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Short communication

# Estimating cut points: A simple method for new wearables

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ABSTRACT

Wearable technology is readily available for continuous assessment due to a growing number of commercial devices with increased data capture capabilities. However, many commercial devices fail to support suitable parameters (cut points) derived from the literature to help quantify physical activity (PA) due to differences in manufacturing. A simple metric to estimate cut points for new wearables is needed to aid data analysis.

*Objective:* The purpose of this pilot study was to investigate a simple methodology to determine cut points based on ratios between sedentary behaviour (SB) and PA intensities for a new wrist worn device (PRO-Diary™) by comparing its output to a validated and well characterised 'gold standard' (ActiGraph™).

*Study design:* Twelve participants completed a semi-structured (four-phase) treadmill protocol encompassing SB and three PA intensity levels (light, moderate, vigorous). The outputs of the devices were compared accounting for relative intensity.

*Results:* Count ratios (6.31, 7.68, 4.63, 3.96) were calculated to successfully determine cut-points for the new wrist worn wearable technology during SB (0–426) as well as light (427–803), moderate (804–2085) and vigorous (≥2086) activities, respectively.

*Conclusion:* Our findings should be utilised as a primary reference for investigations seeking to use new (wrist worn) wearable technology similar to that used here (i.e., PRO-Diary™) for the purposes of quantifying SB and PA intensities. The utility of count ratios may be useful in comparing devices or SB/PA values estimated across different studies. However, a more robust examination is required for different devices, attachment locations and on larger/diverse cohorts.



## 1. Introduction

Wearable technology in the form of accelerometer-based body worn monitors are replacing traditional self-report measures of sedentary behaviour (SB) and physical activity (PA) [1]. Compact design and advances in computing have made devices suitable for prolonged wear time in longitudinal and/or large epidemiological studies that investigate associations between objectively measured behaviour/activity and clinical outcomes [2]. Moreover, these devices are now capable of identifying the environmental context of one's habitual sedentary/activity lifestyle [3] as well as provide ecological momentary prompts [4] for situational interventions [5]. One such wearable device is the (PRO-Diary™), which incorporates a touch sensitive screen to deliver intermittent survey prompts throughout a prescribed time-period, and as such facilitates opportunities for greater participant monitoring or PA intervention within the community. However, commercial devices such as this fail to accommodate suitable parameters (cut scores/points) from the literature to differentiate SB and PA levels/intensities due to each device specification.

Objective quantification of SB and PA has been extensively investigated within the literature by utilising the (waist mounted) (ActiGraph™) device which converts acceleration signals over repeated time intervals into 'epochs/counts'. Subsequently, the distinctions between SB and various PA levels (intensities) are reliant on the application of cut points [6]. The importance of appropriate cut points has been stressed due to consequent impact on data interpretation and resulting activity levels e.g., over or

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**Table 1**
Outline of the four phase semi-structured protocol and accompanying intensity data.

| Phase and intensity | | Time (Mean ± SD) | Run information (Mean ± SD) | |
|---|---|---|---|---|
| | | (mins) | Speed (km/h) | Gradient (%) |
| Phase 1 | Sedentary ($n$ = 12) | 6.58 ± 3.60 | – | – |
| Phase 2 | Light ($n$ = 12) | 5.08 ± 0.52 | 4.80 ± 0.00 | 0.00 |
| Phase 3 | Moderate ($n$ = 5) | 20.00 ± 0.00 | 7.68 ± 0.44 | 0.80 ± 1.10 |
| | Vigorous ($n$ = 7) | 18.71 ± 3.40 | 9.74 ± 0.68 | 2.86 ± 1.07 |
| Phase 4 | Light ($n$ = 12) | 5.00 ± 0.00 | 4.80 ± 0.00 | 0.00 |

under-estimation of minutes of moderate to vigorous PA [3], or relationships between PA and various outcomes e.g., health, cognition [7]. The range of values used for cut points varies and relies greatly on the device specifications and a broad range of participant characteristics (age, gender, weight, etc.). For example, numerous iterations (>11) of (ActiGraph™) cut points have been established for young healthy subjects [8]. In order to reduce the subjectivity of activity count data analysis (epoch lengths, cut points) suggestions have been made that all prospective devices that derive PA measures from cut-offs require independent validation against other similar devices [9].

Therefore, when identifying appropriate cut-points for SB and PA intensity classification, appropriate valid continuity of new wearable technologies is paramount. This pilot study aims to investigate a simple methodology to determine SB and PA intensity cut points for a new accelerometer-based wearable technology (PRO-Diary™) by comparing it to a widely used and pre-validated activity monitoring 'gold standard'(ActiGraph™) [10]. Establishing (robust) cut-points derived from a simple ratio metric will inform future SB and PA assessments for the device used here and other wearable technology new to market.

## 2. Methods

### 2.1. Wearable technology

The (PRO-Diary™) (camNtech Ltd. Cambridge, UK) is a small (51 × 34 × 8 mm), lightweight (16 g) device that was attached to the dominant wrist (predominantly right) of each participant by use of the strap attachment. The device is embedded with a tri-axial accelerometer which samples at 50 Hz (0.02 s) and was programmed to capture motion at 1 min (60 s) epochs.

Participants were also fitted with an (ActiGraph™) (wGT3X-BT, LLC, Penascola, US) which was taken as the reference 'gold standard' to determine (PRO-Diary™) cut points. It is a small (46 × 33 × 15 mm), lightweight (19 g) device that was attached at the right waist. The (ActiGraph™) has a tri-axial accelerometer and was programmed to sample at 30 Hz, with data processed in 1 min epochs. Devices were synchronised and data from both devices were stored locally on the sensor's internal memory and were downloaded upon the completion of each testing session.

### 2.2. Protocol

Participants were required to complete a four stage semi-structured protocol designed to synthesise different intensities. Participants were randomly allocated to the third phase based on (i) moderate or (ii) vigorous intensity run, Table 1. Allocation was determined by participant based on participant's ventilation threshold (VT, either 20% below VT or 10% above VT) using Ekkekakis's dual mode model [11]. The treadmill-based protocol consisted of the following:

*Phase 1:*

Sedentary, quiet standing (>5 min) at the beginning and end of testing.

**Table 2**
Participant characteristics.

| Characteristic | Mean ± SD |
|---|---|
| Gender (M/F) | 3/9 |
| Age (years) | 28.50 ± 4.56 |
| Height (m) | 1.67 ± 0.06 |
| Weight (kg) | 62.38 ± 8.12 |
| BMI (kg/m$^2$) | 22.37 ± 2.19 |

*Phase 2 and 4:*

Light, periods of controlled (≈5 min) brisk walking at low intensity (<5 km/h, 0% treadmill gradient).

*Phase 3:*

(i) Moderate, run for a prolonged period (20 min) at high intensity (7.0–8.0 km/h, 0–2% treadmill gradient).

(ii) Vigorous, run for a prolonged period (20 min) at highest intensity (8.1–11.2 km/h, 2–4% treadmill gradient).

### 2.3. Data segmentation & analysis

Data were downloaded from both devices and segmented via a Matlab® program into phases (1–4) with the aid of time-stamps taken at testing. The program calculated the mean intensity values for each device, to determine a ratio in activity counts between (ActiGraph™) and (PRO-Diary™), Eq. (1). The count ratio between phases were averaged to provide values that accounted for the intensity of activity that were applied to cut points from a previous methodology using the (ActiGraph™) intensity values [10].

$$\text{Count ratio} = \frac{\text{ActiGraph Activity Count } n}{\text{ProDiary Activity Count } n} \quad (1)$$

$$\text{ProDiary cut points} = \frac{\text{ActiGraph cut point values}}{\text{Count ratio}} \quad (2)$$

## 3. Results

Participant characteristics are presented in Table 2. There were a greater number of women participants. All participants had a body mass index (BMI) within the healthy range (18.5–24.9). Phase 3 testing for one participant was prematurely ended due to their inability to maintain intensity (vigorous: 11.2 km/h, 4.0%).

Similar trends were observed between (ActiGraph™) and (PRO-Diary™) activity counts for all participants during different intensities (Fig. 1). This is reflected in the mean differences between counts where values increased relative to activity intensity (mean difference); sedentary (1223), light (3688), moderate (6829) and vigorous (6463).

Table 3 shows the result for the estimated (PRO-Diary™) cut scores for sedentary behaviour and physical activity intensities, derived from previous (ActiGraph™) cut points and the count ratio calculated in this study.

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