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Validity of a wrist-worn consumer-grade wearable for estimating energy expenditure, sedentary behaviour, and physical activity in manual wheelchair users with spinal cord injury

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ABSTRACT

Purpose: To evaluate the validity of a consumer-grade wearable for estimating energy expenditure, sedentary behaviour, and physical activity in manual wheelchair users with spinal cord injury (SCI).
Materials and methods: Fifteen manual wheelchair users with SCI (C5-L1, four female) completed activities of daily living and wheelchair propulsion (2–8 km·h^{-1}). Wrist-worn accelerometry data were collected using consumer-grade (z-Track) and research-grade (ActiGraph GT9X) devices. Energy expenditure was measured *via* indirect calorimetry. Linear regression was used to evaluate the prediction of criterion metabolic equivalent of task (MET) by each accelerometer's vector magnitude (VM). Area under the receiver operating characteristic curve (ROC-AUC) evaluated the accuracy of VM for discriminating between physical activity intensities and for identifying accelerometer cut-points.
Results: Standardised β-coefficients for the association between z-Track and ActiGraph VM for criterion MET were 0.791 (p < 0.001) and 0.774 (p < 0.001), respectively. The z-Track had excellent accuracy for classifying time in sedentary behaviour (ROC-AUC = 0.95) and moderate-to-vigorous physical activity (ROC-AUC = 0.93); similar values to the ActiGraph (ROC-AUC = 0.96 and 0.88, respectively). Cut-points for the z-Track were ≤37 g·min^{-1} for sedentary behaviour and ≥222 g·min^{-1} for moderate-to-vigorous physical activity.
Conclusions: This study supports the validity of a consumer-grade wearable to measure sedentary time and physical activity in manual wheelchair users with SCI.

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Spinal cord injury; wheelchair users; physical activity; sedentary behaviour; accelerometry; wearable device

IMPLICATIONS FOR REHABILITATION

- A consumer-grade wearable device provides valid estimations of sedentary time and physical activity in manual wheelchair users with spinal cord injury.
- Commercially available consumer-grade wearables may enable accurate self-monitoring in this population and, therefore, have potential for supporting behaviour change.

Introduction

Spinal cord injury (SCI) causes partial or complete loss of motor and sensory function to organs and limbs below the neurological level of injury. Globally, traumatic SCI affects an estimated 250,000–500,000 individuals annually [1]. Individuals with SCI have a higher risk of cardiovascular disease (CVD) mortality compared with non-disabled individuals [2] and a high prevalence of poor psychological well-being [3]. This leads to a significant reduction in life expectancy and quality of life. The decline in metabolic and mental health may be related to reduced physical activity in individuals with SCI [4]. Exercise guidelines for this population group, therefore, recommend regular engagement in moderate-to-vigorous aerobic exercise [5]. However, 44% of individuals with SCI self-reported engaging in no physical activity whatsoever [6] and a small sample of adults with paraplegia accumulated just 12 min/day of moderate-to-vigorous physical activity (MVPA) [7]. Individuals with paraplegia are also highly sedentary, engaging in sedentary behaviours for an average of 12.7 h/day in one study when measured using accelerometry [8]. Sedentary behaviour, distinct from physical inactivity, is associated with adverse cardiovascular and psychological outcomes in the general population [9,10]. Thus, it is important to support individuals with SCI in limiting sedentary time and engaging in regular physical activity to improve their physical and psychological health.

There is a wide range of consumer-grade wearable devices (e.g., Apple Watch, Fitbit, and Garmin) that enables the general population to self-monitor, set goals, and receive feedback on physical activity and sedentary behaviour. These wearables have proven effective for behavioural interventions in non-disabled individuals

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[11,12]. While body-worn and wheelchair-mounted sensor-based activity monitors have been developed and validated for quantifying movement, energy expenditure, and physical activity in individuals with SCI [13–15], these monitors are research-grade. Thus, they are of limited use in interventions due to their expense, requirement for specialist knowledge to operate, and lack of automated feedback on behaviour. There is scarce availability and evaluation of consumer-grade wearables for the measurement of physical activity, and no evidence for the measurement of sedentary behaviour, in individuals with SCI or manual wheelchair users more generally. A pilot study demonstrated that a customised intervention using a smartphone, wrist-worn smartwatch, and Bluetooth wheel rotation monitor with near-real-time feedback had the potential to increase physical activity in individuals with SCI [16]. However, this measurement system has limitations including the need for daily charging, data loss when Bluetooth disconnects, and lack of commercially availability. In 2016, Apple Inc. released an Apple Watch wheelchair mode to allow manual wheelchair users to monitor physical activity *via* tracking of wheelchair pushes. However, the Apple Watch has a large degree of error in the prediction of push count compared to direct observation [17,18] and does not provide feedback on sedentary time. Currently, there is a notable absence of consumer-grade wearables for the accurate measurement of sedentary behaviour (e.g., resting and computer work) and physical activity (e.g., activities of daily living and wheelchair propulsion) in wheelchair users with SCI. This limitation hampers the potential use of consumer-grade wearables in supporting behaviour change in this population group.

A consumer-grade wearable capable of accurately measuring sedentary behaviour and physical activity in manual wheelchair users with SCI would be a valuable tool for behavioural surveillance and intervention delivery. The z-Track, a commercially available wrist-worn device originally designed for non-disabled individuals, uses an inbuilt tri-axial accelerometer to monitor movement. This study aimed to:

1. Assess whether the z-Track provides valid estimations of energy expenditure and physical activity intensity across a range of sedentary behaviours, activities of daily living, and exercise intensities in manual wheelchair users with SCI;
2. Determine whether the z-Track has sensitivity and specificity for accurately discriminating between sedentary *vs.* non-sedentary activity and MVPA *vs.* non-MVPA; and
3. Identify z-Track accelerometer cut-points for classifying time spent in sedentary behaviour, light-intensity physical activity, and MVPA.

Materials and methods

Participants and recruitment

A convenience sample of 15 manual wheelchair users with SCI were recruited and took part on a rolling basis between August 2022 and April 2023. Recruitment was *via* social media, spinal injury charities, and other organisations who provide support and services to the target population, and participants from previous studies conducted by the researchers. This recruitment strategy was employed to reach as wide an audience as possible to achieve a representative sample of individuals with SCI living in the community. Inclusion criteria were: female or male, aged 18–65 years, a congenital or acquired SCI for ≥1 years, manual wheelchair as the primary mode of mobility, and able to communicate in English. Individuals were excluded if they suffered from illness or injury that could impede their ability to undertake the study protocols, had a history of poorly controlled autonomic dysreflexia, were a current or recent smoker (as this could confound associations between accelerometery-assessed physical activity and energy expenditure), or were fitted with a pacemaker. Information on lesion level and completeness was collected *via* self-report. This study was conducted in accordance with the Declaration of Helsinki and was approved by Brunel University London Research Ethics Committee (reference: 35330-MHR-Mar/2022-38597-2). Participants provided written informed consent before taking part.

Sample size

Sample size calculations were performed using GPower v3.1.9.2 (Kiel University, Kiel, Germany). To detect a correlation coefficient (r) of 0.68 between accelerations measured by the z-Track and physical activity energy expenditure (PAEE) estimated by indirect calorimetry [19], it was estimated that 15 participants would be required using a one-tailed test with an alpha of 0.05 and a power of 90%.

Participant preparation and preliminary measures

Before testing, participants fasted overnight for ≥10 h, refrained from strenuous exercise for ≥24 h, and avoided alcohol and caffeine intake for ≥12 h. They were permitted to consume water to maintain hydration. Upon arrival, body mass was measured using wheelchair double-beam scales (300 series; Marsden, Rotherham, UK). Participant height, and waist circumference at the level of the umbilicus, were measured using an anatomical tape measure while the participant lay supine on a treatment couch. In the same position, body fat percentage was estimated using bioelectrical impedance (Bodystat 1500; Bodystat Ltd., Isle of Man). Resting metabolic rate (RMR) was then measured followed by consumption of a standardised breakfast comprising cornflakes, semi-skimmed milk, and orange juice.

Experimental protocol

Participants wore both a consumer-grade and a research-grade accelerometer on the wrist of their dominant arm throughout the protocol. In addition, a portable gas analysis system was strapped to the participant for measurement of energy expenditure. The protocol involved participants completing a standardised set of activities in their own wheelchair, with each activity lasting 5 min (Table 1). These activities were selected to represent activities of daily living across a range of intensities, based on previous research [14,19]. To mitigate potential carryover effects, the activities were assigned from low to high intensity with ~1 min between each activity [19]. Sedentary and housework tasks were undertaken in a laboratory, with participants instructed to complete the activities as they would typically at home. Wheelchair propulsion was conducted on an outside path, with the pace set by a researcher who walked/jogged alongside the participant while holding a GPS system (Garmin EDGE 500; Garmin Ltd., Southampton, United Kingdom). Participants were instructed to undertake only the tasks they felt comfortable with.

Energy expenditure

During the RMR and activity protocols, energy expenditure was assessed breath-by-breath using a portable gas-analysis system

Table 1. Activity task protocol.

Activity order	Activity	Type of activity	Description
1	Sitting upright	Sedentary	Participants sat upright and still in their wheelchair
2	Working on a computer	Sedentary	Participants transcribed text from a news article into a word processing document
3	Moving items	Housework	Participants continuously moved boxes of different weights (1, 2, and 3 kg) from a shelf on one side of the laboratory to a shelf on the opposite side of the laboratory
4	Folding clothes	Housework	Participants continuously untangled t-shirts placed on a desk, then neatly folded and stacked them
5	Dusting	Housework	Participants continuously used a feather duster to clean shelving and objects in the laboratory
6	Wheelchair propulsion	Locomotion	Participants pushed their chair along an outdoor path at speeds of 2, 4, 6, and 8 km·h^{-1} for 5 min at each speed

Table 2. Participant characteristics ($n = 15$).

Characteristic	Mean ± *SD*/*n*
Age (years)	51 ± 9
Age range (years)	28–63
Sex (*n*)	
Female	4
Male	11
Lesion level (*n*)	
C5	1
C7	1
T4	1
T9	1
T10	4
T11	2
T12	3
L1	2
Completeness of injury (*n*)	
Motor complete	8
Motor incomplete	6
Syringomyelia	1
Supine height (cm)	166.8 ± 9.2
Body mass (kg)	87.1 ± 26.4
Body mass index (kg·m^2)	30.1 ± 8.0
Waist circumference (cm)	101.8 ± 18.8
Body fat (%)	32.7 ± 11.0
Resting metabolic rate (kcal·day^{-1})	1938 ± 463

Body fat % measured using bioelectrical impedance analysis.

comprising a turbine flowmeter with O_2 and CO_2 gas analysers (Cosmed K5; Cosmed, Rome, Italy). Participants wore a facemask, and the system was calibrated according to the manufacturer's guidelines before each testing session. Resting metabolic rate was assessed in a semi-recumbent position following best practice guidelines [20]. The laboratory remained quiet and was maintained at 20–25 °C. After 10 min of quiet rest, RMR was assessed for ≥10 min in 5 min blocks, with the initial 5 min discarded. This process continued until a coefficient of variation (CV) of ≤10% for VO_2 and VCO_2 was achieved during a 5 min block [20].

Accelerometer measurements

The consumer-grade z-Track device (Glenworth Associates, Cambridge, UK) uses a Microelectro-Mechanical-System (MEMS) accelerometer configured to measure accelerations between ±4 g across *x*, *y*, and *z* axes at a sampling rate of 10 Hz. Raw acceleration data (g) were collected during the activity protocols and extracted for each 5-s epoch *via* Bluetooth transfer using a smartphone app (LightBlue). Data from the app were exported into a txt file, then converted into a csv file using a custom Python script. Signal vector magnitude (SVM [g·min^{-1}]) was calculated using the equation $\sqrt{a(x)^2 + a(y)^2 + a(z)^2}$, where *a* is acceleration (g) and *x*, *y*, and *z* are the acceleration axes.

A research-grade accelerometer (ActiGraph GT9X Link; ActiGraph, Pensacola, USA) was included to provide comparative data. This device has been validated for estimating energy expenditure and classifying sedentary behaviour and MVPA in manual wheelchair users with SCI [13,14,21]. The ActiGraph GT9X uses a MEMS accelerometer that measures acceleration within the range of ±8 g across *x*, *y*, and *z* axes. The device was initialised to collect raw accelerometer data at a sampling rate of 30 Hz. Following the completion of the testing protocol, vector magnitude (VM; counts·min^{-1}) for each 5-s epoch was downloaded and exported into a csv file using ActiLife software v6.13.4 (ActiGraph, Pensacola, USA).

Data processing

All data were processed using Microsoft Excel. For the assessment of energy expenditure, only data from the 60-s intervals during each 5-min task where participants were in a steady state were used. Steady state was defined as a CV <10% for VO_2 and VCO_2 over a 60-s period [15]. The average VO_2 (mL·kg^1·min^{-1}) during each task was divided by 2.7 ml·kg^1·min^{-1} to provide an SCI-appropriate metabolic equivalent of task (MET) [22]. Values ≤1.5 METs were classified as sedentary behaviour, >1.5 to <3.0 METs as light intensity physical activity, and ≥3.0 METs as MVPA [23]. Physical activity energy expenditure was calculated by subtracting resting metabolic rate (kcal·min^{-1}) from the total energy expenditure measured for each activity [14]. Acceleration data from the z-Track (SVM) and ActiGraph (VM) during the 60-s periods when participants were at a steady state were averaged for each activity and used for analysis.

Data analysis

The relationships between acceleration (SVM for the z-Track and VM for the ActiGraph) and PAEE were analysed using Pearson's product moment correlation coefficient (*r*) and coefficient of determination (R^2). Multiple linear regression models, using the enter method, were used to predict criterion MET by z-Track SVM and ActiGraph VM along with age, sex, SCI level, and body fat %. To explore the validity of z-Track SVM and ActiGraph VM in discriminating between sedentary *vs.* non-sedentary and MVPA *vs.* non-MVPA minutes of data, Area Under the Receiver Operating Characteristic Curve (ROC-AUC) was used [14]. ROC-AUC values were categorised as excellent (≥0.90), good (0.80–0.89), fair (0.70–0.79), or poor (<0.70) [24]. The point on the ROC curve that maximised both sensitivity and specificity (identified as the point closest to the-top left corner of the ROC-curve) was used to derive cut-points for distinguishing between sedentary and non-sedentary behaviour and between MVPA and non-MVPA. Statistical analysis was conducted using SPSS software (v28.0; IBM SPSS Inc, Armonk, NY, USA). Statistical significance was accepted as $p \leq 0.05$.

Results

Participant characteristics are shown in Table 2. All participants completed the sedentary and housework tasks. For the wheelchair propulsion task, all participants completed the 2 km·h^{-1} speed, whereas 14, 13, and 7 participants completed the 4, 6, and 8 km·h^{-1} speeds, respectively.

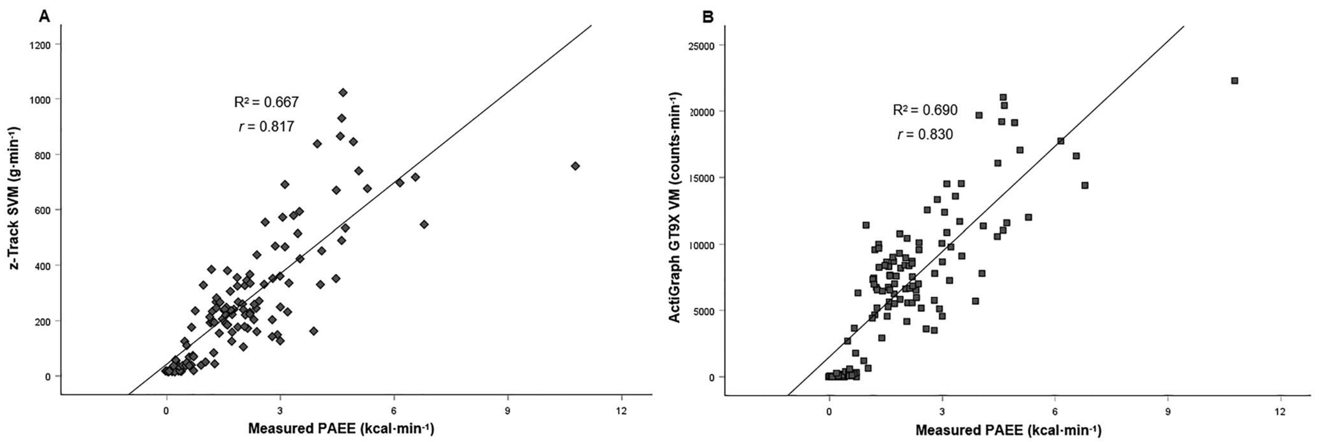

Figure 1. Correlations between physical activity energy expenditure and accelerations for the z-Track (A) and ActiGraph (B). SVM: signal vector magnitude; PAEE: physical activity energy expenditure.

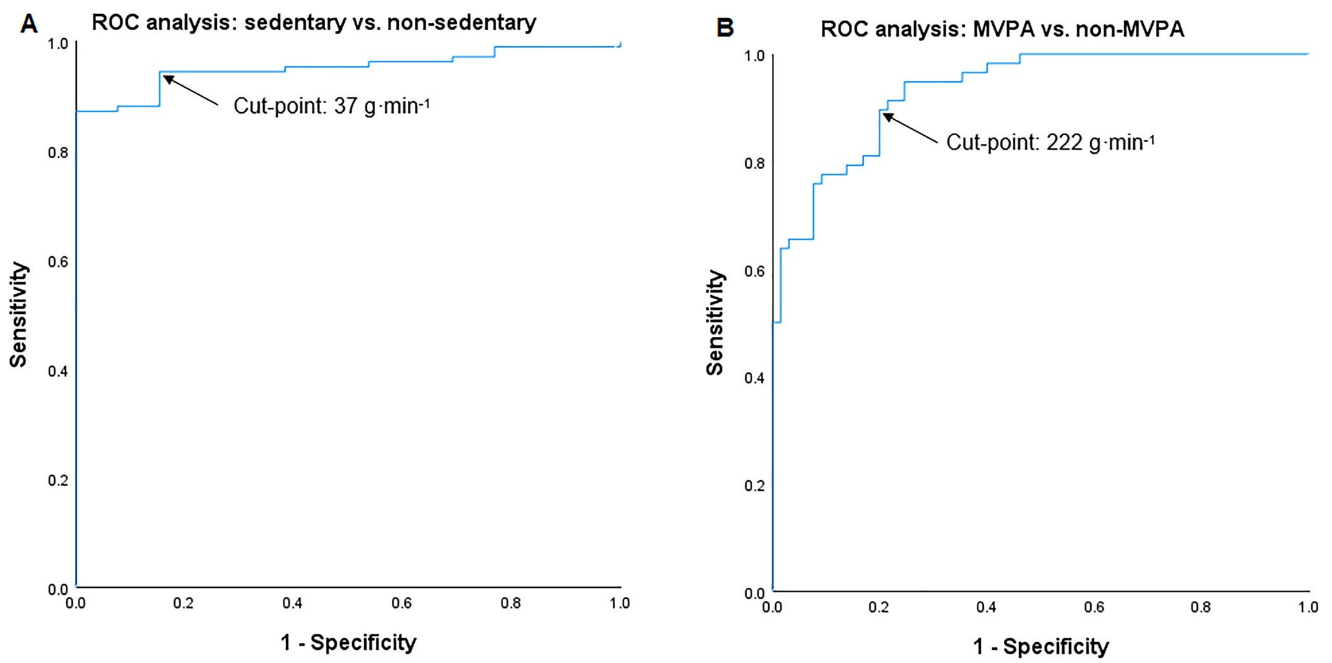

Figure 2. ROC analysis of z-Track vector magnitude for sedentary *vs.* non-sedentary (A) and MVPA *vs.* non-MVPA (B) cut-points. MVPA: moderate-to-vigorous physical activity.

There was a significant positive correlation between z-Track SVM and PAEE ($r = 0.817$, $p < 0.001$) and between ActiGraph VM and PAEE ($r = 0.830$, $p < 0.001$) (Figure 1). There was also a significant positive correlation between z-Track SVM and criterion MET ($r = 0.827$, $p < 0.001$) and between ActiGraph VM and criterion MET ($r = 0.807$, $p < 0.001$) (Supplementary Material 1).

Multiple regression analysis found that R^2 was 0.781 ($p < 0.001$; standard error of estimate [SEE] 0.817) for z-Track SVM's ability to predict criterion MET when entered alongside age, sex, SCI level, and body fat %; this indicates that 78% of the variance in MET was explained by the model. The standardised β-coefficient for the association between z-Track SVM and MET was 0.791 ($p < 0.001$; Supplementary Material 2). For ActiGraph VM (entered with age, sex, SCI level, and body fat %), the R^2 was 0.759 ($p < 0.001$; SEE 0.857), indicating that 76% of the variance in MET was explained by the model. The standardised β-coefficient for the association between ActiGraph VM and MET was 0.774 ($p < 0.001$; Supplementary Material 2). The linear regression equation for predicting criterion MET from z-Track SVM was: MET = 3.893 + 0.0060 (SVM g·min^{-1}). For ActiGraph VM, the equation was: MET = 3.893 + 0.0003 (VM counts·min^{-1}).

The ROC-AUC analysis for the z-Track is shown in Figure 2. The ROC-AUC was excellent for z-Track SVM classifying both sedentary and non-sedentary minutes and MVPA and non-MVPA minutes (Table 3). Cut-points of ≤37 g·min^{-1} for sedentary behaviour, 37–221 g·min^{-1} for light-intensity PA and ≥222 g·min^{-1} for MVPA were identified. The ROC-AUC analysis for the ActiGraph is shown in Supplementary Material 3. For the ActiGraph, there was an excellent ROC-AUC for classifying sedentary and non-sedentary minutes and a good ROC-AUC for classifying MVPA and non-MVPA minutes. The cut-points identified were ≤306 counts·min^{-1} for sedentary behaviour, 307–6792 counts·min^{-1} for light-intensity PA and ≥6793 counts·min^{-1} for MVPA (Table 3).

Discussion

The main finding was that z-Track SVM has a strong, linear correlation with PAEE and criterion MET in manual wheelchair users

Table 3. ROC analysis for time in sedentary *vs.* non-sedentary behaviour and MVPA *vs.* non-MVPA with proposed cut-points for the z-Track and ActiGraph GT9X.

	ROC-AUC (95% CI)	p for ROC-AUC	Cut-point	Sensitivity %	Specificity %
z-Track					
Sedentary *vs.* non-sedentary	0.95 (0.92–0.99)	<0.001	≤37 g·min^{-1}	95	85
MVPA *vs.* non-MVPA	0.93 (0.89–0.97)	<0.001	≥222 g·min^{-1}	90	80
ActiGraph GT9X					
Sedentary *vs.* non-sedentary	0.96 (0.92–0.99)	<0.001	≤306 counts·min^{-1}	91	100
MVPA *vs.* non-MVPA	0.88 (0.83–0.94)	<0.001	≥6793 counts·min^{-1}	81	77

ROC-AUC: area under the receiver operating characteristic curve; CI: confidence interval.

with SCI performing a range of sedentary, housework, and wheelchair propulsion activities. Acceleration measured using this wrist-worn consumer-grade device provided a valid estimate of physical activity intensity, as evidenced by its excellent discriminatory performance in classifying time spent in sedentary behaviour and MVPA. The cut-points derived for sedentary behaviour, light-intensity physical activity, and MPVA from both z-Track and ActiGraph GT9X permit the characterisation of sedentary time and different levels of physical activity intensity.

This study is the first to establish cut-points for physical activity intensity using a consumer-grade device in individuals with SCI. Nightingale et al. [19] evaluated the validity of the wrist-worn research-grade GENEActiv accelerometer for predicting PAEE in manual wheelchair users with paraplegia. The GENEActiv measures raw accelerations (g·min^{-1}), thereby enabling direct comparison with the z-Track. Although Nightingale et al. [19] did not determine a cut-point for sedentary behaviour, they reported a mean GENEActiv SVM for rest of 46 ± 24 g·min^{-1}, which is similar to the z-Track sedentary cut-point of <37 g·min^{-1} identified in the present study. In the study by Nightingale et al. [19], folding clothes, classified as light-intensity physical activity with a MET of 2.0 ± 0.3, had an SVM of 296 ± 66 g·min^{-1} [19]. This value exceeds the z-Track cut-point range of 37–222 g·min^{-1}. As the present study used a range of activities of daily living and adopted a ROC approach to data analysis, the SVM cut-points in the current study are more representative of sedentary behaviours and light-intensity activities compared to average SVM's identified for isolated activities in previous research.

The z-Track demonstrated comparable performance to the ActiGraph in predicting PAEE and criterion MET. Several studies have demonstrated accurate prediction of energy expenditure and physical activity intensity in manual wheelchair users with SCI using wrist-worn research-grade accelerometers during activities of daily living and wheelchair propulsion speeds similar to those in the present study [13,14,19]. Both the z-Track and ActiGraph exhibited excellent discriminatory performance in classifying sedentary behaviour. Previous research has also shown that the ActiGraph accurately classified sedentary behaviour, with a ROC-AUC of 0.95 [13]. The ROC-AUC values for classifying MVPA and non-MVPA minutes were greater for the z-Track than the ActiGraph in the present study (good ROC-AUC) and previous research (fair to good ROC-AUC) [13]. Raw accelerations from the z-Track may outperform arbitrary outputs (counts·min^{-1}) from ActiGraph devices that are subject to on-board manufacturer-defined bandpass filters. These filters, designed to discard "noise" not representative of human movement, may not adequately capture wrist movements of manual wheelchair users [19]. Wrist-worn consumer-grade wearables may provide excellent accuracy in measuring sedentary time and MVPA, comparable to research-grade accelerometers. The z-Track could, therefore, serve as a relatively simple, low-cost option (~£50), providing an accurate alternative to research-grade accelerometers (~£400 for the ActiGraph GT9X) for studies aiming to characterise physical activity and sedentary behaviour in manual wheelchair users with SCI.

The sedentary behaviour cut-point identified for the ActiGraph (<216 counts·min^{-1}) is lower than the previously found cut-point of <2057 counts·min^{-1} in manual wheelchair users with SCI [13]. This disparity could stem from variations in activities performed by participants, such as watching TV, loading and unloading a dishwasher, TheraBand exercises, being pushed in a wheelchair, and weight lifting [13]. The ActiGraph bandpass filters may perform variably across different low-intensity wrist movements, leading to discrepancies across studies [19]. Nightingale et al. [19] reported 119 ± 151 counts·min^{-1} during rest using an earlier generation of the ActiGraph (GT3X) in manual wheelchair users primarily with SCI. The similar sedentary activities performed may account for the comparable ActiGraph counts·min^{-1} noted in the present investigation and the study by Nightingale et al. [19]. Researchers may, therefore, need to consider the types of activities they wish to capture when selecting appropriate cut-points in manual wheelchair users with SCI.

A user-friendly and accessible tool, such as the z-Track could be used to address current gaps in knowledge regarding the association of sedentary behaviour and physical activity with health outcomes in individuals with SCI. Current knowledge regarding the beneficial associations of physical activity with fitness, body composition, and cardiometabolic health in individuals with SCI is primarily derived from self-report measures [25]. However, these measures may introduce inaccuracies due to recall bias. The limited data from device-measured physical activity in this population group have demonstrated null associations with cardiometabolic health, although the sample size has been small [26]. The paucity of literature limits the development of appropriate physical activity and sedentary behaviour recommendations for individuals with SCI. The cut-points established in the current study provide an opportunity for future surveillance research to address the aforementioned gaps in knowledge.

The accompanying z-Track app, originally designed for non-disabled individuals, facilitates the self-monitoring of sedentary time, physical activity (feedback on energy expenditure, active time, and activity points), goal setting, and inactivity alerts. It is recommended that future research is conducted to implement the z-Track cut-points and refine the app specifically for manual wheelchair users with SCI. This approach will provide researchers and individuals in the community with a user-friendly consumer-grade device that provides a greater level of accuracy than currently available options. For example, the z-Track appears to perform better than other consumer-grade smartwatches, such as the Fitbit Flex 2 and Garmin Vivofit, which exhibit high error in counting wheelchair pushes [27]. It is anticipated that the z-Track will also provide accurate feedback on sedentary behaviour, which is currently lacking in consumer-grade devices designed for wheelchair users. Enabling individuals to self-monitor and set goals in relation to physical activity and sedentary behaviour is likely to enhance intervention effectiveness, as noted in non-disabled populations [28].

Estimation of energy expenditure across a wide range of daily living activities and during wheelchair propulsion in an outdoor setting enhances the ecological validity of our findings. Assessing the comparability of the z-Track to the ActiGraph is a further strength. This comparison extends our understanding by demonstrating that a consumer-grade accelerometer can achieve comparable accuracy to research-grade accelerometers in manual wheelchair users with SCI. However, there are potential limitations to consider. The cut-points derived for the z-Track may not be applicable to other wearable devices that use different hardware. There may also be limited generalisability of these cut-points beyond the specific population group studied here. It has been suggested that MVPA cut-points are individually calibrated for individuals with SCI to account for heterogeneity with respect to metabolic responses to exercise [29]. However, this requires individual measurement of resting and physical activity energy expenditure, which would not be practical or scalable for consumer-based devices. The averaging of physical activity intensity data over each minute may have led to misclassifications if any 60-s interval contained a mixture of physical activity intensities. Furthermore, the identified cut-points require validation in other samples to establish their stability across different individuals and diverse settings. Lastly, methods that enable wearable sensors to distinguish between aerobic and resistance exercises are needed in light of each of these being recommended in physical activity guidelines for individuals with SCI [5].

In conclusion, this study is the first to establish the validity of a consumer-grade device for the measurement of energy expenditure and physical activity intensity across a range of sedentary behaviours, activities of daily living, and wheelchair propulsion in manual wheelchair users with SCI. The identified cut-points provided excellent discriminatory accuracy, underscoring their value in research aimed at characterising sedentary behaviour and physical activity intensity in this population. Furthermore, the findings are encouraging with respect to accurate self-monitoring using a relatively low-cost consumer-grade wearable. Such devices have the potential to facilitate behaviour change interventions tailored to the needs of individuals with SCI, thereby contributing to improved health outcomes within this population.

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Data availability statement

The datasets supporting the conclusions of this article are available in Figshare (https://figshare.com/s/e1db69ec9f38bdd1ab16), DOI: 10.17633/rd.brunel.24551791.

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