*Original Article*

**SAGE Open Medicine**

SAGE Open Medicine
Volume 4: 1–9

DOI: 10.1177/2050312116666941
smo.sagepub.com

# Reliability and validity of daily physical activity measures during inpatient spinal cord injury rehabilitation

**Dominik Zbogar[1], Janice J Eng[1], William C Miller[2], Andrei V Krassioukov[3] and Mary C Verrier[4]**

**Abstract**

**Objectives:** To assess the test–retest reliability and convergent validity of daily physical activity measures during inpatient spinal cord injury rehabilitation.

**Design:** Observational study.

**Setting:** Two inpatient spinal cord injury rehabilitation centres.

**Subjects:** Participants ($n$ = 106) were recruited from consecutive admissions to rehabilitation.

**Methods:** Physical activity during inpatient spinal cord injury rehabilitation stay was recorded on two days via (1) wrist accelerometer, (2) hip accelerometer if ambulatory, and (3) self-report (Physical Activity Recall Assessment for People with Spinal Cord Injury questionnaire). Spearman's correlations and Bland–Altman plots were utilized for test–retest reliability. Correlations between physical activity measures and clinical measures (functional independence, hand function, and ambulation) were performed.

**Results:** Correlations for physical activity measures between Day 1 and Day 2 were moderate to high ($\rho$ = 0.53–0.89). Bland–Altman plots showed minimal bias and more within-subject differences in more active individuals and wide limits of agreement. None of these three physical activity measures correlated with one another. A moderate correlation was found between wrist accelerometry counts and grip strength ($\rho$ = 0.58) and between step counts and measures of ambulation ($\rho$ = 0.62). Functional independence was related to wrist accelerometry ($\rho$ = 0.70) and step counts ($\rho$ = 0.56), but not with self-report.

**Conclusion:** The test–retest reliability and convergent validity of the instrumented measures suggest that wrist and hip accelerometers are appropriate tools for use in research studies of daily physical activity in the spinal cord injury rehabilitation setting but are too variable for individual use.

**Keywords**

Spinal cord injury, rehabilitation, reliability, validity, accelerometry, step counts, self-reported physical activity

Date received: 26 April 2016; accepted: 3 August 2016

## Introduction

For individuals with spinal cord injury (SCI), physical activity plays a vital role in countering an often profoundly sedentary lifestyle and the consequent higher incidence and earlier onset of secondary complications such as cardiovascular disease, dyslipidemia, and diabetes.[1–3] Physical activity early after an SCI may optimize recovery and decrease or prevent the degree of post-SCI deconditioning that occurs after weeks of bed rest which is important because physical activity during the early period can affect an individual's ultimate functional capacity.[4,5] Inpatient rehabilitation provides opportunities for increasing

[1]Rehabilitation Research Lab, GF Strong Rehabilitation Centre, The University of British Columbia, Vancouver, BC, Canada
[2]The University of British Columbia, Vancouver, BC, Canada
[3]International Collaboration on Repair Discoveries, The University of British Columbia, Vancouver, BC, Canada
[4]Department of Physical Therapy, University of Toronto, Toronto, ON, Canada

**Corresponding author:**
Janice J Eng, Rehabilitation Research Lab, GF Strong Rehabilitation Centre, The University of British Columbia, Vancouver, BC V5Z 2G9, Canada.
Email: janice.eng@ubc.ca

physical activity after an SCI, both within formal therapy sessions, as well as during the remainder of the day. It is important to establish the reliability and validity of measures that quantify daily physical activity early after an SCI where the greatest gains in recovery are made;[6,7] such measures can be used by clinicians (as well as patients) to optimize activity prescription and maximize recovery.

Variations in physical activity from day to day present a challenge for reliable assessment,[8–10] and there are multiple options for assessing physical activity, each with strengths and weaknesses. Some are infrastructure and resource intensive, such as direct observation,[11] precluding their viability as convenient options for measurement over an entire inpatient day, though direct observation has been used to observe small portions of the day during physical therapy and occupational therapy during inpatient rehabilitation.[12–15]

Non-invasive, low-cost options for measuring physical activity include accelerometry and self-report. For those who are ambulatory, hip step counters provide a reliable option used much in able-bodied research but have also demonstrated reliability in community-dwelling individuals with chronic incomplete SCI.[16] Wrist accelerometry is shown to be a valid indicator of physical activity for wheelchair users in laboratory and community-dwelling environments.[17] For wheelchair users, wrist accelerometry is well tolerated, does not interfere with regular activity, and detects activity such as wheeling that would otherwise not be detected by hip accelerometry.[11]

Perhaps because no equipment is required, self-report is the most widely used method for measuring physical activity.[11] However, the subjective nature of self-reported physical activity renders it prone to recall error and social desirability bias.[18] However, information not available from objective measures can be obtained from self-report. 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 and activity of daily living). The Physical Activity Recall Assessment for People with SCI (PARA-SCI) is a self-report questionnaire developed for use in the SCI population and allows respondents to indicate time and intensity of physical activities performed during the day. The reliability and validity of this questionnaire have been established in community-dwelling individuals with SCI.[19,20]

There are many contextual differences between the inpatient SCI rehabilitation setting compared to the community setting. The inpatient setting provides a semi-structured environment for supporting therapeutic activities. Importantly, during this time, the inpatient's physical and psychological status may be highly variable due to fatigue, rapid changes in neurological recovery, and learned movement compensations that may impact the reliability and validity of physical activity measures. Being able to estimate the daily physical activity during inpatient rehabilitation is critical as greater activity during this time results in greater motor recovery,[21] shorter inpatient stay,[4] quicker improvement in activities of daily living (ADL) performance,[5,22] and may counteract the significant decrease in physical activity that frequently follows discharge.[23] Despite the importance of measuring physical activity early after SCI, these measures are not currently assessed during inpatient rehabilitation as to date no research has investigated whether daily physical activity measures are reliable or valid during inpatient rehabilitation. Therefore, our purpose was to determine (1) the day-to-day (test–retest) reliability of accelerometry and self-report daily physical activity measures during inpatient SCI rehabilitation and (2) the relationship of accelerometry measures with self-reported physical activity, as well as with relevant clinical outcome measures (convergent validity). We hypothesized that because of the semi-structured nature of participant schedules during inpatient rehabilitation that test–retest reliability of physical activity measures would show a high correlation ($\rho \geq 0.7$) between two separate days. In addition, we postulated that objective physical activity measures would show a high ($\rho \geq 0.7$) correlation with self-report measures and clinical outcomes.

## Research methods

### Participants

Participants were a consecutive sample of traumatic and nontraumatic SCI admissions to inpatient subacute care at two Canadian rehabilitation centres in two provinces. Nontraumatic SCI was defined as SCI resulting from spinal stenosis, tumour, ischaemia, transverse myelitis, and infection.[24] Participants were excluded if they had a traumatic brain injury that significantly affected the content and delivery of therapy, consent could not be obtained within the first week of admission, or their length of stay in rehabilitation was projected to be less than 4 weeks as a very short length of stay would likely focus primarily on discharge planning, rather than physical activities.

### Data collection

Data were collected over a single week at a time point when participants would have likely been undertaking physical activity independently through the day and when bias from discharge planning activities would not be occurring. Thus, we collected data over two separate weekdays in the second week before discharge. On each data collection day, a research assistant met the participant in their room in the morning, prior to breakfast, before participants had transferred from bed. At this time, the participant was fitted with the accelerometers and was reminded that they would be required to recall the events of their day that evening. In the evening of each day, when participants had transferred to bed, the research assistant returned to collect the accelerometers and to administer the PARA-SCI questionnaire. Clinical outcome measures were collected on a separate day within the same week period.

Approval for this study was obtained from the respective local university and hospital ethics boards, and all participants provided informed consent before study enrolment.

## Physical activity measures

Physical activity over an entire day was assessed by three different measures. First, all participants wore an Actical accelerometer (Mini Mitter Co., Bend, OR) on the dominant wrist like a wrist watch to quantify the amount and intensity of upper extremity activity using mean activity kilocounts per day. 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 and samples data at 32 Hz. Acceleration is detected in all three planes, although more sensitivity is present in the vertical plane. The accelerometer record is rectified and integrated over 15 s as activity counts. Higher activity counts may indicate longer use, more movement, and/or greater intensity of movement.

Second, participants who were ambulatory (i.e. could walk independently with or without assistive devices at the time of their assessment) wore an accelerometer on the right hip secured with a waist strap to detect the number of steps using the step-count function of the accelerometer.

Third, participants completed the PARA-SCI, a questionnaire that measures the amount of physical activity individuals with SCI accumulate over a day.[19] This semi-structured interview 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').

## Validation measures

Convergent validity was assessed between clinical outcome measures of hand function and wrist accelerometry, as well as between measures of ambulatory function and hip accelerometry. Convergent validity was also assessed between functional independence and all three measures of daily physical activity.

Functional independence was measured using the mobility subscale of the Spinal Cord Independence Measure III (SCIM III) which includes nine items that measures the ability of individuals with SCI to accomplish ADLs in the area of mobility (e.g. transfers, indoor, and outdoor mobility).[25] The mobility subscale has excellent reliability.[26,27] We expected the physical activity measures of accelerometry, step counts, and self-reported physical activity to relate to functional independence since a substantial part of physical activities comprised ADLs.

The upper extremities contribute significantly to physical activity in individuals with SCI. The arms are relied on more heavily for ADLs and leisure-time activities as they take on activities that previously involved the lower body. Upper extremity function has implications for how much activity is engaged in by the upper extremities (e.g. using a manual versus a power wheelchair). Grip strength was tested using a hand-held Jamar Dynamometer (Nicholas MMT; Lafayette Instrument, Lafayette, IN). For the dominant hand, participants performed three maximal voluntary contractions, with at least 30 s of rest between trials. The three trials were averaged to obtain a mean score in kilograms. All measurements were taken with the participant seated, with the elbow at 90° and the hand in a neutral position. This test has proven reliable and valid for assessing manual grip in both healthy and hand-injured populations.[28,29]

Participants with SCI who take more steps during rehabilitation are expected to perform better on assessments of ambulatory ability. Participants with ambulatory ability were assessed with the Walking Index for Spinal Cord Injury (WISCI II), which gauges locomotor performance on a 0–20 hierarchical scale and accounts for the requirement of devices, braces, and physical assistance used to complete a 10-meter distance. Higher scores indicate better ambulatory ability. The WISCI II is reliable and valid in the SCI population.[30]

The 10-Meter Walk Test (10MWT) is a measure of functional capacity. For this test, ambulatory participants walk 14 meters while being timed at their comfortable pace. The first and last two meters are eliminated from the speed calculation to negate acceleration/deceleration effects.[31] The 10MWT has been shown to have excellent reliability and validity in persons with incomplete SCI.[32]

## Descriptive measures

Information was collected for age, sex, plegia type (paraplegia/tetraplegia), aetiology (traumatic or nontraumatic), American Spinal Injury Association Impairment Scale (AIS) score,[33] length of stay in acute care, and length of stay in rehabilitation.

## Data analyses

Given the presence of skewness in the physical activity measures, we used non-parametric analyses with these measures. The three intensities of mild, moderate, and heavy intensity minutes in the PARA-SCI were binned into one category. The total sample was separated into ambulatory and non-ambulatory individuals. Spearman's $\rho$ correlation coefficients with 95% confidence intervals were used to assess the reliability (Day 1 versus Day 2 of measurement) of wrist accelerometry counts and self-report physical activity for non-ambulatory individuals and wrist accelerometry counts, self-report physical activity, and step counts for ambulatory individuals. Bland–Altman plots with non-parametric 95% limits of agreement[34] were created for each of the aforementioned categories to evaluate the measurement error on repeated measurements.[35]

**Table 1.** Participant characteristics and clinical measures.

| Variable | Non-ambulatory patients | *n* | Ambulatory patients | *n* |
|---|---|---|---|---|
| Age, mean (SD), years | 48.9 (18.3) | 70 | 51.8 (15.4) | 35 |
| Sex: M/F (%) | 49/21 (70/30) | 70 | 26/9 (74/26) | 35 |
| Traumatic/nontraumatic (%) | 47/23 (67/33) | 70 | 24/11 (69/31) | 35 |
| Paraplegic/tetraplegic (%) | 34/36 (49/51) | 70 | 22/13 (63/37) | 35 |
| AIS score (A/B/C/D) (%)[a] | 23/10/15/20 (33/14/21/29) | 68 | 1/2/0/32 (3/6/0/91) | 35 |
| LOS in rehabilitation, mean (SD), days | 109.1 (45.5) | 70 | 72.5 (44.0) | 35 |
| LOS in acute care, mean (SD), days | 47.9 (42.2) | 70 | 20.1 (13.2) | 35 |
| SCIM III mobility score, mean (SD) | 11.6 (7.3) | 66 | 25.6 (7.7) | 35 |
| Grip strength, mean (SD), kg | 20.6 (18.4) | 67 | – | |
| 10MWT, mean (SD), m/s[b] | – | | 0.75 (0.39) | 32 |
| WISCI II, mean (SD)[b] | – | | 15.7 (5.8) | 31 |

*n*: number of patients; M: male; F: female; SD: standard deviation; AIS: American Spinal Injury Association Impairment Scale; LOS: length of stay; SCIM III: Spinal Cord Independence Measure III mobility score (0–40); 10MWT: 10-Metre Walk Test – comfortable speed; WISCI II: Walking Index for Spinal Cord Injury II (0–20).
[a]While the AIS is valid for traumatic SCI, it has not been validated in nontraumatic SCI.
[b]Gait measures are applicable only to the ambulatory group, defined as individuals able to ambulate at the time of the assessment.

Spearman's ρ correlation coefficients were calculated to quantify the relationship between the physical activity measures of wrist accelerometry counts, step counts, and self-report physical activity. Correlations were also assessed between wrist accelerometry and hand function measures and between number of walking steps and ambulatory ability. Finally, all measures of physical activity were correlated with functional independence mobility score. A $\rho \leqslant 0.25$ indicated a weak correlation, a ρ between 0.26 and 0.49 a low correlation, a ρ between 0.5 and 0.69 moderate correlation, and a ρ value $\geqslant 0.7$ was considered a high correlation.[36] Statistical software, SPSS 17 (SPSS Inc, Chicago, IL, USA), was used for the analysis.

## Results

A total of 385 participants were admitted to SCI rehabilitation over the course of 2 years. Of the 385 participants, 102 declined participation in the study and 168 did not meet study inclusion criteria. The remaining 115 participants entered into the study, and we obtained an evaluation for 106 (92%). While we could not attain an evaluation for nine participants because they were discharged with insufficient notice, demographic variables for these participants were not notably different from those included for analyses. One outlier was removed from the dataset as this individual had very high activity on one day and almost no activity on the second day. This individual had an AIS D injury and was very high functioning with an L1 injury. Descriptive statistics (means, standard deviations, and frequencies) for participant demographics and clinical outcome measures for the participants in this study are included in Table 1. Due to participant fatigue, lack of participant availability, or clerical error, we attained data for 97% of clinical measures, with the lowest completion rate (89%) for the gait measures. Just over half of the participants had paraplegia, one-third had motor complete injuries, one-third had nontraumatic injuries, and one-third were ambulatory. As expected, the ambulatory subset had better functional scores and shorter length of stays.

### *Reliability and agreement of physical activity measures*

Reliability data are found in Table 2. The average time between testing days was $2.2 \pm 1.9$ days. Wrist accelerometry for both groups and step counts in ambulatory individuals exhibited a high test–retest reliability ($\rho \geqslant 0.74$) between Day 1 and Day 2. For self-reported physical activity in both groups, there was a moderate test–retest reliability ($\rho = 0.53$ and 0.68, in ambulatory and non-ambulatory groups, respectively). Confidence intervals were particularly large for self-reported physical activity in ambulatory individuals. Bland–Altman plots (Figure 1) show the data relatively centred around the zero bias line with 6%–9% of the data outside of the 95% limits of agreement. In general, physical activities at the highest level (top 10%) had larger within-subject differences. Wrist accelerometry, step counts, and self-reported physical activity measures had wide limits of agreement with these values approaching or surpassing the median and interquartile range of the samples. Two individuals in the top 10% of the step counts had large within-subject variability; the limits of agreement (−3544, 3071) reduced substantially (−1308, 3175) after removing these two individuals.

### *Validity of physical activity measures*

Correlations of physical activity measures are provided in Table 3. Wrist accelerometry showed a moderate correlation with grip strength ($\rho = 0.58$) and a high correlation with

**Table 2.** Reliability statistics for wrist accelerometry, PARA-SCI, and steps.

| | Day 1 | Day 2 | ρ (95% CI) |
|---|---|---|---|
| Non-ambulatory participants | | | |
| Wrist accelerometry ($n=70$) | 169, 63–206 | 169, 63–231 | 0.89 (0.82–0.93)** |
| PARA-SCI ($n=70$) | 190, 110–274 | 179, 92–288 | 0.68 (0.53–0.79)** |
| Ambulatory participants | | | |
| Wrist accelerometry ($n=35$) | 224, 137–318 | 230, 121–291 | 0.74 (0.54–0.86)** |
| PARA-SCI ($n=35$) | 255, 163–369 | 254, 130–337 | 0.53 (0.24–0.73)** |
| Step counts ($n=35$) | 1916, 212–3850 | 1281, 209–3094 | 0.84 (0.70–0.92)** |

Day 1 and Day 2 values are median, Q1–Q3; wrist accelerometry values are kilocounts; PARA-SCI values are minutes.
ρ: Spearman's rho; CI: confidence interval; PARA-SCI: Physical Activity Recall Assessment for People with Spinal Cord Injury (mild, moderate, and heavy intensity).
*$p \leq 0.05$; **$p \leq 0.01$ (two-tailed).

functional independence (ρ=0.70). In ambulatory participants, step counts exhibited a moderate correlation with functional independence (ρ=0.56) and with measures of ambulation (ρ=0.62). There was no significant correlation between self-reported physical activity and functional independence. There was no correlation amongst the three physical activity measures, save a low correlation between self-reported physical activity and step counts (ρ=0.35).

## Discussion

The median amount of wrist accelerometry counts observed in this study was 169 kilocounts. Normative values for wrist accelerometry counts do not exist for individuals with SCI. However, able-bodied older adults have been shown to accumulate, on average, between 164 and 224 daily kilocounts using the same instrument,[37] and our median value falls within this window albeit with a large amount of variability between participants. Ambulatory individuals in this study accrued a median 1959 steps during a weekday which is typical of individuals living with disability and/or chronic illness who have been shown to accumulate an average of 1200–8800 steps/day.[38]

Minutes of self-reported mild, moderate, and high intensity activity amounted to a median 3.5 h for the total study sample while previous research using the PARA-SCI has reported amounts with an average of between 3.2 and 4 h[20] in community-dwelling individuals with SCI. However, the variability of the measure amongst our rehabilitation participants was high, as was the case for those living in the community.

### Test–retest reliability and agreement

We expected to see high reliability from Day 1 to Day 2 due to the consistent nature of the participant schedules during inpatient rehabilitation; during inpatient rehabilitation, a participant will usually be woken at the same time every day, have a regularly scheduled bowel/bladder and medication routine, meals, and therapy sessions, and such activities will all generally occur in the same locations and take the same amount of time every day. We did find high test–retest reliability for wrist accelerometry and step counts, however the agreement was poor with large measurement error between days, which indicates that these tools provide a reliable measure in sufficiently powered research studies, however they are limited for measuring change at an individual level.

While the test–retest reliability was moderate for the self-reported PARA-SCI, the agreement over two days was poor with large measurement error. The minimal detectable change for the PARA-SCI is 179.4 min[19] which does not surpass the limits of agreement in our results which exceed 200 min. We acquired the responses to the PARA-SCI at the end of each day which should minimize recall bias more effectively than the original questionnaire which followed up after 3 days of activity.[19] While our follow-up after a single day may have contributed to more accurate recall, perhaps more days are required to capture the variability in activities. Additionally, participants must recall not only the activity but also the duration and the perceived intensity of activity. These two characteristics, already difficult to accurately estimate, may be particularly challenging for participants in SCI rehabilitation who have experienced a very recent life-changing and devastating injury with both physical and emotional consequences.

Research with able-bodied adults has shown that 2–6 days are required to characterize daily physical activity.[9,39–42] It appears that the nature of activities during inpatient SCI rehabilitation may require more than one day to capture daily physical activity patterns accurately if they are captured by self-report.

### Validity

The lack of correlation between physical activity measures in the inpatient rehabilitation setting suggests that the three measures are capturing different aspects of physical activity. This contrasts with studies in individuals living in the community where the PARA-SCI has been shown to relate to indirect calorimetry in individuals living in the community,[19,20]

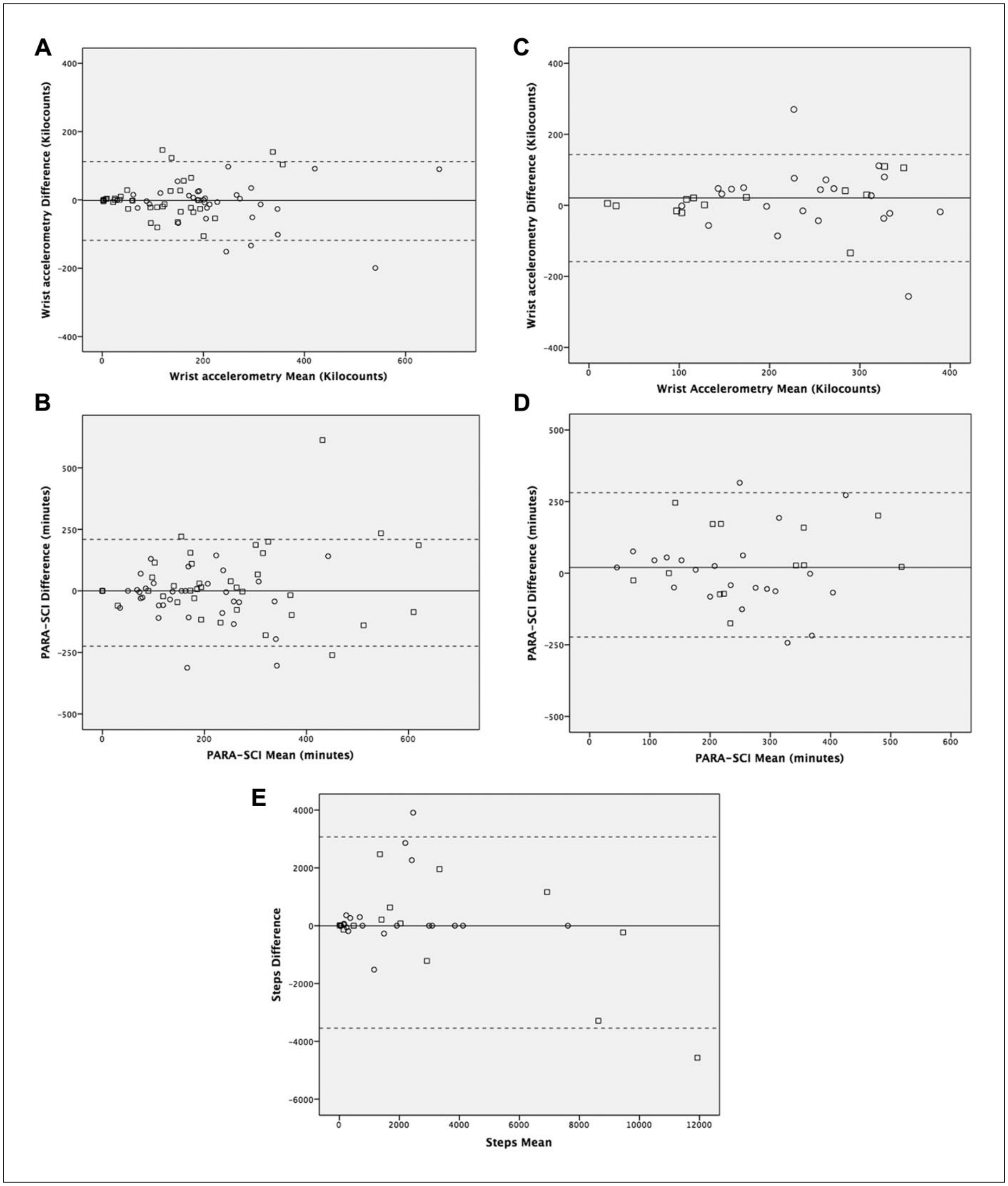


**Figure 1.** Bland−Altman plots of difference between Day 1 and Day 2 versus mean value of Day 1 and Day 2; solid line: median of the difference; dashed lines: 5th and 95th percentile; circle: participants with paraplegia; square: participants with tetraplegia; (a) wrist accelerometry for non-ambulatory participants; (b) PARA-SCI for non-ambulatory participants; (c) wrist accelerometry for ambulatory participants; (d) PARA-SCI for ambulatory participants; and (e) steps for ambulatory participants.

accelerometry-derived step counts have been shown to relate to observed steps in community-dwelling persons with incomplete SCI,[43] and wrist accelerometry has also been shown to relate to indirect calorimetry and heart rate in community-dwelling

**Table 3.** Spearman correlations for physical activity measures and clinical measures.

| | ρ (95% CI) |
|---|---|
| Wrist accelerometry[a] | |
| PARA-SCI ($n$=70) | −0.04 (–0.27 to 0.20) |
| SCIM III mobility score ($n$=66) | 0.70 (0.55 to 0.81)** |
| Grip strength ($n$=67) | 0.58 (0.40 to 0.72)** |
| PARA-SCI[a] | |
| SCIM III mobility score ($n$=66) | −0.14 (−0.37 to 0.11) |
| Step counts[b] | |
| Wrist accelerometry ($n$=35) | 0.17 (−0.17 to 0.48) |
| PARA-SCI ($n$=35) | 0.35 (0.01 to 0.61)* |
| SCIM III mobility score ($n$=35) | 0.56 (0.28 to 0.75)** |
| 10MWT ($n$=32) | 0.62 (0.36 to 0.79)** |
| WISCI II ($n$=31) | 0.62 (0.36 to 0.79)** |

CI: confidence interval; PARA-SCI: Physical Activity Recall Assessment for People with Spinal Cord Injury (mild, moderate, and heavy intensity); SCIM III: Spinal Cord Independence Measure III; 10MWT: 10-Meter Walk Test – comfortable speed; WISCI II: Walking Index for Spinal Cord Injury II.
[a]Values reported are for non-ambulatory individuals.
[b]Values reported are for ambulatory individuals.
*$p \leqslant 0.05$; **$p \leqslant 0.01$ (two-tailed).

wheelchair users.[17,44] However, other self-report measures such as the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD), a self-report questionnaire of time spent on various physical activities, has shown to have a poor relationship with objective measures of fitness such aerobic capacity and power output.[45]

One expects the physical activity of an able-bodied ambulatory person to manifest itself in accelerometry counts regardless of whether activity is measured at the hip or wrist. However, it is likely that ambulatory individuals with SCI still use a wheelchair for part of the day. Thus, high wrist accelerometry counts may occur during wheeling in the presence of no step counts, while step counts while using an assistive device like a wheeled walker may result in minimal wrist accelerometry counts and hence contribute to the lack of correlation between wrist accelerometry counts and step counts. In the future, it would be useful to add instrumentation to the wheelchair, as recently seen by Kooijmans et al.[46] where accelerometers on the wheel and wrist were able to validly detect self-propelled wheeling, so that wheeling activity can be accounted for.

Hip-mounted accelerometry/pedometer measures of physical activity have correlated weakly or not at all to self-reported physical activity in other sedentary or chronic disease populations.[47] The lack of a relationship between self-report physical activity measured by the PARA-SCI and wrist accelerometry/step counts may occur because these subjective and objective assessments may be quantifying different facets of physical activity. Perhaps, the PARA-SCI captures more ADLs and leisure-time physical activities in the rehabilitation setting; ADLs make up a large portion of the day and may be done relatively slowly and thus substantial wrist accelerometry counts are not generated. Likewise, ADLs and leisure-time physical activity measured by the PARA-SCI may not correlate with step counts because much of an ambulatory participant's time will be spent on challenging activities such as working on stabilization or specific leg muscles that do not involve taking steps.

In the context of the International Classification of Functioning, Disability, and Health, our measures of physical activity indicate performance, assessing what a participant actually does over their day in their current environment, while the clinical assessments are measures of capacity, assessing what a participant is capable of doing under a standardized test setting.[48] Grip strength was moderately correlated with wrist accelerometry, providing convergent validity that daily wrist accelerometry is capturing constructs requiring hand strength. The moderate positive correlation between daily step counts and the 10MWT and WISCI II also provides convergent validity, in this case, such that the step counts are capturing constructs of ambulation.

Our results demonstrated that wrist accelerometry counts and step counts do relate to constructs of ADLs since our measure of functional independence (SCIM III mobility score) is a strong indicator of the ability to complete ADLs. Given that ADLs make up a substantial portion of the physical activities within the rehabilitation day, this provides additional convergent validity to the measures of wrist accelerometry and step counts.

The lack of correlation between mobility independence and self-reported physical activity is noteworthy and appears to show that the level of functional independence does not impact how much activity individuals report they do. Perceived exercise self-efficacy has been shown to relate to physical activity in individuals with SCI,[49] and it is possible that the relationship between functional independence and physical activity is mediated by self-efficacy. Indeed, the use of a behavioural intervention has been found successful in increasing physical activity in individuals with subacute SCI.[50]

### *Limitations*

We did not include weekends as part of this analysis. It is expected that activity patterns would be significantly lower during weekends compared to weekdays since therapy sessions, group classes, and most other appointments do not occur during this time.

Research has shown that hip-mounted step counts may underestimate the number of steps in slow walkers.[51,52] For example, Martin et al.[51] found a 25% underestimation in step counts at a gait speed of 0.75 m/s and approximately one-fourth of our sample walked slower than this speed.

## Conclusion

The test–retest reliability and convergent validity of the instrumented measures suggest that wrist and hip accelerometers are appropriate for use in sufficiently powered research studies on daily physical activity in the SCI rehabilitation setting, but are limited for detecting change at an individual level.

## Clinical messages

Accelerometers are appropriate for measuring change in daily physical activity in sufficiently powered research studies but are limited in detecting change at the individual level during inpatient SCI rehabilitation.

Better measurement of physical activity has the potential to inform the clinical community of the intensity required to attain more effective outcomes.

### Acknowledgements

The authors thank the research assistants for their work, especially Erika Brown, Jenna Homer, and Amanda Mow, and the rehabilitation centres, therapists, and patients who participated in this study.

### Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Ethical approval

Ethical approval for this study was obtained from the University of British Columbia's Research Ethics Board (certificate no. H09-02633) and Toronto Rehabilitation Institute–University Health Network's Research Ethics Board (certificate no. 10-033).

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: 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 acknowledges salary support from the Canada Research Chair Program.

### Informed consent

Written informed consent was obtained from all subjects before the study.

### References

1. Jacobs PL and Nash MS. Exercise recommendations for individuals with spinal cord injury. *Sports Med* 2004; 34(11): 727–751.
2. Hitzig SL, Eng JJ, Miller WC, et al.; SCIRE Research Team. An evidence-based review of aging of the body systems following spinal cord injury. *Spinal Cord* 2011; 49(6): 684–701.
3. Frankel HL, Coll JR, Charlifue SW, et al. Long-term survival in spinal cord injury: a fifty year investigation. *Spinal Cord* 1998; 36(4): 266–274.
4. Sumida M, Fujimoto M, Tokuhiro A, et al. Early rehabilitation effect for traumatic spinal cord injury. *Arch Phys Med Rehabil* 2001; 82(3): 391–395.
5. Scivoletto G, Morganti B and Molinari M. Early versus delayed inpatient spinal cord injury rehabilitation: an Italian study. *Arch Phys Med Rehabil* 2005; 86(3): 512–516.
6. Geisler FH, Coleman WP, Grieco G, et al.; Sygen Study Group. Measurements and recovery patterns in a multicenter study of acute spinal cord injury. *Spine* 2001; 26(24 Suppl.): S68–S86.
7. Waters RL, Adkins R, Yakura J, et al. Donal Munro Lecture: functional and neurologic recovery following acute SCI. *J Spinal Cord Med* 1998; 21: 195–199.
8. Baranowski T and De Moor C. How many days was that? Intra-individual variability and physical activity assessment. *Res Q Exerc Sport* 2000; 71(2 Suppl.): S74–S78.
9. Hart TL, Swartz AM, Cashin SE, et al. How many days of monitoring predict physical activity and sedentary behaviour in older adults? *Int J Behav Nutr Phys Act* 2011; 8(1): 62.
10. Nicolai S, Benzinger P, Skelton DA, et al. Day-to-day variability of physical activity of older adults living in the community. *J Aging Phys Act* 2010; 18(1): 75–86.
11. Warms C. Physical activity measurement in persons with chronic and disabling conditions: methods, strategies, and issues. *Fam Community Health* 2006; 29(1 Suppl.): 78S–88S.
12. Foy T, Perritt G, Thimmaiah D, 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(2): 162–175.
13. Whiteneck G, Gassaway J, Dijkers M, et al. Inpatient treatment time across disciplines in spinal cord injury rehabilitation. *J Spinal Cord Med* 2011; 34(2): 133–148.
14. Whiteneck GG, Gassaway J, Dijkers MP, et al. Inpatient and postdischarge rehabilitation services provided in the first year after spinal cord injury: findings from the SCIRehab Study. *Arch Phys Med Rehabil* 2011; 92(3): 361–368.
15. Zbogar D, Eng JJ, Miller WC, et al. Movement repetitions in physical and occupational therapy during spinal cord injury rehabilitation. *Spinal Cord*, 2016.(in press).
16. Ishikawa S, Stevens SL, Kang M, et al. Reliability of daily step activity monitoring in adults with incomplete spinal cord injury. *J Rehabil Res Dev* 2011; 48(10): 1187–1194.
17. Warms CA and Belza BL. Actigraphy as a measure of physical activity for wheelchair users with spinal cord injury. *Nurs Res* 2004; 53(2): 136–143.
18. Prince SA, Adamo KB, Hamel ME, et al. 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(1): 56.
19. Martin Ginis KA, Latimer AE, Hicks AL, et al. Development and evaluation of an activity measure for people with spinal cord injury. *Med Sci Sports Exerc* 2005; 37(7): 1099–1111.
20. Latimer AE, Martin Ginis KA, Craven BC, et al. The physical activity recall assessment for people with spinal cord injury: validity. *Med Sci Sports Exerc* 2006; 38(2): 208–216.
21. Harness ET, Yozbatiran N and Cramer SC. Effects of intense exercise in chronic spinal cord injury. *Spinal Cord* 2008; 46(11): 733–737.
22. Janssen TW, Van Oers CA, van der Woude LH, et al. Physical strain in daily life of wheelchair users with spinal cord injuries. *Med Sci Sports Exerc* 1994; 26(6): 661–670.
23. Van den Berg-Emons RJ, Bussmann JB, Haisma JA, 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(11): 2094–2101.
24. New PW and Marshall R. International Spinal Cord Injury Data Sets for non-traumatic spinal cord injury. *Spinal Cord* 2014; 52(2): 123–132.

25. Catz A, Itzkovich M, Tesio L, et al. A multicenter international study on the Spinal Cord Independence Measure, version III: Rasch psychometric validation. *Spinal Cord* 2007; 45(4): 275–291.
26. Glass CA, Tesio L, Itzkovich M, et al. Spinal Cord Independence Measure, version III: applicability to the UK spinal cord injured population. *J Rehabil Med* 2009; 41(9): 723–728.
27. Itzkovich M, Gelernter I, Biering-Sorensen F, et al. The Spinal Cord Independence Measure (SCIM) version III: reliability and validity in a multi-center international study. *Disabil Rehabil* 2007; 29(24): 1926–1933.
28. Mathiowetz V, Weber K, Volland G, et al. Reliability and validity of grip and pinch strength evaluations. *J Hand Surg Am* 1984; 9(2): 222–226.
29. Bohannon RW and Schaubert KL. Test-retest reliability of grip-strength measures obtained over a 12-week interval from community-dwelling elders. *J Hand Ther* 2005; 18(4): 426–427, quiz 428.
30. Burns AS, Delparte JJ, Patrick M, et al. The reproducibility and convergent validity of the walking index for spinal cord injury (WISCI) in chronic spinal cord injury. *Neurorehabil Neural Repair* 2011; 25(2): 149–157.
31. Jackson AB, Carnel CT, Ditunno JF, et al. Outcome measures for gait and ambulation in the spinal cord injury population. *J Spinal Cord Med* 2008; 31(5): 487–499.
32. Scivoletto G, Tamburella F, Laurenza L, et al. Validity and reliability of the 10-m walk test and the 6-min walk test in spinal cord injury patients. *Spinal Cord* 2011; 49(6): 736–740.
33. Kirshblum SC, Burns SP, Biering-Sorensen F, et al. International standards for neurological classification of spinal cord injury (revised 2011). *J Spinal Cord Med* 2011; 34(6): 535–546.
34. Bland JM and Altman DG. Measuring agreement in method comparison studies. *Stat Methods Med Res* 1999; 8(2): 135–160.
35. De Vet HCW, Terwee CB, Knol DL, et al. When to use agreement versus reliability measures. *J Clin Epidemiol* 2006; 59(10): 1033–1039.
36. Domholdt E. *Physical therapy research: principles and applications*. 2nd ed. Philadelphia, PA: W.B. Saunders, 2000.
37. Rand D and Eng JJ. Arm-hand use in healthy older adults. *Am J Occup Ther* 2010; 64(6): 877–885.
38. Tudor-Locke C, Craig CL, Aoyagi Y, et al. How many steps/day are enough? For older adults and special populations. *Int J Behav Nutr Phys Act* 2011; 8: 80.
39. Gretebeck RJ and Montoye HJ. Variability of some objective measures of physical activity. *Med Sci Sports Exerc* 1992; 24(10): 1167–1172.
40. Kang M, Bassett DR, Barreira TV, et al. How many days are enough? A study of 365 days of pedometer monitoring. *Res Q Exerc Sport* 2009; 80(3): 445–453.
41. Matthews CE, Ainsworth BE, Thompson RW, et al. Sources of variance in daily physical activity levels as measured by an accelerometer. *Med Sci Sports Exerc* 2002; 34(8): 1376–1381.
42. Van Schooten KS, Rispens SM, Elders PJ, et al. Assessing physical activity in older adults: required days of trunk accelerometer measurements for reliable estimation. *J Aging Phys Act* 2015; 23(1): 9–17.
43. Bowden MG and Behrman AL. Step Activity Monitor: accuracy and test-retest reliability in persons with incomplete spinal cord injury. *J Rehabil Res Dev* 2007; 44(3): 355–362.
44. Washburn RA and Copay AG. Assessing physical activity during wheelchair pushing: validity of a portable accelerometer. *Adapt Phys Act Q* 1999; 16: 290–299.
45. De Groot S, Van der Woude LHV, Niezen A, et al. Evaluation of the physical activity scale for individuals with physical disabilities in people with spinal cord injury. *Spinal Cord* 2010; 48(7): 542–547.
46. Kooijmans H, Horemans HLD, Stam HJ, et al. Valid detection of self-propelled wheelchair driving with two accelerometers. *Physiol Meas* 2014; 35(11): 2297–2306.
47. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med* 2003; 37(3): 197–206.
48. Almansa J, Ayuso-Mateos JL, Garin O, et al. The International Classification of Functioning, Disability and Health: development of capacity and performance scales. *J Clin Epidemiol* 2011; 64(12): 1400–1411.
49. Kroll T, Kratz A, Kehn M, et al. Perceived exercise self-efficacy as a predictor of exercise behavior in individuals aging with spinal cord injury. *Am J Phys Med Rehabil* 2012; 91(8): 640–651.
50. Nooijen CF, Stam HJ, Bergen MP, et al. A behavioural intervention increases physical activity in people with subacute spinal cord injury: a randomised trial. *J Physiother* 2016; 62(1): 35–41.
51. Martin JB, Krč KM, Mitchell EA, et al. Pedometer accuracy in slow walking older adults. *Int J Ther Rehabil* 2012; 19(7): 387–393.
52. Cyarto EV, Myers AM and Tudor-Locke C. Pedometer accuracy in nursing home and community-dwelling older adults. *Med Sci Sports Exerc* 2004; 36(2): 205–209.