ORIGINAL ARTICLE

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

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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 *activ*PAL physical activity monitor in measuring step number and cadence.
Methods: The ability of the *activ*PAL 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 *activ*PAL (ICC (2,1)⩾0.99) for both step number and cadence. The absolute percentage error for the *activ*PAL 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 *activ*PAL monitor is a valid and reliable measure of walking in healthy adults. Its accuracy is not influenced by walking speed. The *activ*PAL may be a useful device in sports medicine.

Lack of physical activity has been recognised as a major underlying cause of death, disease, and disability.[1] Physical activity helps in the prevention of certain diseases and favourable effects of regular physical activity have been reported in individuals suffering from chronic diseases such as type II diabetes mellitus, cardiovascular disease, obesity, and certain cancers.[2 3] Several physical activity guidelines have been developed to reduce the risk of developing specific diseases. However, the most commonly cited guideline is directed at sedentary adults. This recommends 30 min of moderate intensity physical activity on most, preferably all, days of the week.[4] The activity may be achieved in a single session or accumulated in 10 min bouts throughout the day.[5] Activity guidelines specify that time and intensity are important factors which should be considered when selecting a valid and reliable device to measure walking. The accurate measurement of activity is needed to better establish the relationship between physical activity and health.[6]

In order to provide objective measures of walking, a number of measuring devices have been employed, the most simple of these being waist worn pedometers. Due to their low cost and ease of use, they are attractive to researchers, clinicians, and individuals interested in their personal activity levels. Pedometers display cumulative step number giving the user a daily tally. This total may provide a person with a target to aim for but gives no indication as to when in the day the wearer was active, how long each walk lasted, or the intensity (for example, cadence) of the walk. Additionally, waist worn pedometer accuracy is compromised by slow walking speeds[7–14] and obesity.[15–17] The poor accuracy of waist mounted pedometers in recording slow walking may be a serious limitation when monitoring activity in patient groups such as the frail elderly. Ankle mounted pedometers (for example, the StepWatch Activity Monitor and the Activity Monitoring Pod 331) using accelerometer technology appear to have overcome the problems identified with waist worn devices, and research has shown such devices to be valid and reliable irrespective of walking speed and obesity.[11 18–20]

The *activ*PAL professional physical activity monitor (PAL Technologies Ltd, Glasgow, Scotland) is a single unit device, requiring no calibration, that records step number and instantaneous cadence for each period of walking. In addition, the monitor identifies episodes of walking, sitting, and standing in real time. As no validity or reliability data exist for this physical activity monitor, the primary purpose of this study was to evaluate the validity and reliability of the *activ*PAL for measuring step number and cadence. Video analysis was used as an objective measure of step number and cadence and was the criterion measure used for comparison to the *activ*PAL. In practice most clinicians use pedometers to quantify walking, so the secondary purpose of the study was to compare the *activ*PAL to two commercially available and widely used pedometers, the Yamax Digi-Walker SW-200 and the Omron HJ-109-E.

METHODS

This study followed the procedures outlined in previous research[7 10 14] investigating the accuracy of motion sensor devices for measuring walking. There were two sections to this study. In the first part, participants walked at predetermined speeds on a treadmill and in the second part at self selected speeds outdoors. All walking sensors were worn simultaneously for each test. The data from the *activ*PAL activity monitor and the pedometers were compared to video observation which was regarded as the criterion measure.

Participants

A convenience sample of 20 (8 male and 12 female) individuals was recruited from the staff and student population of Glasgow Caledonian University. Participants ranged widely in age and BMI (table 1). The study procedure was approved by the University's School of Health and Social

Table 1 Characteristics of the study population

	Total (n = 20)	Females (n = 12)	Males (n = 8)
Age (years)	34.5±6.9 (23–48)	33.4±6.6 (23–48)	36.0±7.5 (24–48)
Height (m)	1.72±0.09 (1.62–1.89)	1.67±0.06 (1.62–1.85)	1.79±0.08 (1.68±1.89)
Weight (kg)	79.1±16.2 (57.6–115.3)	73.6±14.9 (57.6±98.0)	87.3±15.3 (63.7–115.3)
BMI (kg/m^2)	26.8±4.8 (20.7–36.0)	24.6±5.3 (20.7–36.0)	27.3±4.5 (20.8–33.7)

Values are means±1 SD (range).

Care Ethics Committee, and all participants provided written informed consent prior to commencement of the study.

Instruments

The *activ*PAL 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 *activ*PAL interfaces via a USB connection with a Windows compatible PC. The activity pattern was analysed using proprietary algorithms (*activ*PAL 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 *activ*PAL 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[21] 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 *activ*PAL physical activity monitors (two on each leg) were attached by PAL*stickies* (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.

Figure 2 The monitors in position for testing. The *activ*PAL monitor is worn on anterior mid-thigh, and the pedometers placed on the hip with the Omron lateral to the Yamax. Informed consent was obtained for publication of this figure.

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

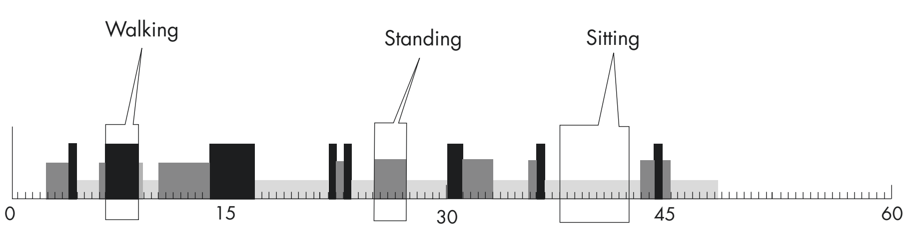

Figure 1 A representation of the output of the *activ*PAL for a 1 h period (0–60 min on the horizontal bar). In this figure the pattern of activity for the participant can be seen as they change between the postures of sitting, standing, and walking. The tall bars represent walking, the medium bars standing, and the short bars sitting/lying.

Table 2 Reliability of the monitors for step number and cadence at the various walking speeds

Speed (m/s)	Interdevice reliability (ICC 2,1) Omron	Yamax	*activ*PAL (step number)	*activ*PAL (cadence)
Treadmill				
0.90	0.48	0.30	0.99	0.99
1.12	0.22	0.52	1.00	0.99
1.33	0.12	0.45	0.99	0.99
1.56	0.56	0.37	1.00	0.99
1.78	0.89	0.89	0.99	0.99
Outdoor				
Slow	0.01	0.48	0.99	0.99
Normal	0.73	0.56	0.99	0.99
Fast	0.70	0.74	0.99	0.99

ICC, intraclass correlation coefficient.

the treadmill and experienced the different speeds that were used in the study. On completion of the familiarisation period, a chair was placed on the treadmill and the participant sat down before data collection commenced. This postural transition facilitated synchronisation of the *activ*PAL data with the video analysis. All pedometers were reset to zero before each trial.

The participant walked on the treadmill at five different speeds (0.90, 1.12, 1.33, 1.54, and 1.78 m/s) for 5 min at each speed. This was in line with previous protocols.[7 10 14] After each speed the participant stopped the treadmill and sat down on a chair, and the pedometer counts were recorded. The pedometers were reset to zero before the participant proceeded to the next speed. The rest time between each period of walking was approximately 1 min. Throughout this study a digital video recorder focussed on the participant's lower limbs recorded the walking activity.

Outdoor walking protocol

In the second part of this study, each participant walked outdoors around a 500 m course on the university campus. Three walks were undertaken, one at each of the following self selected speeds: slow, normal, and fast. After each walk the participant stopped and sat down on a chair and the pedometer values were recorded. The pedometers were then set to zero before the next walk. The time between each walking trial was approximately 1 min. Each walk was recorded on a digital video camera focussed on the lower limbs by a researcher walking behind the participant.

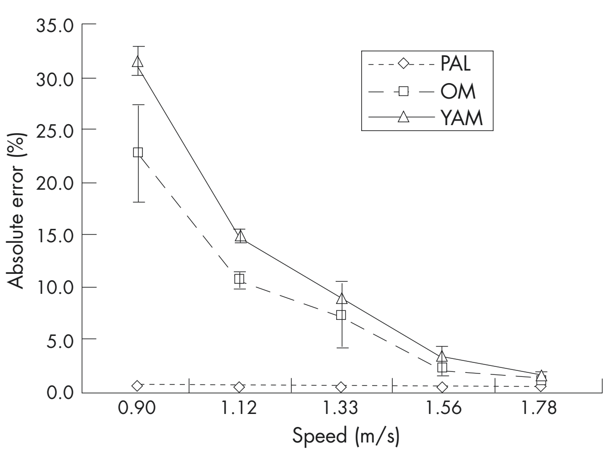

Figure 3 The absolute percentage error for the different devices at each treadmill speed. The Omron data represent the mean ± 1 SD of the two Omron pedometers. The Yamax data represent the same for the two Yamax pedometers. The *activ*PAL data represent the same for the four *activ*PAL monitors.

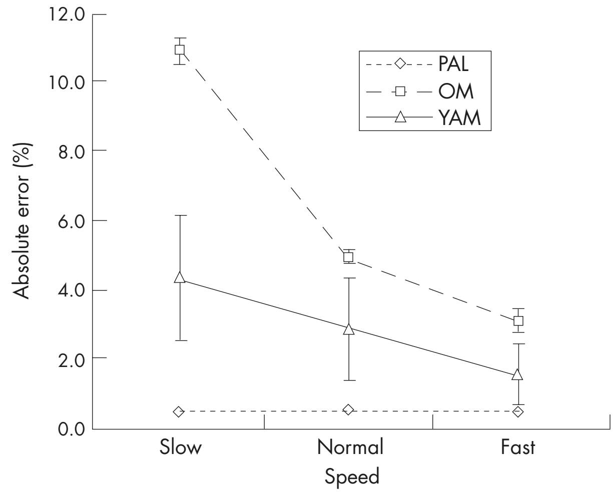

Figure 4 The absolute percentage error for the different devices at each outdoor walking speed. The Omron data represent the mean ± 1 SD of the two Omron pedometers. The Yamax data represent the same for the two Yamax pedometers. The *activ*PAL data represent the same for the four *activ*PAL monitors.

Data analysis

On the completion of each trial, the data from the *activ*PAL 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 *activ*PAL 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 *activ*PAL and both brands of pedometer were compared to observation. Only the *activ*PAL 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 $\pm$ SD. To investigate device validity, the method of Bland and Altman[22] was used to assess the percentage level of agreement between the *activ*PAL 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. *activ*PAL inter-device reliability for step number and cadence was calculated using intraclass correlation coefficients (ICC 2,1)[23] using the software package SPSS (version 12). ICCs were also used to determine pedometer interdevice reliability for step number. Absolute percentage error for the *activ*PAL 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 *activ*PAL data was lost which represented less than 1% of the recording

Table 3 The percentage agreement for step number and cadence between observation and the *activ*PAL monitor

Speed (m/s)	Step number: Observation (step number)	Mean difference (%)	ULOA (%)	LLOA (%)	Cadence: Observation (step number)	Mean difference (%)	ULOA (%)	LLOA (%)
Treadmill								
0.90	498±42	0.94	1.87	0.01	93±8	0.80	3.10	−1.40
1.12	555±44	0.59	1.13	0.06	103±7	0.76	2.65	−1.12
1.33	590±48	0.50	1.18	−0.18	110±7	0.70	3.20	−1.80
1.56	622±45	0.44	1.08	−0.20	118±7	0.80	3.20	−1.50
1.78	666±45	0.63	1.89	−0.63	127±7	0.99	2.60	−0.63
Outdoor								
Normal	608±44	−0.02	1.15	−1.18	121±8	0.90	3.20	−1.30
Slow	653±40	0.06	1.17	−1.05	112±8	0.30	2.60	−2.00
Fast	579±41	0.18	1.39	−1.03	128±7	0.10	2.90	−2.60

LLOA, lower limit of agreement; ULOA, upper limit of agreement. Step number and cadence are presented as means±1 SD.

time. One *activ*PAL monitor switched off before the start of a trial which resulted in no data being recorded. No pedometer data were lost.

Step number

The *activ*PAL demonstrated excellent inter device reliability (ICC (2,1)⩾0.99) for step number (table 2).[23] As inter device reliability was excellent for the *activ*PAL monitors, only one *activ*PAL was compared to observation to assess absolute percentage error and the level of agreement. The *activ*PAL 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).[23]

Using the method of Bland and Altman, there was an excellent level of agreement between the *activ*PAL 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 *activ*PAL 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 speeds and improved considerably as speed increased (fig 3). A similar trend was shown for outdoor walking (fig 4).

Cadence

The *activ*PAL demonstrated excellent inter device reliability for cadence (ICC (2,1)⩾0.99).[23] The Bland and Altman comparison shows excellent agreement for cadence between observation and the *activ*PAL monitor (table 3). The absolute value of percentage error for cadence for the *activ*PAL monitor was <1.11% for all speeds both on the treadmill and outdoors (table 4).

DISCUSSION

Walking is the primary form of physical activity undertaken by the general public and, therefore, it is essential that any study wishing to measure physical activity uses a valid and reliable tool for measuring walking. The primary purpose of this study was to evaluate the *activ*PAL as an objective measurement device for walking. The results indicate that the monitor is valid and reliable for measuring step number and cadence, with an absolute value of percentage error of less than 1.2% for both these parameters regardless of walking speed and surface. The accuracy for measuring step number is comparable to that reported for the Step Watch activity monitor which has been shown previously to be a very accurate walking measurement device.[18 19]

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.[16 17 24]

In this study the BMI of participants ranged widely (table 1) with five individuals possessing a BMI>30 kg/m^2, the clinical classification of obese. While investigating the effect of obesity on the accuracy of the *activ*PAL 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.[25–27] In order to encourage a person to be active, the activity must

Table 4 The absolute percentage error for step number and cadence for the *activ*PAL physical activity monitor at the various walking speeds

Speed (m/s)	Actual step no. (step number)	% Error	Actual cadence (step number/min)	% Error
Treadmill				
0.9	498±42	0.94±0.47	93±8	0.93±1.05
1.12	555±44	0.59±0.27	103±7	0.86±0.86
1.33	590±48	0.53±0.28	110±7	1.08±0.94
1.56	622±45	0.47±0.27	118±7	1.09±0.96
1.78	666±45	0.66±0.60	127±7	1.06±0.71
Outdoor				
Normal	608±44	0.37±0.47	121±8	1.11±0.97
Slow	653±40	0.42±0.37	112±8	1.01±0.63
Fast	579±41	0.47±0.43	128±7	1.03±0.94

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.[26] 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 *activ*PAL 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 *activ*PAL, 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 *activ*PAL 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,[7 10 14] 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 *activ*PAL 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.

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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 *activ*PAL, for measuring cadence and step number, at a range of different speeds in a healthy adult population
- The *activ*PAL performed equally well in outdoor and treadmill trials

Competing interests: one of the authors is a co-inventor of the *activ*PAL 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

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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 commonwealths 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.

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