The validity and reliability of a novel activity monitor as a measure of walking

C G Ryan, P M Grant, W W Tigbe, M H Granat

Background: The accurate measurement of physical activity is crucial to understanding the relationship between physical activity and disease prevention and treatment.

Objective: The primary purpose of this study was to investigate the validity and reliability of the activiPAL physical activity monitor in measuring step number and cadence.

Methods: The ability of the activiPAL monitor to measure step number and cadence in 20 healthy adults (age 34.5 ± 6.9 years; BMI 26.8 ± 4.8 (mean ± SD)) was evaluated against video observation. Concurrently, the accuracy of two commonly used pedometers, the Yamax Digi-Walker SW-200 and the Omron HJ-109-E, was compared to observation for measuring step number. Participants walked on a treadmill at five different speeds (0.90, 1.12, 1.33, 1.56, and 1.78 m/s) and outdoors at three self-selected speeds (slow, normal, and fast).

Results: At all speeds, inter device reliability was excellent for the activiPAL (ICC (2,1)=0.99) for both step number and cadence. The absolute percentage error for the activiPAL was <1.11% for step number and cadence regardless of walking speed. The accuracy of the pedometers was adversely affected by slow walking speeds.

Conclusion: The activiPAL monitor is a valid and reliable measure of walking in healthy adults. Its accuracy is not influenced by walking speed. The activiPAL may be a useful device in sports medicine.
Care Ethics Committee, and all participants provided written informed consent prior to commencement of the study.

**Instruments**

The *activPAL* is a small activity monitor (5×3.5×0.7 cm) weighing 20 g worn on the anterior aspect of the thigh. It contains a uni-axial accelerometer which responds to gravitational acceleration as well as the acceleration resulting from segmental movement. From the inclination of the thigh, posture can be classified as sitting/lying, standing or walking. In addition, lower limb movement can provide information relating to step number and cadence. The device has a substantial processing capacity and memory allowing activity and posture to be recorded continuously for periods of up to 10 days. The *activPAL* interfaces via a USB connection with a Windows compatible PC. The activity pattern was analysed using proprietary algorithms (*activPAL* Professional Research Edition). The software allows data to be presented in various ways consistent with the needs of the user. The activity can be summarised over 24 h periods in graphical and quantitative formats (fig 1).

Before each walking trial, the *activPAL* monitors were connected to a personal computer through a USB interface and were synchronised with the internal computer clock.

The pedometers used in the study were the Yamax Digi-Walker SW-200 (Yamax Corporation, Tokyo, Japan) and the Omron HJ-109-E (OMRON HEALTHCARE UK LTD, Milton Keynes, UK). The sensitivity of the Omron HJ-109-E was adjusted to the middle setting. A shake test as described by Vincent and Sidman was performed on all of the pedometers used in the study. It was found that all pedometers were within 3% of the actual number of shakes.

Four *activPAL* physical activity monitors (two on each leg) were attached by PALstickies (double-sided hypoallergenic hydrogel adhesive pads) to the skin on the midline of the anterior aspect of the thigh (fig 2). Four pedometers were attached to the waistband of each participant: one pedometer of each brand (Yamax Digi-Walker SW-200 and Omron HJ-109-E) was positioned according to the manufacturers’ recommendations on both the left and right sides of the body.

Following the manufacturer’s instructions, the sensitivity of the Omron HJ-109-E pedometers was adjusted for each participant. With the pedometers in position and step number cleared, each participant was asked to walk 100 steps. The step number display on the Omron HJ-109-E was checked and if the digital display exceeded ±4% (steps) the sensitivity of the pedometers was adjusted. This process was repeated until the Omron HJ-109-E displayed 100±4 steps. The Yamax Digi-Walker SW-200 pedometers did not require calibration.

**Treadmill walking protocol**

The motorised treadmill (PPS Med, Woodway, Waukesha, WI) was calibrated prior to testing. An emergency stop cord was clipped on to the participant who was instructed in the use of the treadmill. There was a 5 min familiarisation period, during which the participant adjusted the controls on

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**Table 1** Characteristics of the study population

<table>
<thead>
<tr>
<th></th>
<th>Total (n = 20)</th>
<th>Females (n = 12)</th>
<th>Males (n = 8)</th>
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<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>34.5 ± 6.9 (23–48)</td>
<td>33.4 ± 6.6 (23–48)</td>
<td>36.0 ± 7.5 (24–48)</td>
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<tr>
<td><strong>Height (m)</strong></td>
<td>1.72 ± 0.09 (1.62–1.89)</td>
<td>1.67 ± 0.06 (1.62–1.85)</td>
<td>1.79 ± 0.08 (1.68–1.89)</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>79 ± 16.2 (57.6–115.3)</td>
<td>73.6 ± 14.9 (57.6–98.0)</td>
<td>87.3 ± 15.3 (63.7–115.3)</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>26.8 ± 4.8 (20.7–36.0)</td>
<td>24.6 ± 5.3 (20.7–36.0)</td>
<td>27.3 ± 4.5 (20.8–33.7)</td>
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Values are means ± 1 SD (range).
The absolute percentage error for the different devices at each outdoor walking speed. The Omron data represent the mean ± 1 SD of the two Omron pedometers. The Yamax data represent the same for the two Yamax pedometers. The activPAL data represent the same for the four activPAL monitors.

**Data analysis**

On the completion of each trial, the data from the activPAL monitors were downloaded to a PC and step number and cadence were calculated by the proprietary software. The video files were downloaded to a PC using Windows Movie Maker (Version 5.1) and played on Windows Media Player. The recordings were visually analysed and the step number for each trial counted. The time line on the recording allowed the observer to calculate cadence. The mean cadence for each walk was calculated from the second, third, and fourth minutes for both the video analysis and activPAL data record. The video data provided the criterion values for step number and cadence at each speed. In looking at step number, the data from the activPAL and both brands of pedometer were compared to observation. Only the activPAL was compared to observation in calculating cadence as the pedometers used in this study were unable to record this parameter.

All descriptive data are presented as mean ± SD. To investigate device validity, the method of Bland and Altman was used to assess the percentage level of agreement between the activPAL and observation for step number and cadence. Observation was regarded as the criterion measure and the narrower the limits of agreement, the more accurate the measurement device. activPAL inter-device reliability for step number and cadence was calculated using intraclass correlation coefficients (ICC 2,1) using the software package SPSS (version 12). ICCs were also used to determine pedometer interdevice reliability for step number. Absolute percentage error for the activPAL monitors and pedometers was calculated to facilitate comparison with other studies.

**RESULTS**

The treadmill walking speeds were predetermined at 0.90, 1.12, 1.33, 1.56, and 1.78 m/s. The mean outdoor walking speeds for the self selected speeds slow, normal and fast were 1.38 ± 0.12, 1.65 ± 0.12, and 1.84 ± 0.14 m/s, respectively.

Over the duration of the study, one session of activPAL data was lost which represented less than 1% of the recording data.
time. One activPAL monitor switched off before the start of a trial which resulted in no data being recorded. No pedometer data were lost.

**Step number**

The activPAL demonstrated excellent inter device reliability (ICC (2,1)=0.99) for step number (table 2). As inter device reliability was excellent for the activPAL monitors, only one activPAL was compared to observation to assess absolute percentage error and the level of agreement. The activPAL monitors were numbered from 1 to 4 and number 2 was randomly selected to be used for all the comparisons. The reliability of the two pedometers of each brand at the different speeds varied considerably from poor to good (ICC (2,1) 0.01–0.89).

Using the method of Bland and Altman, there was an excellent level of agreement between the activPAL and observation (table 3) for all walking speeds on both surfaces (treadmill and outdoors). The values of absolute percentage error for the devices are summarised in figs 3 and 4. For the activPAL monitor, the absolute value of percentage error for step number was less than 1% for all speeds both on the treadmill and outdoors (table 4). The absolute percentage error was large for both brands of pedometer at the slower treadmill and outdoors (table 4). The absolute percentage error values for cadence (ICC (2,1) 0.99) for step number (table 2).

The results for the pedometers revealed poor inter device reliability and poor agreement for step numbers at slow speeds. These findings concur with previous studies.

In this study the BMI of participants ranged widely (table 1) with five individuals possessing a BMI>30 kg/m², the clinical classification of obese. While investigating the effect of obesity on the accuracy of the activPAL was not the focus of the study, the low absolute percentage error values for all participants suggest that the monitor accuracy is not adversely affected by obesity. However, as the number of obese individuals was low, further research may be needed to confirm these observations.

The positive effects of physical activity are well documented and guidelines quantifying the amount of exercise needed to achieve health benefits have been published. In translating the guidelines into practice, it is essential to consider the dose-response relationship between activity and health. In order to encourage a person to be active, the activity must

<table>
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<th>Table 3</th>
<th>The percentage agreement for step number and cadence between observation and the activPAL monitor</th>
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<tr>
<td>Speed (m/s)</td>
<td>Observation (step number)</td>
</tr>
<tr>
<td>Treadmill</td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td>498 ± 42</td>
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<tr>
<td>1.12</td>
<td>555 ± 44</td>
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<tr>
<td>1.33</td>
<td>590 ± 48</td>
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<tr>
<td>1.56</td>
<td>622 ± 45</td>
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<tr>
<td>1.78</td>
<td>666 ± 45</td>
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<tr>
<td>Outdoor</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>608 ± 44</td>
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<tr>
<td>Slow</td>
<td>653 ± 40</td>
</tr>
<tr>
<td>Fast</td>
<td>579 ± 41</td>
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LLOA, lower limit of agreement; ULOA, upper limit of agreement. Step number and cadence are presented as means ± 1 SD.

<table>
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<th>Table 4</th>
<th>The absolute percentage error for step number and cadence for the activPAL physical activity monitor at the various walking speeds</th>
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<tr>
<td>Speed (m/s)</td>
<td>Actual step no. (step number)</td>
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<tr>
<td>Treadmill</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
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Values are means ± 1 SD.
be perceived to be feasible and the minimum dosage for health benefits established. When quantifying activity, dose is related to the duration, frequency, intensity, and mode. In walking, duration can be determined by a daily total of step number, time, or distance. Frequency relates to the number of walking episodes per day and intensity is indicated by cadence or speed. The different elements of walking as an activity (duration, frequency, and intensity) are also of clinical interest. Although a daily total (step number, distance, or time) may provide useful information, it may be more relevant to a clinician to know if this is accumulated from one long walk or multiple short walks. In combating sedentary behaviour, frequent short walks may be recommended. However, lengthy periods of walking may be advocated when increasing endurance. Consequently, measurement devices that are able to record all of these parameters are valuable. This study identifies the activPAL as such a device and considering it is unaffected by walking speed or BMI, it may prove a useful tool, not only in healthy groups but in elderly and clinical populations. The main disadvantage of accelerometer based monitors, including the activPAL, is their relatively high cost when compared to waist mounted pedometers. However, this has to be balanced against the quality and detail of information provided by these devices.

This study focussed on the performance of the device with healthy adults walking at a wide range of cadences, and showed consistently good performance across all testing conditions. However, it is possible that the activPAL may not perform as well with other populations, such as the frail elderly or young children, as the algorithms used may be favoured towards the gait of healthy adults. For example, frail elderly adults may walk with a hesitant, slow gait different to that of a healthy population. As with all such devices, further testing in these groups would be required.

The total duration of testing, for each participant, was approximately 40 min, which was a small percentage of the monitor’s full time recording capability of 10 days. This methodology is consistent with other similar studies in the literature, but testing overall performance of the device over a longer period may be warranted.

It is acknowledged that treadmill walking is not representative of normal walking, which may be a limitation of the study. However, it is useful to evaluate ambulatory monitors at controlled walking speeds. The outdoor free-walking section of this study allowed the monitor to be tested under normal walking conditions as the route required subjects to negotiate curbs, small slopes, road crossings, and limited traffic within the university campus.

CONCLUSION

The activPAL has been shown to be a valid and reliable device for measuring step number and cadence in a healthy adult population. The monitor performed equally well in outdoor and treadmill trials. The accuracy of the monitor was unaffected by walking speed.

ACKNOWLEDGEMENTS

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What is already known on this topic

- Walking is usually assessed using devices which primarily measure the total number of steps taken
- Little information is available on other characteristics of walking activity such as cadence and time spent walking

What this study adds

- This study demonstrated the validity and reliability of a new device, the activPAL, for measuring cadence and step number, at a range of different speeds in a healthy adult population
- The activPAL performed equally well in outdoor and treadmill trials

Competing interests: one of the authors is a co-inventor of the activPAL physical activity monitor and a director of PAL Technologies Ltd. However that author was not involved in data collection or the statistical analysis of the results. The remaining authors declare no competing interests

Ethics approval: the study procedure was approved by the Glasgow Caledonian University’s School of Health and Social Care Ethics Committee, and all participants provided written informed consent prior to commencement of the study

Informed consent was obtained for publication of figure 2

REFERENCES

2 Chakravarty MV, Joyner M, Booth FW. An obligation for primary care physicians to prescribe physical activity to sedentary patients to reduce the risk of chronic health conditions. Mayo Clin Proc 2002;77:165–73.


Who said that?

“In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual.”

“Measure what is measurable, and make measurable what is not so. I do not feel obliged to believe that the same God who endowed us with sense, reason, and intellect intended us to forgo their use.”

“All truths are easy to understand once they are discovered; the point is to discover them. Infinities and indivisibles transcend our finite understanding, the former on account of their magnitude, the latter because of their smallness; imagine what they are when combined.”

“I have never met a man so ignorant that I could not learn something from him.”

“And who can doubt that it will lead to the worst disorders when minds created free by God are compelled to submit slavishly to an outside will...when people devoid of whatsoever competence are made judges over experts and are granted authority to treat them as they please? These are the novelties which are apt to bring about the ruin of commonweals and the subversion of the state.” (Written on the margin of his own copy of Dialogue on the great world systems.)

“Epur si muove. (And yet it does move)” (Apocryphal words to himself after making his abjuration of heliocentricity to the Inquisition.)

See page 806 for the answer.