Cardiovascular stress during inpatient spinal cord injury rehabilitation

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Abstract

Background—Physical activity that challenges cardiorespiratory function is beneficial for individuals recovering following a spinal cord injury (SCI) from a neurological, musculoskeletal, and cardiovascular perspective. However, it is not known how much conventional clinical rehabilitation challenges cardiorespiratory function.

Objectives—1) To measure the amount of a) cardiovascular stress, b) self-reported physical activity and c) accelerometry-measured physical activity by individuals with SCI during physical

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Device Status: Dr. Zbogor has nothing to disclose.

Financial Disclosure: Dr. Zbogor has nothing to disclose.

therapy (PT) and occupational therapy (OT) and, 2) to investigate the relationship between these measures.

Design—Observational study.

Setting—Two inpatient SCI rehabilitation centres.

Subjects—SCI patients (n=87) were recruited from consecutive admissions to rehabilitation.

Methods—Heart rate (HR) was recorded by a Holter monitor, while physical activity was captured by self-report (PARA-SCI questionnaire) and real-time wrist accelerometry during a total 334 PT and OT inpatient sessions. Differences between individuals with paraplegia and tetraplegia were assessed via Mann-Whitney U tests. Spearman correlations were used to explore the relationship between measurements of physical activity and HR.

Results—Time spent at a HR within a cardiovascular training zone (40% heart rate reserve) was low and did not exceed a median 5 minutes. In contrast, individuals reported at least 60 minutes of higher intensity time during therapy. There was a low, but statistically significant correlation between all measures.

Conclusion—The cardiovascular stress incurred by individuals with SCI during inpatient PT and OT sessions is low and not sufficient to obtain a cardiovascular training effect to optimize their neurological, cardiovascular, or musculoskeletal health; this represents a lost opportunity to maximize rehabilitation. Self-reported minutes of higher intensity PA do not reflect actual time spent at higher intensity measured objectively via a HR monitor.

Keywords

Accelerometry; heart rate; occupational therapy; self-report; spinal cord injuries

Introduction

Cardiovascular disease is a leading cause of death in persons with spinal cord injury (SCI)^{1,2} and has a higher prevalence, earlier onset, and occurs at an accelerated rate after SCI compared to the general population.^{3,4} Exercise training in individuals with SCI has the potential to improve cardiovascular health and alleviate numerous medical complications associated with being physically inactive^{5–8} which underscores the importance of participating in an exercise program after SCI.⁹

Early after SCI, a prolonged amount of bed rest contributes to very low levels of physical activity and cardiovascular fitness.⁹ Physical capacity, defined as the combined ability of the cardiovascular and musculoskeletal systems to perform at a given level of activity, is extremely low in individuals with acute SCI¹⁰ and improves over time,¹¹ likely due to a number of factors including improvements in neurological status, recuperation from trauma, and training effects of the rehabilitation program. There is also increasing evidence that aerobic activity may facilitate neuroplasticity;¹² for example, Leech and Hornby found that increases in serum brain-derived neurotrophic factor were greater with higher intensity exercise in individuals with incomplete SCI.¹³ However, little information exists on how

much, if at all, conventional rehabilitation protocols (that typically include PT and OT to achieve goals related to functional recovery) in SCI challenge cardiovascular fitness.

It is well known that physical activity of a sufficiently high intensity confers cardiovascular benefits not obtained by lighter activity,¹⁴ and the importance of this fact is accounted for in physical activity recommendations by various organizations. For both able-bodied individuals¹⁵ and individuals with disability¹⁶ it is recommended that, throughout the week, one obtains at least 150 minutes of moderate-intensity, 75 minutes of vigorous-intensity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity in bouts of no less than 10 minutes. More recently, SCI specific guidelines suggest individuals accrue, at a minimum, two bouts of 20 minutes of moderate to vigorous intensity aerobic activity per week.¹⁷ Unfortunately it appears most individuals with chronic SCI do not meet these guidelines at one year following discharge from rehabilitation.¹⁸ Indeed, individuals with SCI have been shown to have the lowest physical activity levels when compared to persons with different chronic diseases.¹⁸ One might assume that the cardiovascular stress experienced after SCI injury would be equally low. However, one study¹⁹ assessed eight individuals with paraplegia and three with tetraplegia over a typical rehabilitation day and concluded that there was sufficient strain to improve aerobic fitness, but there was heterogeneity of the subjects (participants with paraplegia/tetraplegia/walking ability were combined), and subsequently large variability in the data. Clearly more research is required.

The primary goals of physical therapy (PT) and occupational therapy (OT) include motor and functional recovery, however SCI rehabilitation also has opportunity to reverse the cycle of reduced cardiovascular fitness that limits functioning.¹¹ Cardiovascular stress can improve physical capacity, and in turn contribute to better performance of activities of daily living (ADLs).¹¹ Furthermore, awareness of the demands placed on the cardiovascular system by rehabilitation interventions may play a role in both patient safety and for optimizing activity prescription.

Non-invasive, low-cost options of physical activity measurement include accelerometry and self-report. Wrist accelerometry is a valid indicator of physical activity for wheelchair-users in laboratory and community-dwelling environments²⁰ and self-report is the most widely used method for measuring physical activity.²¹ While the subjective nature of self-reported physical activity renders it prone to recall error and social desirability bias²² it does offer information not available from objective measures. For example, accelerometry may measure when and how much an individual moves the upper limbs, while self-report captures information on how difficult this activity was and the purpose of the activity (e.g., leisure, activity of daily living). Despite increasing emphasis on aerobic activity for neuroplastic recovery as well as for cardiovascular fitness, it is not yet known whether accelerometry and self-report physical activity measures reflect the actual intensity of aerobic activity engaged in by patients in rehabilitation.

Therefore, the purpose of this study was 1) to measure the amount of cardiovascular stress experienced by individuals with SCI during inpatient rehabilitation, and 2) to investigate the relationship between this cardiovascular stress and other measures of physical activity (self-reported physical activity, wrist accelerometry) during inpatient rehabilitation. It was

hypothesized that the amount of time spent in PT and OT at an intensity sufficient to achieve a cardiovascular training effect ($\geq 40\%$ heart rate reserve (HRR)) would be low (not meeting the recommendations of SCI physical activity guidelines). It was expected that the different measures would be correlated since they measure constructs of physical activity.

Research Methods

Participants

Participants were recruited as part of a larger study examining consecutive traumatic and non-traumatic SCI admissions to inpatient subacute care at two stand-alone rehabilitation centres.²³ Non-traumatic SCI was defined as SCI resulting from spinal stenosis, tumour, ischemia, transverse myelitis, and infection.²⁴ All adults with a new SCI of any aetiology, severity, or level, who were admitted for SCI rehabilitation were eligible. In addition, the admission criteria for Canadian rehabilitation hospitals require patients to be able to tolerate 2–3 hours of rehabilitation therapy daily. Patients were excluded if they were a readmission, had a traumatic brain injury that notably affected the content and delivery of therapy (as determined by their health care team), if consent could not be obtained within the first week of admission, or if their length of stay in rehabilitation was projected to be less than four weeks as it precluded the ability to potentially progress their rehabilitation activities prior to discharge.

Approval for this study was obtained from the university and hospital ethics boards and all participants provided informed consent prior to measurements.

Data collection protocol

Data were collected over two weekdays in the second-last week of inpatient rehabilitation stay as it was expected that at this point in time participants would be near their peak inpatient recovery and would be able to maximally participate in rehabilitation activities. On each day a research assistant met the participant in their room in the morning where they were fitted with a Holter monitor and accelerometer(s). In the evening of each day, when participants had returned to bed, the research assistant returned to collect the Holter monitor and accelerometer(s) and administer the self-report physical activity questionnaire.

On each measurement day, research assistants were present for all PT and OT sessions and collected information on the start, end, and content, of sessions. Therapeutic time was defined as any activity undertaken by the therapist with the goal of treating the patient and included physical rehabilitation, education, assessments, and interventions designed to improve functional independence. Therapy sessions were included for analysis if $\geq 50\%$ of therapeutic time was comprised of physical rehabilitation. Sessions were excluded if more than 50% of therapeutic time was comprised of assessments, equipment fitting, or non-motor issues. If a session did not occur on a scheduled day or did not meet the criteria indicated above, an additional day was collected if it occurred during the 1-week data collection window. Thus, the study criteria allowed for the collection therapy sessions under a best-case scenario.

Demographic information was collected for age, sex, aetiology (traumatic or nontraumatic), American Spinal Injury Association Impairment Scale (AIS) grade,²⁵ β -blocker status, and length of stay in acute care and rehabilitation.

Physical activity measures

Holter monitoring^a was used to record and store continuous heart rate data. This device provides 3-channel ECG and consists of five electrodes on the chest and abdomen attached via leads to a small recorder that was worn around the waist, around the neck, or attached to the wheelchair depending on participant preference.

The Physical Activity Recall Assessment for People with SCI (PARA-SCI)²⁶ is a self-report questionnaire administered via a semi-structured interview and is found valid and reliable where community dwelling individuals with SCI recall their activity at the end of a 3 day period.²⁷ To minimize recall issues, the PARA-SCI was modified where participants were asked to recall their activity at the end of the day, and this was done over two separate days within a week. The PARA-SCI measures the amount of physical activity individuals with SCI accumulate over a day and provides an estimate of time (in minutes) spent participating in mild, moderate and heavy intensity physical activities, as well as activities with no intensity (“nothing at all”).

Actical accelerometers^b worn on the dominant wrist like a wristwatch quantified the amount and intensity of upper extremity activity using total activity kilocounts. The Actical accelerometer is a small device with a frequency range of 0.3–3 Hz. The unit is sensitive to 0.05–2.0 G-force in three planes and samples data at 32 Hz.

Data Analyses

Heart rate data for all therapy sessions was downloaded to a computer. The ECG waveform was investigated and any artefacts were corrected. Data were entered into MATLAB (MathWorks Inc, Natick, MA USA) where the waveform was converted to beat-by-beat HR by identifying RR-intervals across the analysis period. The HR data was re-sampled to a time series with a sampling frequency of 10Hz, such that the HR could be determined at any point throughout the therapy sessions. Maximal HR was calculated using the formula $HR_{max} = 208 - 0.7 \times \text{age}$.²⁸ A modified formula was used for those individuals on β -blocker medications: $HR_{max} = 164 - 0.72 \times \text{age}$.²⁹ Resting HR was obtained during a 10-minute period of supine rest on a separate day. Heart rates were binned into deciles ranging from 0 to 100% of predicted maximal HR, calculated using the Heart Rate Reserve (HRR) method: $HR_{target} = [\% \text{ intensity } (HR_{max} - HR_{rest})] + HR_{rest}$ and the time spent in each decile was obtained. The time in each decile was averaged over the two observation days for both PT and OT sessions. The number of minutes spent at 40% HRR was calculated and used to represent the time spent in a cardiovascular training zone.³⁰ Participants who met SCI specific physical activity guidelines¹⁷ of 20 minutes within this intensity were noted and

^aHolter monitoring: Nasiff CardioCard® PC Based Holter Monitoring ECG System, Nasiff Associates Inc., 841 County Route 37, Suite 1, Central Square, New York 13036, USA, <https://nasiff.com/holter.html>

^bAccelerometers: Actical, Bio-Lynx Scientific Equipment Inc., PO Box 8, Station Ahuntsic, Montreal, Quebec H3L 3N5, Canada, <http://www.actigraphy.com/solutions/actical>

the characteristics of individuals were reported. As per American College of Sports Medicine guidelines, moderate intensity was defined as 40–59% HRR and vigorous intensity as 60–89% HRR.³⁰

The accelerometer record was rectified and integrated over 15 second intervals as activity counts and averaged over the two observation days for both PT and OT. Higher activity counts may indicate longer use, more movement, and/or greater intensity of movement.

For the purpose of this study, only PARA-SCI minutes occurring during observed PT and OT sessions were reported, and averaged over the two observations days. The four intensities of the PARA-SCI were binned into two categories: ‘lower intensity’ comprising nothing or mild intensity and ‘higher intensity’ comprising moderate or heavy intensity. Moderate and heavy physical activity are intensities recommended by exercise guidelines for accruing health benefits.^{17,30}

Sub-analyses to compare paraplegia and tetraplegia values using Mann-Whitney U tests were performed for HR parameters (resting, mean, and peak HR, and time in cardiovascular training zone), self-reported physical activity, and wrist accelerometry. The Z value and effect size ($r(\text{abs})=Z/\sqrt{n}$) (0.1=small effect, 0.3=moderate effect, 0.5=large effect)³¹ are documented.

To relate the three measures of activity collected during therapy time, Spearman rho correlations were performed between minutes where HR was in the cardiovascular training zone, self-reported minutes of physical activity at a higher intensity, and accelerometry measured activity kilocounts.

A minimum sample size of 28 was calculated *a priori* using G*Power version 3.1 (available at <http://www.gpower.hhu.de>) using a moderate effect size ($d=0.5$), an alpha of 0.05, and power of 0.80, for a Mann-Whitney U test comparing two dependent means with a directional hypothesis.

Alpha was set at $p < 0.05$. Statistical analyses were performed using SPSS 20 (SPSS Inc, Chicago, IL USA).

Results

Recruitment to the study is displayed in Figure 1 and demographic information for participants in this study is found in Table 1. Demographic variables for the excluded 26 participants were not notably different from those included for analyses. Thirty-six participants were ambulatory at discharge. Observations of 215 PT sessions and 119 OT sessions were undertaken. On occasion more than one PT or OT session occurred on an observation day. The number of valid OT sessions was less than PT, as many OT sessions did not involve physical activity, and thus, were not included in the final analyses.

Heart rate during physical and occupational therapy

Heart rate variables are reported in Table 2. The resting HR and median HR during therapy was approximately 10 beats/min higher in individuals with paraplegia than individuals with

tetraplegia. During PT sessions, the median time spent at an intensity $\geq 40\%$ HRR was 2.4 minutes and in OT sessions it was 0.9 minutes (Table 2). For both individuals with paraplegia and tetraplegia, 80 to 90% of OT or PT sessions consisted of activity below 40% HRR. Over half of all therapy time was spent in activity less than 20% HRR except in the case of individuals with paraplegia in PT where 46% of time was spent at an intensity between 20–39% HRR.

Self-reported physical activity during physical and occupational therapy

The majority of self-reported physical activity of a higher intensity occurred during PT sessions (Table 2). Self-reported minutes of lower and higher intensity activity were similar between individuals with paraplegia and tetraplegia with both groups reporting ≈ 60 minutes of higher intensity activity during therapy.

Accelerometry kilocounts during physical and occupational therapy

Wrist accelerometry kilocounts in PT were over three times that of OT. Individuals with paraplegia accrued more kilocounts (26 kilocounts) than individuals with tetraplegia (17 kilocounts), $p=0.027$ (Table 2).

Correlation between heart rate, self-reported physical activity, and wrist accelerometry

There were low³² ($\rho < 0.3$) but statistically significant correlations between minutes of HR at intensity $\geq 40\%$ HRR, higher intensity self-reported physical activity, and wrist accelerometry (Table 3).

Activities engaged in by those who met physical activity guidelines

Only 11 of the 87 individuals met or exceeded 20 minutes of time at an intensity of at least 40% HRR in PT and/or OT (Table 4). These individuals had low injury severity (AIS D) or a low lesion level. Observational logs of their therapy sessions confirmed higher intensity activities including walking (with/without various supports), leg exercises in standing, jumping, leg cycle ergometry, shuttle leg press for high repetitions, and ADLs including dressing (seated), repetitive transfers and bed mobility movements.

Discussion

Measures of heart rate and physical activity during physical and occupational therapy

For HR, current findings indicate that individuals with SCI are spending very little time during PT and OT sessions at the moderate to vigorous intensities required for conferring cardiovascular benefits. The time spent in the training zone during PT or OT is a quarter of that recommended by SCI specific aerobic guidelines.¹⁷ Only 11 of 87 individuals (13%) met the required guidelines of 20 minutes at moderate to vigorous intensity. In fact, over three quarters of time in OT and PT sessions was spent at a HR under 40% HRR, with the largest portion under 20% HRR. These findings are a best-case scenario, as only active therapy sessions were included, β -blocker status was accounted for, and consecutive minutes at the target HR were not required. Results indicate that patients may not be receiving sufficiently intense cardiovascular activity to optimize their neurological, cardiovascular, or

musculoskeletal health; this represents a lost opportunity to maximize rehabilitation. It is possible however, that therapists avoided aerobic activity as they perceived that such activity may not be safe for their SCI patients, or alternatively, they did not believe that aerobic activity sufficiently benefited the recovery or health of their patients compared to the need for other treatments.

In contrast to the small amount of cardiovascular activity measured via HR, self-reported physical activity shows that participants perceived that their PT sessions were physically challenging (55 higher intensity minutes). This disparity was corroborated by the very low correlation (0.23) between the two measures. A number of factors may contribute to this mismatch. High intensity measured by the PARA-SCI is derived from perceptions of multiple physical domains (e.g., breathing hard, burning muscles, warm or sweaty skin). A greater reliance on the arms which have relatively small mass compared to the legs may result in a perception of high physical effort, but is not necessarily cardiovascular in nature.^{5,33} In addition, many participants are extremely deconditioned following their acute stay and even a low intensity exercise may be perceived as challenging. Further, there is recall bias, as well as potential for social desirability bias where individuals tend to overrate their physical activity participation during recall questionnaires.³⁴ Lastly, the PARA-SCI rating is representative of the entire therapy session and not as refined as beat-by-beat HR. Thus, self-report may not be an appropriate tool for gauging time spent within the cardiovascular training zone.

Wrist accelerometry also had a very low correlation with cardiovascular activity. While one might expect wheeling to result in both high accelerometry counts and high HR, there are many other therapeutic activities that do not have this correspondence that likely contributed to this low correlation. For example, a repetitive reach and grasp task to improve fine motor skills would accumulate large accelerometry counts but would not be challenging to the cardiovascular system.

The SCIRehab project, a multi-centre account of numerous facets of SCI rehabilitation in the United States shows that in PT, about half of patients are engaging in endurance activities (e.g. ergometry, walking, using gym machines³⁵) and these patients average 7.5 ± 13.3 minutes of time in these activities³⁶ while no endurance activities occurred in OT.³⁷ Our research in two Canadian rehabilitation centres extends these findings with objective, continuous HR data showing that individuals with SCI spent 2.4 and 0.9 minutes per session during PT and OT, respectively in moderate/vigorous intensity activities.

It was unexpected that the amount of cardiovascular activity was similar between individuals with paraplegia and tetraplegia. One might anticipate higher HR responses to exercise from individuals with paraplegia who exhibit cardiovascular responses similar to able-bodied individuals,³⁸ while individuals with a spinal cord injury above the T6 spinal segment (sympathetic innervation to the heart exits at the T1-T5 level) may experience disruption of sympathetically driven cardiac control, resulting in bradycardia at rest³⁹ and a blunted chronotropic response to exercise, with a maximal HR in the range of 120 beats per minute.^{3,40} While individuals with paraplegia did have higher resting and average HRs, it is likely that physiological differences were not a factor as both groups (paraplegia and tetraplegia)

simply did very little cardiovascular physical activity. The greater accelerometry counts with individuals with paraplegia was surprising as it has been shown previously²³ that observer-counted repetitions of therapeutic upper extremity movement during inpatient rehabilitation sessions are highest in individuals with incomplete tetraplegia. However, an individual with tetraplegia is likely performing a repetition slowly, which would generate little acceleration, while individuals with paraplegia may be practicing wheeling or upper extremity strengthening at higher accelerations. This results in variability that may preclude the finding of any differences due to the plegia type.

Vigorous aerobic exercise confers more benefit than moderate aerobic exercise.⁴¹ However, there is evidence to suggest that deconditioned individuals can incur cardiovascular benefit from activities below 40% HRR. Swain et al.^{42,43} noted that deconditioned persons improved maximal oxygen consumption at intensities equivalent to 30% HRR. If one includes any intensity at or above 30% HRR for a minimum recommended 10 minutes³⁰ as sufficient for obtaining cardiovascular benefit in this population, this more lenient intensity guideline applied to the study sample would result in 41 of the 87 participants meeting the requirement. Or in other words, 53% of participants are not meeting even these most lenient activity guidelines.

Which activities elicited the highest heart rates?

Participants who were able to accrue at least 20 minutes of activity at 40% of HRR were mostly ambulatory and with AIS D injuries. It was observed that activities garnering HRs in the target zone usually involved ambulation but also included ADLs, suggesting that both types of activities can be utilized in an intervention designed to stimulate cardiovascular fitness in individuals with SCI. It was noted that the ADLs were repeatedly performed during therapy. However, ADLs performed as a part of one's day in a typical fashion (i.e. not repeatedly and not for any length of time), are insufficient for providing fitness gains.^{44,45}

Study Limitations

Using HR as an indicator of intensity may underestimate the response for individuals with a SCI above the T6 spinal segment. Nevertheless, regardless of the status of sympathetic innervation to the heart, the fact remains that individuals are experiencing nowhere near the amount of time required to accrue cardiovascular benefits.

While nine persons with concomitant traumatic brain injury were included, four individuals with severe traumatic brain injury whose therapy had a focus on cognitive, rather than physical rehabilitation, were excluded. Also excluded were nine individuals with a length of stay shorter than four weeks. While the number of participants excluded for these reasons is small, this may limit how well this sample represents the true breadth of the clinical presentation of SCI.

Lastly, the PARA-SCI was modified; activity was recalled after each of two days which may have improved recall over the original PARA-SCI which recalls at the end of a three-day period, but the shorter two-day period may be less representative of typical activity.

Conclusion

The cardiovascular stress incurred by individuals with SCI during PT and OT sessions is very low and insufficient to obtain a cardiovascular training effect. Due to the disparity between self-reported intensity and objectively measured HR, incorporating the use of HR monitors as part of standard practice would provide therapists with important information on optimizing patient therapy through creating baseline assessments and allowing the tracking of intensity and ensuring progression.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Preliminary data was sourced for the following abstract: Zbogar D, Eng JJ, Noble JW, Krassioukov AV, Miller WC, Verrier M. Cardiovascular Stress During Inpatient Spinal Cord Injury Physical and Occupational Therapy. *Archives of Physical Medicine and Rehabilitation*. 2015; 96(10): e67.

D. Zbogar is supported by a Doctoral Frederick Banting and Charles Best Canada Graduate Scholarship from the Canadian Institutes of Health Research.

J.J. Eng is supported by a career scientist award from the Canadian Institutes of Health Research (MSH-63617).

We thank the research assistants for their work, especially Erika Brown MPT, Jenna Homer MPT, and Amanda Mow MPT, and the rehabilitation centers and therapists who participated in this study.

Abbreviations

ADLs	activities of daily living
AIS	American Spinal Injury Association Impairment Scale
HR	heart rate
HRR	heart rate reserve
OT	occupational therapy
PARA-SCI	Physical Activity Recall Assessment for People with SCI
PT	physical therapy
SCI	spinal cord injury

References

1. Cragg JJ, Noonan VK, Krassioukov AV, Borisoff J. Cardiovascular disease and spinal cord injury: results from a national population health survey. *Neurology*. 2013; 81:723–8. [PubMed: 23884034]
2. Garshick E, Kelley A, Cohen SA, Garrison A, Tun CG, Gagnon D, et al. A prospective assessment of mortality in chronic spinal cord injury. *Spinal Cord*. 2005; 43:408–16. [PubMed: 15711609]
3. Jacobs PL, Nash MS. Exercise recommendations for individuals with spinal cord injury. *Sports Med*. 2004; 34:727–51. [PubMed: 15456347]

4. Hitzig SL, Eng JJ, Miller WC, Sakakibara BM. SCIRE Research Team. An evidence-based review of aging of the body systems following spinal cord injury. *Spinal Cord*. 2011; 49:684–701. [PubMed: 21151191]
5. Glaser RM. Arm exercise training for wheelchair users. *Med Sci Sports Exerc*. 1989; 21:S149–57. [PubMed: 2691827]
6. Tawashy AE, Eng JJ, Lin KH, Tang PF, Hung C. Physical activity is related to lower levels of pain, fatigue and depression in individuals with spinal-cord injury: a correlational study. *Spinal Cord*. 2009; 47:301–6. [PubMed: 18936771]
7. Kressler J, Cowan RE, Bigford GE, Nash MS. Reducing cardiometabolic disease in spinal cord injury. *Phys Med Rehabil Clin N Am*. 2014; 25:573–604. viii. [PubMed: 25064789]
8. Ditor DS, Hicks AL. Exercise therapy after spinal cord injury: the effects on health and function. *Crit Rev Biomed Eng*. 2009; 37:165–91. [PubMed: 20201774]
9. Haisma JA, Bussmann JBJ, Stam HJ, Sluis TAR, Bergen MP, Post MWM, et al. Physical fitness in people with a spinal cord injury: the association with complications and duration of rehabilitation. *Clin Rehabil*. 2007; 21:932–40. [PubMed: 17981852]
10. Stewart MW, Melton-Rogers SL, Morrison S, Figoni SF. The measurement properties of fitness measures and health status for persons with spinal cord injuries. *Arch Phys Med Rehabil*. 2000; 81:394–400. [PubMed: 10768526]
11. Haisma JA, Bussmann JB, Stam HJ, Sluis TA, Bergen MP, Dallmeijer AJ, et al. Changes in physical capacity during and after inpatient rehabilitation in subjects with a spinal cord injury. *Arch Phys Med Rehabil*. 2006; 87:741–8. [PubMed: 16731207]
12. Fu J, Wang H, Deng L, Li J. Exercise Training Promotes Functional Recovery after Spinal Cord Injury. *Neural Plast*. 2016; 2016:4039580–7. [PubMed: 28050288]
13. Leech KA, Hornby TG. High-Intensity Locomotor Exercise Increases Brain-Derived Neurotrophic Factor in Individuals with Incomplete Spinal Cord Injury. *J Neurotrauma*. 2017; 34:1240–8. [PubMed: 27526567]
14. Lee IM, Hsieh CC, Paffenbarger RS. Exercise intensity and longevity in men. The Harvard Alumni Health Study. *JAMA*. 1995; 273:1179–84. [PubMed: 7707624]
15. WHO. Global recommendations on physical activity for health [Internet]. 2010. http://www.who.int/dietphysicalactivity/factsheet_recommendations/en [cited 2015 Mar 6]; Available from: http://whqlibdoc.who.int/publications/2010/9789241599979_eng.pdf
16. Office of Disease Prevention and Health Promotion. Physical Activity Guidelines For Americans [Internet]. 2008. <http://www.health.gov/paguidelines/guidelineschapter.aspx> [cited 2015 Mar 10]; Available from: <http://www.health.gov/paguidelines/guidelines/chapter7.aspx>
17. Martin Ginis KA, Hicks AL, Latimer AE, Warburton DER, Bourne C, Ditor DS, et al. The development of evidence-informed physical activity guidelines for adults with spinal cord injury. *Spinal Cord*. 2011; 49:1088–96. [PubMed: 21647164]
18. van den Berg-Emons RJ, Bussmann JB, Haisma JA, Sluis TA, van der Woude LH, Bergen MP, et al. A prospective study on physical activity levels after spinal cord injury during inpatient rehabilitation and the year after discharge. *Arch Phys Med Rehabil*. 2008; 89:2094–101. [PubMed: 18996237]
19. Koopman A, Eken M, Bezeij T, Valent L, Houdijk H. Does clinical rehabilitation impose sufficient cardiorespiratory strain to improve aerobic fitness? *J Rehabil Med*. 2013; 45:92–8. [PubMed: 23096222]
20. Warms CA, Belza BL. Actigraphy as a measure of physical activity for wheelchair users with spinal cord injury. *Nurs Res*. 2004; 53:136–43. [PubMed: 15084999]
21. Warms C. Physical activity measurement in persons with chronic and disabling conditions: methods, strategies, and issues. *Fam Community Health*. 2006; 29:78S–88S. [PubMed: 16344640]
22. Prince SA, Adamo KB, Hamel ME, Hardt J, Connor Gorber S, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act*. 2008; 5:56. [PubMed: 18990237]
23. Zbogar D, Eng JJ, Miller WC, Krassioukov AV, Verrier MC. Movement repetitions in physical and occupational therapy during spinal cord injury rehabilitation. *Spinal Cord*. 2017; 55:172–9. [PubMed: 27752057]

24. McKinley WO, Seel RT, Hardman JT. Nontraumatic spinal cord injury: Incidence, epidemiology, and functional outcome. *YAPMR*. 1999; 80:619–23.
25. American Spinal Injury Association. International Standards for Neurological Classification of SCI (ISNCSCI) Worksheet [Internet]. asia-spinalinjury.org [cited 2017 Apr 20]; Available from: http://asia-spinalinjury.org/wp-content/uploads/2016/02/International_Std_Diagram_Worksheet.pdf
26. SCI Action Canada. Physical activity guidelines for adults with spinal cord injury [Internet]. 2011. sciactioncanada.ca/guidelines [cited 2017 Apr 19]; Available from: <http://sciactioncanada.ca/docs/guidelines/Physical-Activity-Guidelines-for-Adults-with-a-Spinal-Cord-Injury-Health-Care-Professional.pdf>
27. Martin Ginis KA, Latimer AE, Hicks AL, Craven BC. Development and evaluation of an activity measure for people with spinal cord injury. *Med Sci Sports Exerc*. 2005; 37:1099–111. [PubMed: 16015125]
28. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. *J Am Coll Cardiol*. 2001; 37:153–6. [PubMed: 11153730]
29. Brawner CA, Ehrman JK, Schairer JR, Cao JJ, Keteyian SJ. Predicting maximum heart rate among patients with coronary heart disease receiving β -adrenergic blockade therapy. *Am Heart J*. 2004; 148:910–4. [PubMed: 15523326]
30. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011; 43:1334–59. [PubMed: 21694556]
31. Cooper, H., Hedges, LV., editors. *The Handbook of Research Synthesis*. New York: Russel Sage Foundation; 1993.
32. Domholdt, E. *Physical Therapy Research*. 2. W.B. Saunders Company; 2000.
33. Borg G, Hassmén P, Lagerström M. Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *Eur J Appl Physiol Occup Physiol*. 1987; 56:679–85. [PubMed: 3678222]
34. Adams SA, Matthews CE, Ebbeling CB, Moore CG, Cunningham JE, Fulton J, et al. The effect of social desirability and social approval on self-reports of physical activity. *Am J Epidemiol*. 2005; 161:389–98. [PubMed: 15692083]
35. Natale A, Taylor S, LaBarbera J, Bensimon L, McDowell S, Mumma SL, et al. SCIREhab Project series: the physical therapy taxonomy. *J Spinal Cord Med*. 2009; 32:270–82. [PubMed: 19810629]
36. Taylor-Schroeder S, LaBarbera J, McDowell S, Zanca JM, Natale A, Mumma S, et al. The SCIREhab project: treatment time spent in SCI rehabilitation. Physical therapy treatment time during inpatient spinal cord injury rehabilitation. *J Spinal Cord Med*. 2011; 34:149–61. [PubMed: 21675354]
37. Foy T, Perritt G, Thimmaiah D, Heisler L, Offutt JL, Cantoni K, et al. The SCIREhab project: treatment time spent in SCI rehabilitation. Occupational therapy treatment time during inpatient spinal cord injury rehabilitation. *J Spinal Cord Med*. 2011; 34:162–75. [PubMed: 21675355]
38. Hooker SP, Greenwood JD, Hatae DT, Husson RP, Matthiesen TL, Waters AR. Oxygen uptake and heart rate relationship in persons with spinal cord injury. *Med Sci Sports Exerc*. 1993; 25:1115–9. [PubMed: 8231755]
39. Krassioukov AV, Karlsson A-K, Wecht JM, Wuermser L-A, Mathias CJ, Marino RJ. Assessment of autonomic dysfunction following spinal cord injury: Rationale for additions to International Standards for Neurological Assessment. *JRRD*. 2007; 44:103.
40. Teasell RW, Arnold JMO, Krassioukov AV, Delaney GA. Cardiovascular consequences of loss of supraspinal control of the sympathetic nervous system after spinal cord injury. *Arch Phys Med Rehabil*. 2000; 81:506–16. [PubMed: 10768544]
41. Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol*. 2006; 97:141–7. [PubMed: 16377300]
42. Swain DP, Franklin BA. VO(2) reserve and the minimal intensity for improving cardiorespiratory fitness. *Med Sci Sports Exerc*. 2002; 34:152–7. [PubMed: 11782661]

43. Swain DP, Leutholtz BC. Heart rate reserve is equivalent to % VO₂ reserve, not to % VO₂max. *Med Sci Sports Exerc.* 1997; 29:410–4. [PubMed: 9139182]
44. Janssen TW, van Oers CA, van der Woude LH, Hollander AP. Physical strain in daily life of wheelchair users with spinal cord injuries. *Med Sci Sports Exerc.* 1994; 26:661–70. [PubMed: 8052104]
45. Vidal J, Javierre C, Segura R, Lizarraga A, Barbany JR, Pérez A. Physiological adaptations to exercise in people with spinal cord injury. *J Physiol Biochem.* 2003; 59:11–8. [PubMed: 12903900]

Figure 1.
Study recruitment diagram

Table 1

Demographic and clinical information for all patients and subgroups of paraplegia and tetraplegia

Variable	All Patients	Paraplegia	Tetraplegia
n	87	50	37
male/female	63/24 (72/28)	36/14 (72/28)	27/10 (73/27)
traumatic/nontraumatic	61/26 (70/30)	32/18 (64/36)	29/8 (78/22)
AIS score (A, B, C, D) [‡]	20/10/12/45 (23/12/14/52)	11/6/10/23 (22/12/20/46)	9/4/2/22 (24/11/5/60)
β-blocking medication (Y/N)	8/79 (9/91)	8/42 (16/84)	0/37 (0/100)
age, years	49.4 (16.7)	48.4 (16.9)	50.7 (16.5)
LOS in acute care, days	38.4 (39.6)	32.7 (33.3)	46.1 (46.1)
LOS in rehabilitation, days	97.1 (48)	86.7 (39.3)	111.2 (55.3)
duration of PT (minutes/day)	44.4 (16.6)	41.5 (14.6)	48.4 (18.5)
duration of OT (minutes/day)	41.3 (18.0)	36.3 (17.8)	45.6 (17.3)

Values are n(%) or mean (SD); n= number of patients; AIS= American Spinal Injury Association Impairment Scale; LOS= length of stay; PT= physical therapy; OT= occupational therapy.

[‡]While the AIS is valid for traumatic SCI, it has not been validated in non-traumatic SCI.

Table 2

Heart rate, PARA-SCI, and wrist accelerometry measures during physical therapy and occupational therapy:
Comparison between individuals with paraplegia and tetraplegia.

	<u>PT</u>	<u>OT</u>	<u>Paraplegia</u>	<u>Tetraplegia</u>	<u>Z score</u>	<u>p</u>	<u>effect size</u>
Heart Rate							
Resting (beats/min)	~	~	72.9 (64.4–78.8)	60.9 (52.6–70.5)	–3.75	<0.001**	0.40
Median (beats/min)	92.4 (81.3–104.3)	89.3 (78.7–98.1)	95.8 (85.6–104.8)	84.6 (78.6–96.8)	–3.13	0.002**	0.34
Peak (beats/min)	147.2 (128–162.9)	139.1 (122.1–157)	148.6 (130.3–167.2)	140.3 (121.9–155.0)	–1.87	0.061	0.20
Time in target HR zone (min)	2.4 (0.4–8.4)	0.9 (0.1–4.9)	5.0 (1.3–14.8)	2.5 (0.2–13.7)	–1.63	0.10	0.17
PARA-SCI							
Lower Intensity (min)	0 (0–20)	15 (0–37.5)	22.5 (0.0–42.5)	30.0 (0–61.25.0)	–1.30	0.194	0.14
Higher Intensity (min)	55 (30–62)	0 (0–23)	60.0 (33.8–85.6)	67.5 (40.0–90.0)	–1.24	0.214	0.13
Accelerometry							
Wrist (kilocounts)	14 (7–29)	4 (0–12)	26 (18–39)	17 (10–28)	–2.22	0.027*	0.24

All values are median (Q1-Q3);

* $p = 0.05$,

** $p = 0.01$;

PT= physical therapy; OT= occupational therapy; min=minutes.

Table 3

Characteristics of participants who accumulated 20 minutes of activity at 40% HRR in PT or OT

ID	Age	Ambulatory?	β -blocker	AIS score	Lesion level	Minutes	40%HRR	Session type
1	54	No	No	D	C5	39.6		OT
2	21	Yes	No	D	T11	37.8/30.0		PT/OT
3	62	Yes	Yes	D	missing	35.7		PT
4	27	Yes	No	D	T10	34.4		PT
5	53	Yes	No	D	L4	33.8		PT
6	58	No	No	C	T10	33.0		OT
7	22	Yes	No	D	C7	31.2/20.8		OT/PT
8	48	Yes	No	B	L3	25.2		PT
9	53	Yes	No	D	C5	25.0		PT
10	45	Yes	No	B	L3	24.3		PT
11	55	Yes	No	D	C4	23.7		PT

AIS= American Spinal Injury Association impairment scale; HRR= heart rate reserve; PT= physical therapy; OT= occupational therapy.