and body mass.

Table 1. Participant characteristics.

	Mean	SD	Range
Age (years)	38.1	11.4	22-60
Injury Age (years)	13.7	11.85	1-44
Body Mass (kg)	76.4	16.6	48.7-110
	Count		
Anatomical Classification	12 Tetra	13 Para	
Functional Classification	7 NTNT	9 TNT	9 TT
Sex	21 Male	4 Female	
Employment	10 Yes	15 No	

NTNT - no triceps, no trunk
TNT - triceps, no or low function trunk
TT- triceps use and good trunk

Table 2 illustrates the mean scores for the three self-reported scales used (PASIPD SCI ESES and WUSPI). The PASIPD was completed after the 7 days of activity monitoring in order to be able to correlate the self-report data to the duration over which PA was objectively measured. 12 questionnaires were returned, many neglecting to return it upon completion of the PA monitoring. The WUSPI and SCI ESES were completed prior to the monitoring time and were completed by 24 of 25 participants.

Table 2. Average scores for the physical activity, self-efficacy and shoulder pain surveys.

	Mean	SD	Range
PASIPD	27.6	14.4	6.5-65
ESES	31.7	5.15	23-40
WUSPI	11.8	19.8	0-86.9

Normative values for the surveys are not available but comparisons to other studies provides context for characterization of the participants in this study. Fliess-Douer, Vanlandewijck and van der Woude found an average ESES score of 35.87 studying 79 elite athletes at the 2008 Paralympic games. Two recent pain intervention studies by Van Straaten et al (Van Straaten, Cloud, Morrow, Ludewig, & Zhao, 2014), and Kemp et al (Kemp et al., 2011) with inclusion criteria of spinal cord injured individuals with pre-existing shoulder pain reported average baseline WUSPI scores of 22.8 and 52.4 and post treatment scores of 12.5 and 13.8 respectively. 19 of the 24 individuals who completed the survey in this study reported a 0-10 out of a possible 150 score. A study by Dyson-Hudson and colleagues (Dyson-Hudson, Sisto, Bond, Emmons, & Kirshblum, 2007), analyzed the effect of an exercise weight loss intervention on shoulder pain. Inclusion criteria did not include pre-existing shoulder pain. The 23 participants indicated an average baseline WUSPI score of 9.95 (range 0 - 63.8). A thesis work (Ravensbergen, 2013) reported PASPID scores of 17.6 for complete SCI and 13.1 for incomplete SCI. An average PASPID value of 36.1 was found in a group of people with SCI that were considered very active (Learmonth et al, 2015). Overall this characterizes this group as slightly lower self-efficacy than elite athletes, with middle of the road PA self-description, and very low shoulder pain.

Accelerometer Wear Time

Table 3 illustrates the average wear time derived from the wrist and trunk accelerometers. Valid data was defined as days above an 8 hour wear time and 4 or more valid days (Colley et al., 2012). Arm and trunk returned similar wear time results.

Table 3. The wear time characteristics derived from trunk and wrist acceleration.

	Mean	SD
TRUNK		
Days	6.3	1.7
Hours per Day	13.2	2.46
WRIST		
Days	6.3	1.63
Hours per Day	13.7	3.42

Nonetheless, we identified some accelerometer wear time issues during the study. Firstly due to a battery issue, one participant's data was only collected for one 15 hour day. This data was included as it exceeds the minimum 8 hours, and was a representative day for that person. Second, one participant's data revealed 4 days wear time averaging just under 12 hours for both the wrist and trunk accelerometers individually but with only 3 of 4 days where they were worn simultaneously. The 3 days of simultaneous wear were used for analysis.

Individual Specific Accelerometer Thresholds

The average speeds corresponding to slow, normal and moderate pacing for the participants (n=19) were calculated and are reported in Table 4. In imperial units, the mean speeds were 2.86 and 3.84 mph.

Table 4. Wheeling speeds associated with graded pace trials.

Pace	Mean	SD	Range
Slow (m/s)	0.9	0.15	0.59-1.15
Normal (m/s)	1.28	0.26	0.88-1.8
Moderate (m/s)	1.72	0.36	1.1-2.37

A recent study of SCI wheeling speed on a wheelchair ergometer concurs with the findings above indicating speeds of 1 to 1.3 meters per second typical of everyday functional propulsion (Qi, Ferguson-Pell, Salimi, Haennel, & Ramadi, 2015). Normal and moderate speeds achieved between persons with paraplegia and tetraplegia groups were not significantly different (p=0.28), although trending towards increased speeds for participants with paraplegia during moderate paces (p=0.07). A statistically significant difference in the gap in speed from normal to moderate paces was observed between tetra/para groupings (p=0.0028). Interestingly, normal speeds were very similar between tetraplegia and paraplegia groups. However, analyzed using functional levels, statistically significant differences were noted at moderate paces, with the higher function groups achieving moderate intensity at higher speeds (NTNT to TT (p=0.0039), NTNT to TNT (p=0.0025)). The difference between TNT to TT groups was not significant.

Table 5 shows the characteristics derived from the moderate pace trial. Seventeen of 19 individuals reached a BPE value between 12-15. The ACSM describes moderate intensity as determined by a Borg scale as 12-13 and hard as 14-16. One participant stopped at a perceived exertion of 10 due to commencement of wheeling related shoulder discomfort and another felt they had overshot the moderate range resulting in a BPE of 17.

Table 5. Characteristics for moderate intensity pace trial.

	Mean	SD	Range
BORG	13.4	1.43	10-17
LAPS	5.9	2.69	3-12
DISTANCE (M)	346	160.5	172-691
TIME to MOD (S)	199.5	79.9	81-385

Comparison of any parameter for the moderate pace trial using the anatomical categorization (Paraplegia and Tetraplegia) revealed no statistically significant differences. However, using the functional classification, the higher function groups (TT and TNT) propelled their wheelchairs for longer distances than the NTNT (lower function) group (p=0.028, p=0.03 respectively). The time to achieve moderate intensity however was not significantly different using this classification.

Figure 1 shows a typical plot of the wrist accelerometer data for one participant during the individual threshold determination trials. A clear gradation in wrist acceleration magnitude with increasing speed is demonstrated. All participants had demonstrable speed dependent acceleration gradations. The average of the plateaus for each pace trial was used to determine the thresholds.

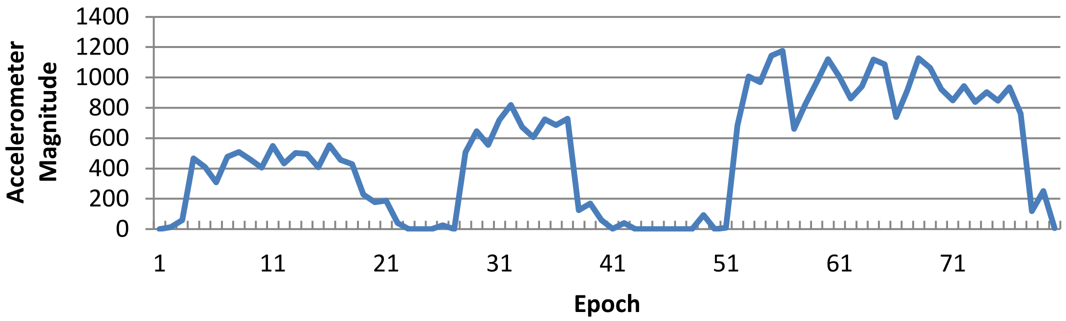

Figure 1. Wrist accelerometer output during the individual specific graded pace trial. Bout 1: slow pace (left) Bout 2: normal pace (middle) Bout 3: moderate pace to moderate intensity BPE (right). An epoch is 5 s duration.

Table 6 shows the wrist accelerometer output for each wheeling pace averaged across participants. Speed dependent increases in acceleration magnitudes are apparent with correlation between average speed and average accelerations reaching 0.96 (trunk) and 0.98 (wrist). Although individual thresholds were used for computation of physical activity characteristics (19 of 25 participants), averages were used to aid in derivation of thresholds for the participants that did not perform the individual threshold determination.

Table 6. Average accelerometer magnitudes (activity counts) for the three paces during the individual specific threshold assessments.

	Mean	SD
TRUNK		
Slow	42	43
Normal	68	50
Moderate	162	136
WRIST		
Slow	535	115
Normal	762	222
Moderate	1319	404

Figure 2 depicts the correlation of the average speed and accelerometer output for each participant during the moderate intensity portion of the individual threshold trials.

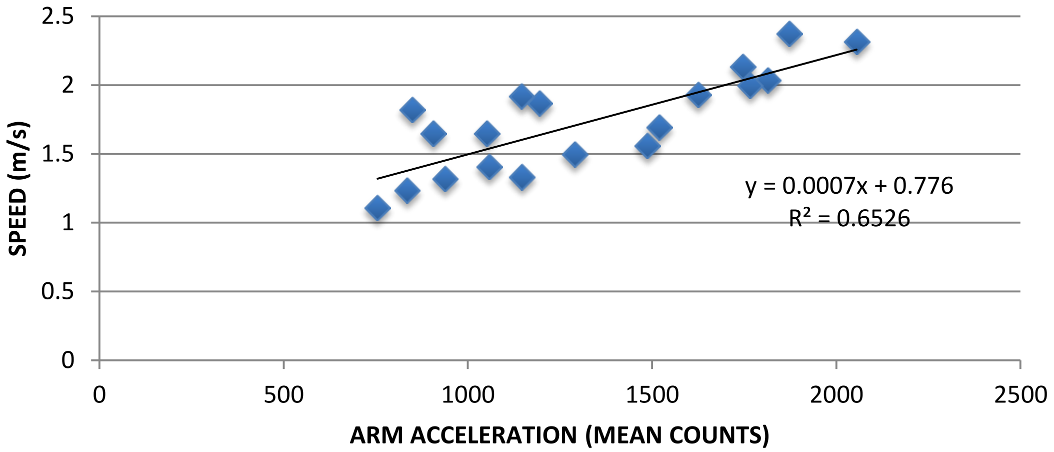

Figure 2. Relationship between wrist acceleration magnitude (activity counts) and speeds of wheeling for each participant during the moderate pace trial. The linear equation is shown (r=0.81, p<0.01).

When comparing moderate accelerometer outputs between groups, once again there were no statistical differences between participants with paraplegia and those with tetraplegia. With the functional classification, there were statistical differences noted in accelerometer outputs between NTNT to TNT ($p=0.014$) and NTNT to TT ($p < 0.001$). There was a non-significant statistical difference between TNT and TT ($p=0.16$). In all cases the higher functioning group had higher acceleration outputs.

Table 7 reports the correlations found between speed and accelerometer output using individual participant data, as well as the correlation between wrist and trunk accelerometers at normal and moderate speeds. Results indicate a strong correlation between wrist activity and speed, showing the activity count's very good sensitivity to altering speeds. Less association was seen between trunk activity counts and speed, presumably due to the varying degrees of trunk control with different levels of injury.

Table 7. Correlation between acceleration magnitude and speed using individual participant data.

	R
WRIST	
Acceleration vs Normal speed	0.61
Acceleration vs Moderate Speed	0.81
TRUNK	
Acceleration vs Normal speed	0.24 (NS)
Acceleration vs Moderate Speed	0.47

Since there were substantial magnitude differences for wrist acceleration between speeds (Table 6) and due to the strong correlation of arm acceleration with speed (Table 7); the wrist accelerometer was selected as the means of detecting intensity differences for the daily physical activity assessment.

Regression equations were derived between speed and wrist acceleration magnitudes for both classification systems (Figure 3, Figure 4). The slopes of equations between the participants with paraplegia and tetraplegia were similar over a broad speed range. The functional classification regressions revealed a separation between the NTNT (no trunk no triceps) group and the other two classifications in terms of a lower slope.

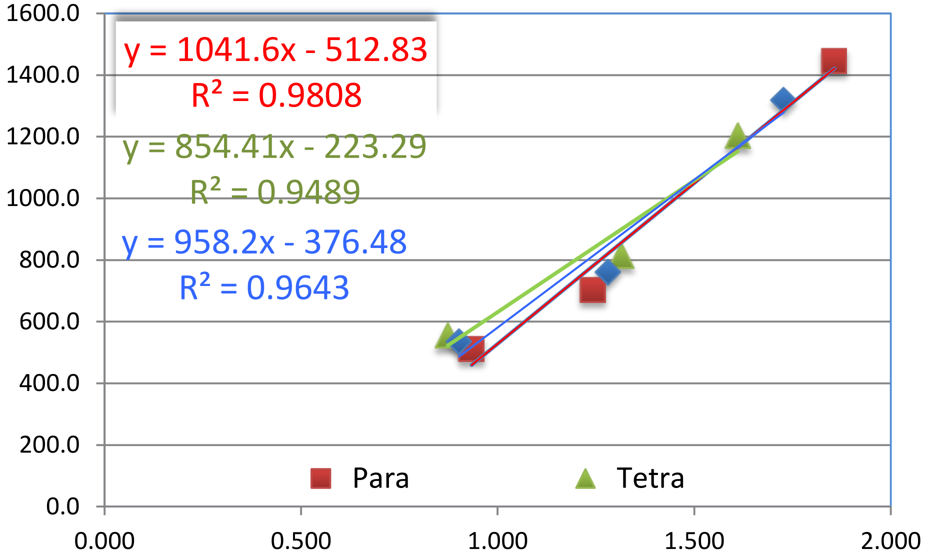

Figure 3. Relationship between speed and wrist accelerometer output for participants with paraplegia, tetraplegia and combined (ALL). Regression equations shown ($p<0.001$).

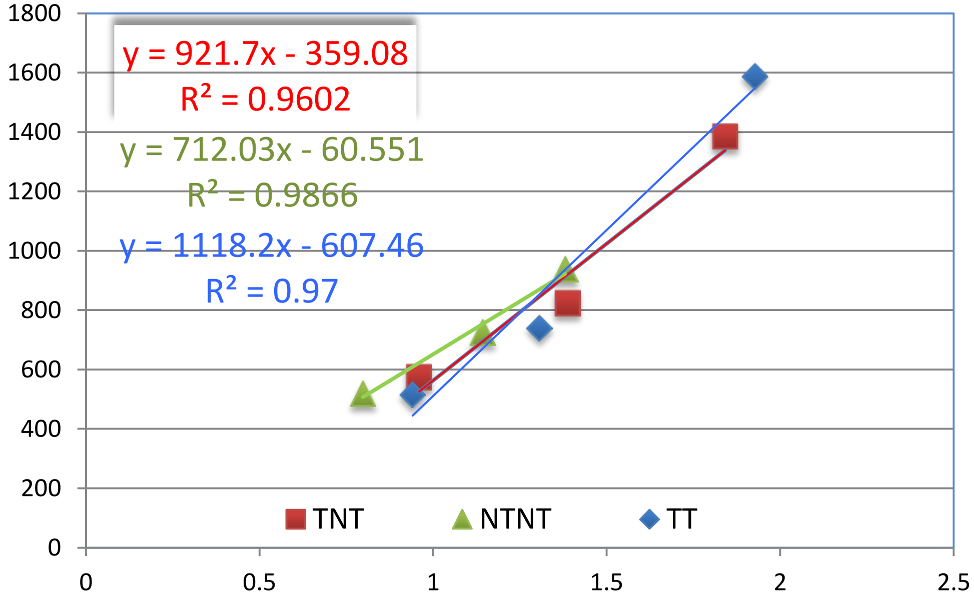

Figure 4 Relationship between speed and wrist accelerometer output for participants based upon functional classification. Regression equations shown ($p<0.001$). NTNT – no triceps no trunk TNT – triceps use but poor trunk TT- triceps use and good trunk.

Comparison of Individual Specific Thresholds with Average Thresholds

For the assessment of daily physical activity characteristics the individual specific thresholds for normal and moderate were used for the 19 participants that completed the graded pace trials. For the remainder of participants, thresholds were set to be just below the average values corresponding to normal and moderate. For the normal threshold, the average acceleration was 762 (Table 6), and a threshold of 700 was applied after inspection of the regression equations (Figures 3 and 4), and all the individual thresholds (range of 507 to 1251). For moderate, the average acceleration was 1319 (Table 6), and a threshold of 1200 was selected after inspection of regression equations and all the individual thresholds (range of 754 to 2055). Clearly, an absolute threshold will carry a certain bias for participants resulting in under-representation for some participants, and over-representation for others. However, although the individual specific threshold determination method was simple to implement and had low participant burden, there may be cases where absolute thresholds may be used. We undertook an analysis to ascertain the average error resulting from the use of these derived absolute thresholds.

We applied the derived thresholds back to the 19 participants that had the individual specific thresholds, and examined differences in physical activity characteristics. Differences in the number of minutes derived per day at each threshold (normal and moderate) were not statistically different. The differences in durations of activity between the individual specific and derived thresholds are shown in Table 8. The estimation error for daily minutes was 3.8 for the normal threshold, which represents 5.2% over estimation (See Table 9). The estimation error for moderate daily minutes was 0.74 min corresponding to a 6.2% over-estimation compared to individual specific values (See Table 9).

Table 8. Differences in durations between individually determined relative thresholds and derived absolute thresholds.

Estimation Error	Mean	SE
Normal		
Total (min)	27.7	67.2
Daily (min/day)	3.8	9.8
Moderate		
Total (min)	6.5	21.4
Daily (min/day)	0.74	3.3

Physical Activity Characterization

All Activity

Table 9 depicts the averages (all participants) using the normal and moderate physical activity thresholds using ALL accelerometer data. As would be expected there is a drop in daily time spent in NPA (60 min/day) to MPA (11.8 min/day) with a difference of 48.2 minutes. Figure 5 depicts the normal and moderate physical activity determined (min/day) for each participant.

A correlation of 0.365 (p=0.073) was observed between normal and moderate activity durations. However, when controlling for injury classification, employment, or injury age using partial correlation the relationship disappears.

Table 9. The average PA characteristics derived for all activity bouts (5 s epochs).

	Mean	SD	Range
Normal (> NPA < MPA)			
Bouts (#)	4685	3777	119-15245
Total Duration (min)	390	314	10-1270
Daily Duration (min/day)	60	42	1.14-181
Normal & Moderate (> NPA)			
Bouts (#)	5580	4022	429-17367
Total Duration (min)	465	335	35.7-1447.2
Daily Duration (min/day)	71.9	44.8	5.9-206.8
Moderate (> MPA)			
Bouts (#)	895	849	34-2871
Total Duration (min)	74.6	70.8	2.8-239.25
Daily Minutes (min/day)	11.8	11.0	0.4-37.14

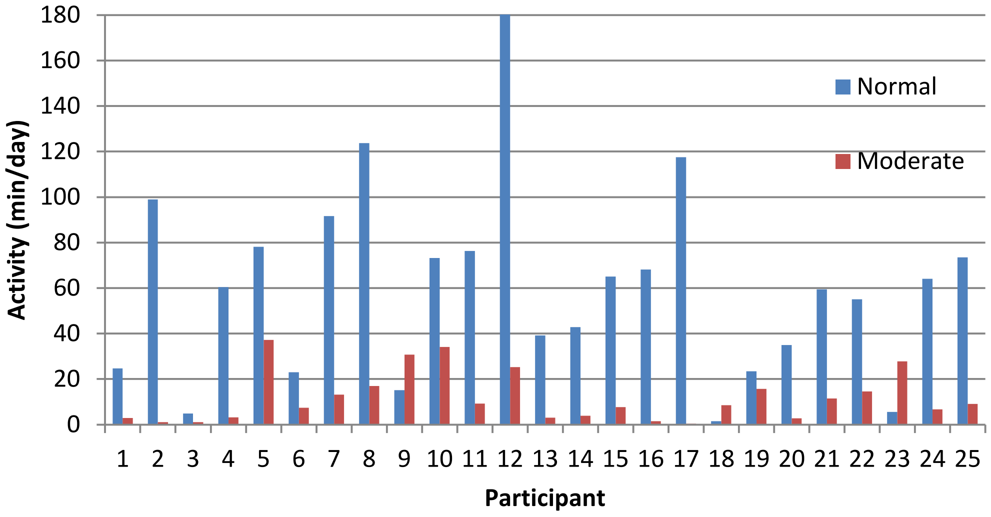

Figure 5. Activity duration (min/day) for normal and moderate thresholds for individual participants.

Three examples of a single day of activity (9000 epochs = 12.5 hours) are illustrated in Figures 6 for a sedentary person (top panel), an active, non-exerciser (middle panel), and an active exerciser (bottom panel).

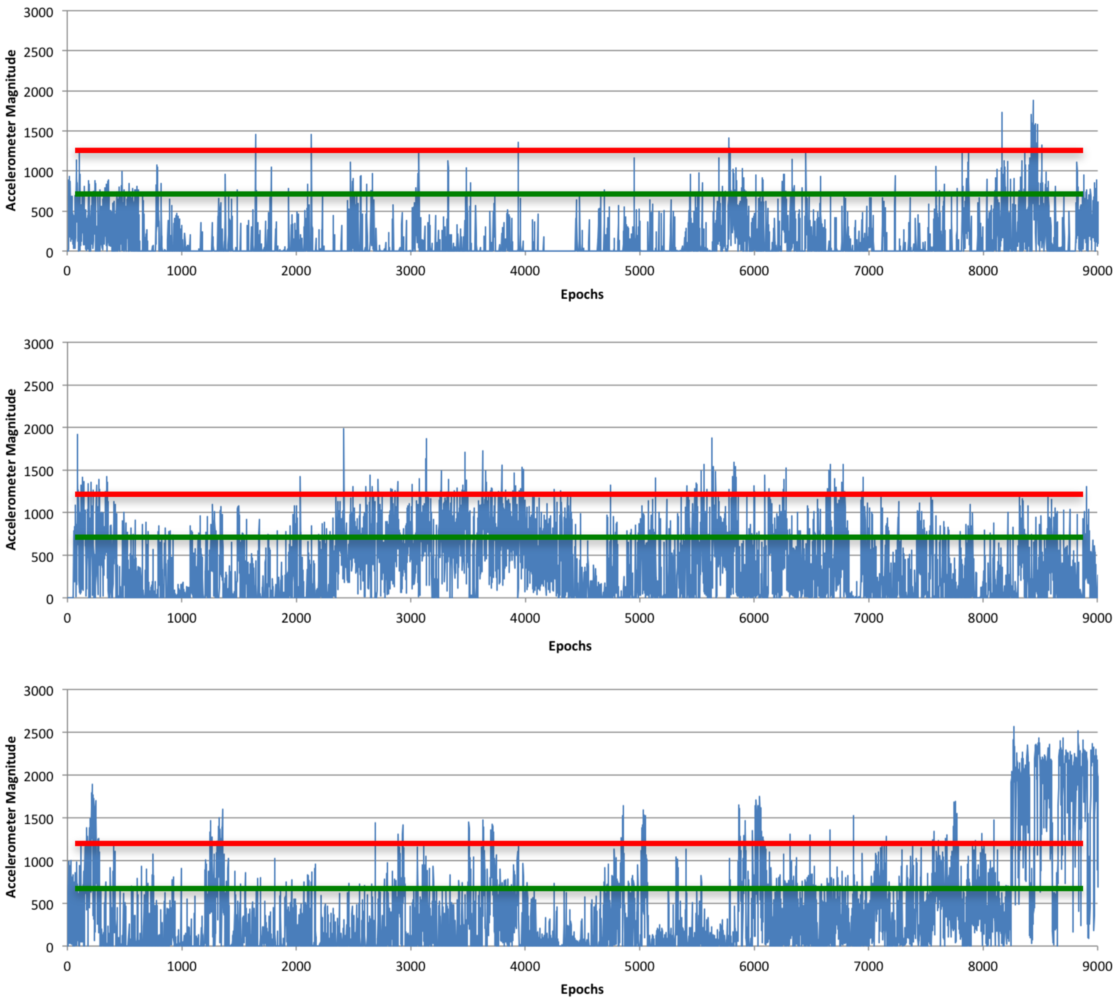

Figure 6. Typical daily physical activity patterns for three types of participants. The green line is the average normal threshold, and red line the average moderate threshold. Panel A: a sedentary person; Panel B: an active, non-exerciser; Panel C: an active exerciser.

Contiguous Activity

The results of the contiguous bout characterization are shown in Table 10. As expected there was an increase in average daily duration of 6.7 min/day (11.8 to 18.5) of moderate activity.

Table 10. Physical activity characterization based upon contiguous bouts.

	Mean	SD	Range
Bouts (#)	277	283	22-1208
Total duration (min)	115	114	3.5-440
Average duration (sec)	30.7	40.3	9.5-217.6
Maximum duration (sec)	462	359	40-1450
Daily duration (min/day)	18.5	17.77	0.5-62.98

Table 11 reports the number of bouts of various durations using the contiguous method. As expected, the average number of bouts decreased as the length of bouts increased.

Table 11. Characterization of number of contiguous bouts at specified bout duration ranges.

	Mean	SD	Range
5 – 30 Seconds	222.9	220.1	20-895
30 Seconds – 2 Minutes	49.5	61.3	2-288
2 – 10 Minutes	7.16	8.3	0-25
Over 10 minutes	1.24	3.0	0-14

Twenty three of the participants had 1 or more bouts lasting longer than 2 minutes. Only 7 were credited with bouts over 10 minutes. All of the latter reported planned exercise in their daily logs. Table 12 demonstrates the characteristics of the 2-10 minute bouts in participants who completed bout durations of 2-10mins (n=23), and similarly, the characteristics of bouts over 10 minutes in those participants completing bouts of this duration (n=7).

Table 12. Average number of bouts and bout durations for those participants with bouts over 2 minutes.

	Mean	SD	Range
Average Number of Bouts			
2 – 10 Minutes (n=23)	7.8	8.4	1-34
Over 10 minutes (n=7)	4.4	4.4	1-14
Average Bout Length (min)			
2 – 10 Minutes (n=23)	3.6	1.3	1.04-6.83
Over 10 minutes (n=7)	13.3	2.4	11.1-24.17

Figure 7 depicts the longest contiguous bout of MPA attained by each individual during the PA monitoring period. All but one participant <u>failed</u> to meet the SCI recommended guidelines of 20 minute moderate bouts.

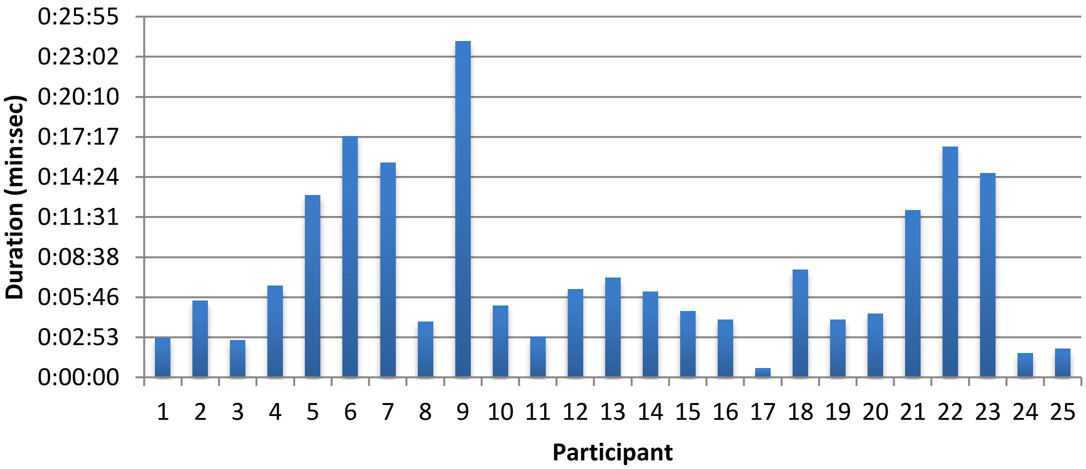

Figure 7. Longest bout duration of MPA achieved by each participant.

Despite numerous self-reported exercising individuals, 20 minutes of sustained moderate activity was rarely seen. Participants 5, 6, 7, 9, 12, 15, 18, 19, 21, 22, 23 each reported at least 1 planned exercise session in their daily logs. Given these results, it may be that individuals do not properly understand the concept of bouts or that the 20 minute bout length benchmark suggested in the SCI guidelines is too long, especially when considering that the able-bodied guidelines recommend minimum bout durations of 10 minutes at or above moderate.

Table 13 illustrates the participant's adherence to the spinal cord and able bodied physical activity guidelines. Achievement of the guideline's requirements are noted based on anatomical, functional and lifestyle classifications. The MPA duration requirement (SCI= 40 min/week, AB= 150 min/week) was frequently met (16 of 25 participants) but MPA duration with concurrent attainment of bout length (SCI= 20 minutes, AB= 10 minutes) was not (3 of 25). The SCILS average trended nicely with attainment of guideline requirements. There was one individual able to satisfy requirements for both SCI and able bodied guidelines .

Table 13. Adherence to guidelines for anatomical and functional classifications. The number of participants achieving MPA durations (top) and MPA durations plus bout length requirements (bottom).

		Did Not Meet	Meets SCI	Meets AB
Duration, +/- Bout length	**Total Participants**	**9**	**11 (16)**	**5**
	Anatomical	7 PARA, 2 TETRA	5 PARA, 6 TETRA	1 PARA, 4 TETRA
	Functional	6 TT, 3 TNT	2 TT, 5 TNT 4 NTNT	1 TT, 1 TNT, 3 NTNT
	SCILS Average	2.3	3.3	4.2
Duration And Bout Length	**Total Participants**	**22**	**1**	**3**
	Anatomical	12 PARA, 10 TETRA	1 TETRA	1 PARA, 2 TETRA
	Functional	8 TT, 8 TNT, 6 NTNT	1 TNT	1 TT, 1 TNT, 1NTNT
	SCILS Average	3.1	5	4

Sedentary Behavior

Sedentary time (hours/day) was calculated using arm and trunk acceleration data (Table 14). The combined daily average sedentary times using trunk & wrist data was predictably less than the individual wrist and trunk derived values.   It was interesting that the amount of sedentary time was not correlated to either NPA or MPA parameters.

Table 14. Sedentary time for the participants derived from trunk, wrist and trunk & wrist acceleration data.

	Mean	SD	Range
WRIST			
Daily Duration (hours/day)	7.06	1.45	3.54-9.97
TRUNK			
Daily Duration (hours/day)	8.42	2.33	0.8-11.0
WRIST & TRUNK			
Daily Duration (hours/day)	6.25	1.4	3.61-8.77

Differences in PA based on Classification Level

Participants were separated into the following groups for the purpose of examining the relationship to moderate PA.

1. Paraplegia versus Tetraplegia (2 levels)
2. Functional wheeling capacity based on motor function (3 levels)
3. Lifestyle rank (5 levels)

Table 15. Correlations of moderate PA with classification and lifestyle rank.

	R	P
Moderate PA vs Level		
Anatomic (Para/Tetra)	-.344	.092
Functional (NTNT/TNT/TT)	-.430	.032
Moderate PA vs Lifestyle Rank	.566	.003
Normal PA vs Lifestyle Rank	.466	.019

Simple correlation (Spearman's) revealed a negative relationship between level of injury and MPA (min/day). This finding was depicted by all three methods. The negative relationship, based on the individual thresholds, indicates that with increased motor function, there was a decrease in MPA.

Interestingly, separating the group by means of the lifestyle rank instead of by level, showed a moderate correlation to both moderate and normal physical activity levels. This perhaps indicates that factors other than level of injury are more relevant to amounts of physical activity than level of injury. Interestingly a moderate correlation between lifestyle rank and injury age (r=0.512, p=0.009) was observed.

Comparison to Published Standards or Guidelines

Participants were compared to published able-bodied and SCI-specific physical activity guidelines using one sample t-tests. Able bodied and SCI specific guidelines suggest 150 minutes and 40 minutes of moderate to vigorous physical activity a week respectively. Recomputed in daily activity this corresponds to 21.4 min/day for able bodied guidelines and 5.7 min/day for the SCI specific guidelines.

Using the *All Activity* method, participants averaged 11.8 minutes moderate physical activity per day. This indicates that the participants were on average exceeding the SCI thresholds by 6.1 minutes per day (11.8 to 5.7, p=0.01). When compared to able-bodied guidelines, the participants were below recommended guidelines by 9.6 minutes per day (11.8 to 21.4, p< 0.001). Using the *Contiguous* method, participants averaged 18.5 minutes per day. Indicating the participants were on average exceeding the SCI thresholds by a margin of 12.8 minutes per day (18.5 to 5.7, p=0.0014). Compared to able-bodied guidelines they were below by only 2.9 minutes per day (18.5 to 21.4). This difference was not statistically significant.

Sedentary times were compared to able-bodied norms (Colley et al., 2013). This accelerometer based study for a Statistics Canada health report on sedentary behavior in able-bodied persons indicated an average of 9.6 hours of sedentary time during waking hours. In the study by Colley, the accelerometers were affixed to the trunk with a threshold benchmark of <100 to depict sedentary behavior.

Combined sedentary time (arm and trunk) was 3.35 hours/day less than their able bodied counterparts (6.25 to 9.6, p< 0.001), 2.54 hours/day less when using arm sedentary time alone (7.06 to 9.6, p<0.001) and 1.18 hours less when comparing to trunk sedentary time (8.42 to 9.6, p= 0.019).

Physical Activity Inventory

Twenty-two participants completed and returned a detailed activity log indicating types of activities performed throughout the accelerometer wear time period. A word diagram was compiled (Figure 8) representing the most frequent words identified as activities by the participants. Most notable are the themes of exercise, ADL (cooking, cleaning, shopping) and sedentary activities (watching TV, deskwork). Home based exercise was evidently the most frequently used environment for exercise derived PA.

Figure 8. Word diagram of logged activities. The sizing of words is scaled relative to the frequency of occurrence of the term.

Table 18 shows the average amount of transfer performed by participants based upon anatomical and functional classifications. One participant (Tetra/NTNT) did not complete any manual transfers as a mechanical lift was utilized for all transfers.

Table 16. Transfers performed per day based upon classification level.

	Mean	SD	Range
Anatomical			
Para	7.96	4.83	3.2-17.5
Tetra	6.39	4.36	0-15.25
Functional			
NTNT	3.48	2.31	0 -7
TNT	9.48	3.87	5.6 - 16
TT	7.37	5.15	3.2 – 17.5

The difference in transfers was statistically significant between NTNT to TNT groups (p=0.0024), and a nearing statistical significance between NTNT to TT classifications (p=0.0581).

Activity Pattern Classification

Using each participant's objective data and activity logs, 5 main subcategories of activity patterns were noted. Three are depicted in this document (Refer to Figure 6), however all 5 subcategories may be depicted upon visual inspection of a resultant acceleration graph of a typical day for individuals in each category.

1. Sedentary: ≤ 5 % NPA **AND** > 55% sedentary **AND** ≤ 0.005% MPA **AND** No reported exercise (Figure 6 – top panel).

2. ADL Active: > 5% NPA **AND** < 55% Sedentary **AND** No reported exercise (Figure 6 – middle panel).

3. Sedentary exercisers: ≤ 5 % NPA **OR** > 55% sedentary **AND** > 1% MPA (≈10mins/day) **AND** Reported exercise

4. Less Active Exercisers: > 5% NPA **OR** ≤ 40% sedentary **AND** > 1% MPA **AND** Reported Exercise (Figure 6 – bottom panel).

5. Active Exercisers: Above 5% NPA **AND** ≤ 40% sedentary **AND** > 1% MPA **AND** Reported Exercise

Table 16 depicts the physical activity patterns noted in the participants as well as the number of participants in each category and their functional and anatomical classifications.

Table 17. Activity Pattern Classifications and level categories.

Activity Patterns	Participants	Anatomical	Functional
Active Exercisers	2	1 Para	1NTNT
		1 Tetra	1TNT
Less Active Exercisers	5	3 Para	3 TNT
		2 Tetra	2TT
Sedentary Exercisers	4	1 Para	3 NTNT
		3 Tetra	1 TNT
ADL Active	10	5 Para	4NTNT
		5 Tetra	4TT
Sedentary	4	4 Para	2TNT
		3 Tetra	2TT

Table 17 provides a visual representation of the relationship of activity pattern classification to the SCILS classification. A Spearman's correlation between SCILS and activity pattern classification of r=0.600, p=0.002.

Table 18. Cross tabulation of SCILS to Activity Pattern

	PA Pattern						Total
SCILS		1	2	3	4	5	
	1	**1**	**1**	**0**	**0**	**0**	2
	2	**2**	**2**	**0**	**0**	**0**	4
	3	**1**	**3**	**4**	**2**	**0**	10
	4	**0**	**2**	**1**	**2**	**1**	6
	5	**0**	**1**	**0**	**1**	**1**	3
Total		4	9	5	5	2	25

Relationships Between PA and Questionnaires

There were no relationships of significance between NPA or MPA variables and the WUSPI, the PASIPD or the SCI ESES scores. Upon inspection of the PASIPD data, the participant with the highest score (65) was objectively assessed as having the lowest level of PA at any threshold. When the correlation was performed without this individual, the association between PASIPD and SCI-ESES approached significance (r=0.533, p=0.075). Interestingly, relationships to NPA and MPA did not achieve significance.

Discussion

This study was successful in the development of a very practical technique for assessment of physical activity with individually specific activity thresholds after spinal cord injury. This study represents the first study to assess the free-living activity patterns of people with spinal cord injury using manual wheelchairs. Comparison to SCI and able-bodied physical activity guidelines revealed that the group average exceeded the time allocation for moderate physical activity posted in the recent SCI guidelines, and was under the able-bodied recommendations. Interestingly, the SCI guidelines suggest bout durations of 20 minutes, and the able bodied guidelines a duration of 10 minutes. Very few of the participants reached these goals.

The data derived in this study utilized advanced accelerometry techniques and analysis overcoming numerous limitations identified in previous studies. First, the accelerometry utilized two small accelerometers, one placed on the dominant wrist and one around the trunk, both were tolerated very well by the participants. The recent study by (Learmonth et al., 2015) illustrates no significant differences in acceleration between right and left arms, which further supports the selection of one arm used in this study. This is further supported by a number of other sources (Conger, Scott, Fitzhugh, Thompson, & Bassett, 2015; García-Massó et al., 2013; Nightingale, Walhim, Thompson, & Bilzon, 2014). The need for a trunk accelerometer may not be needed for PA assessment, but its use for sedentary time prediction may be required. Further study is needed.

Second, we used triaxial accelerometers set to sample at a high frequency (100 Hz) to detect all wheeling related movement. As well, the epoch length was chosen to be very brief (5 s), as compared to numerous studies with much longer epoch durations (typically 30 s or population studies which use 60 s). The problem with longer durations is that they essentially time average the activity, which disallows the detection of actual activity levels of participants. The brief epoch duration allowed us to build from the "bottom up" the actual activity patterns of the participants. This short epoch length revealed that the participants utilized bursts of activity that rarely exceeded a few minutes in duration (average bout was 30 s), even for the "exercising" participants. The implications of this finding, is that a very specific description of what a bout of activity means is required that the general population understands, and this would apply to the able- bodied population as well. However, some sources have recently indicated that any moderate activity independent of duration is beneficial (Fan et al., 2013; Glazer et al., 2013), suggesting that bouts of PA of less than 10 minutes may favorably influence cardio-metabolic risk, and obesity prevention.

Third, we successfully developed a moderate threshold detection method that was easy to implement, as well as providing a threshold that was relative to the general fitness, or physical capacity, of the participant. We achieved this by using a perceived exertion threshold specified by ACSM, which would provide an individual specific exertion level dependent on the wheeling ability of the person. This is distinct and at face value superior to the use of an absolute method of threshold selection, even if it is specific to SCI participants. Absolute thresholds suffer from creating systematic bias. Many of the previous SCI studies actually used the absolute able-bodied thresholds, which clearly would violate face validity when applied to SCI. In a recent study (Learmonth et al., 2015) which employed oxygen consumption, the authors still used an absolute metabolic threshold (3 METS) which essentially equates all participants' physical capacity to a lowest common denominator – certainly inappropriate for any person with higher levels of fitness. Interestingly, had the study performed a graded exercise test to maximum or even used a two point extrapolation method for prediction of maximum (given a sympathetically connected heart), then the authors could have provided relative thresholds for the participants scaled to maximum oxygen consumption. As such, this study suggested the use of a fixed accelerometer "cut point" of about 3600 (for 30 second epochs). With consideration to epoch length, this roughly equates to half the average moderate intensity accelerometer output found using our personalized thresholds using BPE.

A simple graded pace test using perceived exertion was readily implemented in this study, and could easily be used in future studies. This perceived exertion method also avoids the obvious limitations of heart rate in the sub-set of participants with autonomic nervous system denervation. The use of RPE or BPE has become a valid tool in the monitoring of intensity in exercise training programs. It has been shown to correlate well with blood lactate, heart rate, pulmonary ventilation, and the VO2 responses to exercise (Pollock et al., 1998) and has been validated by multiple sources for use in individuals with SCI (Grange, Bougenot, Groslambert, Tordi, Rouillon, 2002; Paulson, Bishop, Leicht, Goosey-Tolfrey 2013; Goosey-Tolfrey, Paulson, Tolfrey, Eston, 2014). It also avoids the need for costly, and relatively cumbersome use of oxygen consumption techniques. Finally, this method could be used in the able bodied population, as the studies to date still employ an absolute threshold methodology.

The use of a graded pace test, as was employed in this study, is supported by the recent Learmonth et al study(2015) which related accelerometer output and its association with energy expenditure in 24 individuals with various disabilities, 15 of which had a SCI.   Oxygen consumption (VO2) was measured while participants wheeled at various set speeds on a wheelchair treadmill. The study utilized Actigraph GT3X accelerometers with 30 second epochs and 30 Hz sampling. The study demonstrated very strong linear correlation between wrist worn accelerations (bilaterally) and V02, and speed. These results are consistent with the strong relationships between speed and acceleration observed in this study. They also demonstrated that steady state of individuals at each intensity stage was achieved within approximately 120 seconds. The achievement of steady state derived from oxygen consumption in this time period is highly consistent with the average duration (3 minutes 20 seconds) required to meet the perceived exertion level corresponding to moderate in this study. This may reflect that the participants in this study were using a "metabolic" perception when indicating their exertion level, which reinforces the use of the method used in this study.

Evidently, the advancement of technology in recent years and modified methodologies has allowed for more accurate assessment of PA, as a number of very recent articles have also confirmed triaxial, wrist worn accelerometers with sampling rates > 30Hz and epochs < 30 seconds a reliable measure of VO2 in manual wheelchair users. (Conger et al., 2015; García-Massó et al., 2013; Kiuchi et al., 2014; Nightingale et al., 2014). These studies have shown, that for individuals of various disabilities, using manual wheelchairs, both V02 and speed are strongly related to output from a wrist worn accelerometer. Along with the results from this study, this strongly supports the use of a single accelerometer mounted on the wrist for assessment of PA in manual wheelchair users.

Classification of SCI in the literature is traditionally reported based on anatomic lesion level, that is paraplegia or tetraplegia. This classification carries with it the implication that individuals with paraplegia are similar in function to each other and distinct from those with tetraplegia, and vice-versa. We make the observation in this study that this conventional classification does not adequately discriminate the functional and physical capacity differences in individuals with SCI. The classification scheme depicted in this study is based on key motor levels corresponding to functional characteristics related to proficiency in wheeling. This scale was derived as a result of the experience of the author as a ward based physiotherapist in the SCI unit. As such, numerous relationships were revealed with this functional classification method as compared to a classic anatomical one. Further study of this method is recommended, as well, in future, it may be that activity specific recommendations are provided based upon this classification as opposed to SCI overall, or classic anatomic classification. There is also a neurological classification based upon completeness of lesion (ASIA) which is not normally utilized for differentiation in health outcomes. An exploration of this classification for prediction of PA and sedentary behavior would also be useful.

The SCILS assessment was a recall assessment performed by a trained physiotherapist with knowledge of the participants and the field of SCI. The scale was well correlated with the normal and moderate PA levels. Because this classification was done without consideration to level of injury, but in fact to lifestyle, we conclude that in general, it is not the level that is critical in achieving higher levels of PA but rather the choices that one makes regarding integrating and prioritizing PA in one's life. The logged activities reported by the participants were very consistent with the activity profiles revealed in the objective PA data, resulting in the ability to classify the participants into different categories of lifestyle – active exercisers, less active exercisers, sedentary exercisers, ADL active and sedentary. These classifications were performed post-hoc and jive closely with the intake assessment of lifestyle performed by the therapist using a 5 level lifestyle classification.

Surprisingly, and opposite to conventional thinking, there was a moderate negative correlation between the amount of moderate activity seen in participants and level of injury using either classification method. There are two primary factors thought to be at play to explain this negative relationship. First, the SCILS assessment scale revealed very good correlation to the amount of MVPA, indicating that a lifestyle effect was a substantial contributing factor to the PA levels, over riding that of the anatomical level of lesion. Secondly, when the individual moderate trials were analyzed, the difference between accelerometer output from normal to moderate paces was progressively larger with increased functional capacity of the participants. The accelerometer output average difference from normal to moderate was 213 for the NTNT group, 561 for the TNT group and 847 for the TT group. NTNT compared to TNT and TT groups was significantly different, $p=0.02$ and $p< 0.001$ respectively. TT to TNT was nearly statistically significant, $p=0.06$, likely a type 2 error. These numbers indicate that higher level injuries with lower functional capacity have a lower absolute MVPA threshold and operate closer to moderate during normal daily activities, and may cross moderate thresholds during activities of daily living such as wheeling for transportation. Lower injuries (higher function), have a larger "below moderate threshold" capacity and a higher absolute MVPA threshold. Reaching moderate intensities requires a more deliberate effort such as planned exercise with necessary equipment or facilities. Given this, the benefits of MVPA may be proportional to both level and completeness (ASIA score) of injury. However, perhaps the more frequent but lower intensity MVPA seen in many of the higher level injuries in this study is also beneficial from a health perspective. More research is required, but clearly these are questions that are relevant to any modifications to be made to the SCI exercise guidelines, and indicate that a single guideline approach to the entire spectrum of SCI may not be suitable.

Further to the above, a recent randomized controlled trial (Totosy de Zepetnek, Pelletier, Hicks, MacDonald, 2015) studying the health benefits (distinct from fitness benefits) associated with a 16 week trial of the SCI guidelines concluded that the PA dosage as prescribed in the guidelines was insufficient to improve many markers of cardiovascular disease risk. The authors indicate that modifications to the guidelines are likely required to improve the potential for cardiovascular protective benefits.

In the 2011 ACSM exercise guidelines, sedentary behavior is considered "Distinct from physical activity and has been shown to be a health risk in itself. Meeting the guidelines for physical activity does not make up for a sedentary lifestyle". Remarkably, sedentary time on average was less in this study population, as compared to the able-bodied sedentary rates in Canada (Colley et al 2011). Although there were some differences in methodology in ascertaining the sedentary rates, this could indicate a higher frequency of lower intensity movement in manual wheelchair users, perhaps due to many tasks (including relatively low level activities) requiring frequent maneuvering in a manual chair. Frequent relatively stationary movement is also commonly seen in manual wheelchair users such as stationary wheelies, or forward/backward reciprocal movements which may result in accumulating more low level PA in manual wheelchair users (akin to standing or mulling about), resulting in decreased true sedentary time. Since it is noted that in the able-bodied population, sedentary time is an independent predictor of disease, it could be suggested that the SCI community is somewhat protected from this risk component. Clearly this requires further exploration and ideally an objective PA analysis with concurrent video analysis of activity in a free living environment would be required to understand the true sedentary behaviors in this population.

Not surprisingly, there were no significant relationships found between self- reported PA (PASIPD) and active minutes at normal threshold or above (r= -0.156, NS). This was partly due to overrepresentation of PA levels common to self- reports (Colley et al., 2011; Troiano et al., 2008). Interestingly, however, there was a tendency of the lower functioning groups (NTNT, Tetra) to trend towards underestimating PA when compared to the higher functioning (TT, TNT, Para) groups who were more likely to overestimate activity levels. This may be attributable to moderate PA attainment unaccounted for during daily tasks for the lower functioning groups and poor perception or recollection of true moderate intensity threshold maintenance in the higher function groups. Two other studies have shown the lack of relationship between PA perception and actual PA measured by accelerometer or doubly labeled water techniques (R. a Tanhoffer et al., 2012; van den Berg-Emons et al., 2011). It has also been suggested that self-report measures may poorly quantify the lower end of the PA continuum (Shephard, 2003). Nonetheless, it is interesting to contemplate the PA dysfunctional level of participants as a form of classification, whereby people with a large perceptual mismatch may be a greater risk than those with a reasonable approximation of their actual PA level. Further study is required.

Similarly, significant findings between PA and ESES or WUSPI were also not apparent. Based on reference data in the literature our group had very low shoulder pain complaints. Whether this was a representative sample regarding amounts of shoulder pain is debatable, however perhaps the consistent low levels pain reports rendered the association of shoulder pain/disability with PA negligible within our sample. As discussed in the results, and not surprisingly, the ESES scores in our sample were lower than those of Paralympic athletes. With the larger score implying more self-efficacy towards exercise, the scores of 35.87 to 31.7 represent a 10.4% difference between groups. As it was compared to high level athletes, our group could perhaps be considered a relatively confident group as it relates to their ability to exercise. Nonetheless, some were very sedentary individuals. Conceivably, this may indicate that even in the SCI population, the ability to partake in regular PA and exercise are not perceived to be out of one's control and perhaps related more to choice than circumstance. Interestingly, the use of the scales in relation to objective PA measures could be used to document perceptual mismatches, PA dysfunction, where the person believes they are sufficiently active but in fact are not.

Limitations

One limitation is that wheeling was the only activity that was used to create the activity thresholds. Certainly, over ground wheeling with cornering, as was used in this study, is a primary means of mobility in this population, however, there are still activities such as arm ergometry and ADLs with upper limb requirements only, where these thresholds may or may not be suitable.

Secondly, despite being a well-accepted form of PA measurement in the able bodied community as well as an emerging form in those with disabilities, there are some general limitations to accelerometer PA monitoring. Accelerometers would tend to underestimate activity when resistance or load is added to the monitored limbs (ergometer, weights) or body (carrying a backpack) or the surface over which the movement is occurring (grass or sand). Accelerations may be decreased in such situations despite the potential for effort and metabolic cost to be greater.

Third, the study sample size was relatively small and certainly there were situations where we likely committed Type II errors as there were quite a few p values approaching the level of significance. Interestingly, when the sample size is compared to SCI specific literature with measurements, this study had a sample size equal to or greater than most.

This study evaluated the free living behaviors in the spring, summer and fall months of Manitoba, thereby avoiding the winter climate. The generalizability of these results to snow covered and cold climates is limited. Although, outdoor mobility is severely limited for wheelchair users in Manitoba, this does not necessarily indicate a lower activity level in the winter months due to the possibility of substitution with indoor activity.

Conclusion

This study was successful in using accelerometry to evaluate the free living activity levels of manual wheelchair users with SCI. A new practical technique was developed and employed, using perceived exertion to create activity thresholds relative to the abilities of each participant. A promising new classification scheme was developed based upon musculature required for wheelchair propulsion, and revealed improvements over the traditional anatomic classification.

Based on the objective PA data compiled in this study, SCI individuals are exceeding the SCI physical activity guidelines of 40 minutes/week, but failing to meet those set for the able-bodied population of 150 minutes/week. Bout lengths of 10 - 20 minutes are rare and incrementally less common to the point of near non-existence at the 20 minute mark. More research is required to establish a dose-response relationship between PA characteristics and health in this population, but given individuals are already exceeding the SCI specific guidelines in terms of accumulated minutes, many without consistent exercise regimes, as well as conclusive literature indicating health benefits for those with SCI who attain a minimum 150 minute/week of moderate activity threshold, this study would support the use of able bodied guidelines for the SCI community.

Clinical Impact

This study provides detailed assessment of the activity patterns of manual wheelchair users which can be used to develop rehabilitation and fitness programming specific to the population. This study will add to past and future studies in the further refinement of physical activity guidelines for individuals with SCI.

The method used for PA assessment in this study is practical and readily employable in various rehabilitation settings especially since we can limit assessment to the use on one accelerometer mounted on the wrist. Applications could include personal PA assessments for those with SCI for the purposes of PA level assessment, feedback regarding the attainment of benchmarked PA goals, encouraging compliance in fitness and weight loss, and diabetic management programming.

Future Studies

Future studies should further examine the utility of functional level categorization as it appears to be more suited to lifestyle interventional approaches in this population.

The strong relationship of wrist acceleration to speed shown in this study and others, and the strong relationship to oxygen consumption (Conger et al., 2015; García-Massó et al., 2013; Kiuchi et al., 2014; Nightingale et al., 2014) indicates that a wheelchair speed or wrist acceleration method could be developed to derive energy expenditure from wheeling. A subsequent analysis of this data could be performed as a preliminary assessment. Ultimately a measurement of speed (GPS), wrist acceleration along with portable oxygen consumption in a free living environment (outdoor track) would verify the ability to derive wheeling related energy expenditure.

We feel that the perceived exertion method of establishing relative thresholds is suitable for this population, and is quite practical to implement. The relationship of the wheeling specific thresholds to other common activities needs to be established, such as arm ergometry, and other purely upper limb activities like household chores.

Future studies should examine the sedentary behaviors in people that use manual wheelchairs, as this study revealed a lower level of sedentary time compared to able-bodied which at first glance was surprising, but upon consideration of the low level PA required to live in a chair, the results were deemed appropriate. However, future studies need to verify these findings with observational studies perhaps using day long videography.

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