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Characteristics of very slow stepping in healthy adults and validity of the activPAL3™ activity monitor in detecting these steps

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ABSTRACT

The use of activity monitors to objectively measure stepping activity allows the characterisation of free-living daily activity performance. However, they must be fully validated. The characteristics of very slow stepping were examined and the validity of an activity monitor, the activPAL3™ (PAL Technologies Ltd., Glasgow, UK) to detect these steps was assessed. 10M/10F healthy adults (36 ± 10y) performed a treadmill walking protocol from 1.0 m/s down to 0.1 m/s (0.1 m/s increments) whilst wearing the monitor under video observation (gold standard). Within the 800 stepping periods recorded the proportion of the steps correctly detected by the activPAL3™ was explored against speed and cadence. Below 0.4 m/s walking began to be intermittent, stepping interspersed with stationary postures. At 0.1 m/s almost 90% of walking periods were intermittent. The percentage of steps detected was over 90% for walking speed at or above 0.5 m/s and cadence at or above 69 steps/min. However, below these limits % steps detected reduced rapidly with zero steps detected at 0.1 m/s and at or below 24 steps/min. When examining the stepping activity of groups with limited stepping cadence the above thresholds of performance should be considered to ensure that outcomes are not misinterpreted and important very slow stepping activity missed.

1. Introduction

Physical activity performance is essential for the maintenance of good health with international guidelines recommending the performance of minimum volumes of physical activity [1]. Stepping is one of the key activities that can be used to fulfil the physical activity recommendations. It has been estimated that 7000 steps per day are associated with the development and maintenance of musculoskeletal, cardiorespiratory and neuromotor fitness [2]. Engagement in stepping activity is also required to facilitate the performance of every-day activities around the home and into the wider community. Therefore, it is of interest to be able to quantify the volume of stepping activity that individuals perform in a free-living context, both to gauge the health benefits accrued and to characterise daily living activity.

Stepping is performed at a range of different stepping rates (cadences) which equate to a range of different translational speeds. Usual purposeful 'healthy' self-selected walking speed has been observed to occur at approximately 1.3 m/s (e.g. men 20–30y, 1.39 m/s, women 70–80y, 1.27 m/s [3]). However, slower stepping activity is performed both in healthy populations and in populations with pathology affecting walking speed. In their review of the literature Peel et al. [4] report gait speeds as low as 0.11 m/s in geriatric populations. Studenski et al. [5] reviewed evidence of the relationship between self-selected gait speed and survival, providing information relating to speeds down to 0.2 m/s to fully characterise life course outcomes. It is possible that relatively slow stepping activity forms a considerable proportion of daily activity for sections of the population who do not regularly perform purposeful walking out of the home (e.g. those with limited cardiorespiratory function). If stepping activity is to be accurately objectively measured the full range of stepping rates used should be characterised. Therefore, if the purpose of a device is to measure stepping activity it is important that it is able to adequately detect stepping at slow stepping rates.

Accelerometer based devices are able to monitor stepping activity through analysis of the signal resulting from the movement of the wearer. An example, the PAL Technologies Ltd. family of monitors (activPAL™ (uniaxial) and activPAL3™ (tri-axial), PAL Technologies Ltd., Glasgow, UK), use proprietary analysis algorithms to determine stepping performance. Output from these monitors is in the form of individual strides with allocated durations. This allows the calculation of instantaneous cadence or true

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cadence [6]. The assessment of the activPAL™ monitor's performance has been carried out across a range of speeds. Typical outcomes of the lowest speeds tested in healthy populations are, mean 9.9y, 0.88 m/s, correlation with video observation: $r = 0.88$ [7]; females mean 18.5y, 0.89 m/s stepping agreement 0.3 steps [LOA 3.9 to −3.3] [8]; mean 23y, speed 0.89 m/s, within 1 ± 9 steps out of approx. 200 [9]; mean 28y, speed 0.6 m/s, 1.7% error [10]; mean 34.5y, speed 0.9 m/s, <0.94% error in step count [11]; older adults mean 72y, speed 0.67 m/s, <1% error [12]. According to the outcomes of these studies the activPAL™ has excellent validity for step detection. However, there is emerging evidence that the monitor does not detect all steps when walking below these speeds. Taraldsen et al. [13] indicate that in both a reference population (mean 46.3y) and people with stoke (mean 75.2y) and inpatients (mean 84.0y) steps were under-detected below 0.47 m/s. Kanoun [14] presents provisional results indicating that at 0.45 m/s, for a group mean 23.5y, the percentage error in steps detected was 3.5% with a range of 0–30%. Lutzner et al. [15] report outcomes of assessment in young healthy adults (23.6 SD 4.4y) of step detection for a treadmill based protocol across a wide range of walking speeds from very slow 0.1 m/s to very fast 2.6 m/s. They indicate for the standard placement of the activPAL™ that there is considerable reduction in step detection below 0.7 m/s, with a mean of less than 50% of steps detected at 0.4 m/s compared to manual step count.

Whilst the literature reports stepping activity as low as 0.11 m/s [4] it is possible that the mode of progression at this speed is discontinuous, i.e. one step is taken followed by a pause before the next step. The mode of stepping is not usually described in the literature. Knowledge of the minimum continuous speed for linear progression would provide information for interpreting very slow cadence stepping as recorded by a monitor. Intermittent stepping may be recorded as very slow continuous stepping, perhaps leading to misinterpretation of free-living activity patterns. Low cadence outcomes have been reported in the literature for the activPAL™ (e.g. Dall et al. [6] report cadence as low as 20 steps/min). It is important to understand what this stepping activity represents and if these are likely to be continuous stepping bouts or to be intermittent stepping reported as a continuous stepping activity.

Ideally the validity of the monitors would be established under free-living conditions. However, this is extremely time-consuming as the recognised gold standard is manually counted steps, usually from a video recording. Long periods of data monitoring are, therefore, difficult to perform. A compromise is to use laboratory based data collection methods over short time periods. These can either involve over-ground walking or treadmill based protocols. If the aim of a study is to systematically analyse a range of speeds of walking this is difficult to achieve using over-ground walking; participants can only be asked to walk 'normally' or 'faster' or 'slower' than normal. Treadmill walking provides a compromised in that speed can be finely controlled [15].

The aims of the current study were twofold: first to establish the relationship between speed of walking and cadence at slow stepping rates, including the determination of the slowest speeds of continuous stepping and secondly to establish the validity of the activPAL3™ physical activity monitor to detect stepping at these slow stepping rates.

2. Methods

Twenty (10M/10F) participants, between 18 and 60 years of age, were recruited from staff and students of Glasgow Caledonian University. Informed consent was obtained from the participants and ethical approval for the study was obtained from the Glasgow Caledonian University School of Health and Life Sciences Ethics Committee. Participants did not have any known neurological conditions, lower limb dysfunction, vascular dysfunction that might affect walking or injury to the lower limb sustained within the preceding 6 weeks. Participants' gender, height, weight and age were recorded.

Table 1
Treadmill protocol including a warm up, 4 stepping cycles and rest breaks. There were two stepping cycles, A and B: A (descending cycle) = decreasing from 1.0 m/s to 0.10 m/s, in 0.1 m/s decrements each 30 s; B (ascending cycle) = increasing from 0.10 m/s to 1.0 m/s, in 0.1 m/s increments each 30 s.

Treadmill protocol	Action	Duration
Warm up	Stepping, 0.1–1.0 m/s	2 min
Rest	Standing on the treadmill	1 min
Stepping cycle 1	Stepping, either cycle A or B	5 min
Rest	Standing on the treadmill	1 min
Stepping cycle 2	Stepping, either cycle A or B	5 min
Rest	Standing on the treadmill	2 min
Stepping cycle 3	Stepping, either cycle A or B	5 min
Rest	Standing on the treadmill	1 min
Stepping cycle 4	Stepping, either cycle A or B	5 min
Rest	Standing on the treadmill	1 min

The physical activity monitor, the activPAL3™ (PAL Technologies Ltd., Glasgow, UK) was used in this study. Two monitors were used, one on each thigh. The monitors were attached using PALStickies™ (PAL Technologies Ltd., Glasgow, UK) on the midline of the thigh at the mid-point between the anterior superior iliac spine and the superior border of the patella as measured in a supine position. Participants wore their own clothing and shoes (not high heels). The activPAL3™ detects each stride. The number of steps was calculated as strides multiplied by 2 for each of the monitors. Version 7.1.18 of the activPAL3™ software was used for all data processing.

Once the activPAL3™s had been put in place the participant mounted the treadmill (Woodway, Waukesha, USA, Model PPS 55med, accuracy ±0.007 m/s across 0.1–1.0 m/s settings) and the session commenced. The protocol outlined in Table 1 was followed and included four stepping cycles performed by each participant. Each stepping cycle followed one of two protocols:

A (descending cycle) = decreasing from 1.0 m/s to 0.10 m/s, in 0.1 m/s decrements each 30 s.
B (ascending cycle) = increasing from 0.10 m/s to 1.0 m/s, in 0.1 m/s increments each 30 s.

Each participant completed 2 × A and 2 × B cycles with the order of cycles manipulated to ensure equal numbers of participants completed AB and BA sequences before and after the mid-testing break. The walking cycles were programmed to run automatically under the control of the treadmill. Acceleration and deceleration were completed within the first 1–2 s of transition between speeds within each cycle. Each cycle took 5 min giving an overall protocol time of approximately 25 min.

The entire session was video recorded in high definition.

3. Data analysis

Time synchronisation was achieved between the video record and the activity monitors by identifying the first stride of walking commencing at 1.0 m/s in the activPAL3™ record and the corresponding time point in the video. This time synchronisation was used across the whole walking sequence which was continuously recorded on video.

From the video the timing of the 20 s of stepping activity in the middle of the 30 s period was selected, i.e. leaving a 10 s gap between evaluation periods for sequential speeds. Within the identified 20 s periods all steps (either left or right foot initial contact with the ground) were counted and agreed by two observers. The