ORIGINAL ARTICLE

The validation of a novel activity monitor in the measurement of posture and motion during everyday activities

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

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See end of article for authors' affiliations

Correspondence to: P Margaret Grant, Glasgow Caledonian University, School of Health and Social Care, Glasgow, UK; m.grant@gcal.ac.uk

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Background: Accurate measurement of physical activity patterns can be used to identify sedentary behaviour and may facilitate interventions aimed at reducing inactivity.
Objective: To evaluate the *activ*PAL physical activity monitor as a measure of posture and motion in everyday activities using observational analysis as the criterion standard.
Methods: Wearing three *activ*PAL monitors, 10 healthy participants performed a range of randomly assigned everyday tasks incorporating walking, standing and sitting. Each trial was captured on a digital camera and the recordings were synchronised with the *activ*PAL. The time spent in different postures was visually classified and this was compared with the *activ*PAL output.
Results: Intraclass correlation coefficients (ICC 2,1) for interdevice reliability ranged from 0.79 to 0.99. Using the Bland and Altman method, the mean percentage difference between the *activ*PAL monitor and observation for total time spent sitting was 0.19% (limits of agreement −0.68% to 1.06%) and for total time spent upright was −0.27% (limits of agreement −1.38% to 0.84%). The mean difference for total time spent standing was 1.4% (limits of agreement −6.2% to 9.1%) and for total time spent walking was −2.0% (limits of agreement −16.1% to 12.1%). A second-by-second analysis between observer and monitor found an overall agreement of 95.9%.
Conclusion: The *activ*PAL activity monitor is a valid and reliable measure of posture and motion during everyday physical activities.

Concern regarding the prevalence of physical inactivity was highlighted in the World Health Report in 2002.[1] The consequences of physical inactivity and the benefits of regular activity have been extensively documented[2–5] and interventions to promote activity have been proposed.[6 7] Accurate measurement of physical activity patterns can be used to identify sedentary behaviour and may facilitate the design of interventions aimed at reducing inactivity.

Physical activity is determined by posture and movement, which can provide a comprehensive profile of an individual's activity and sedentary behaviour when recorded over an extended period of time. Such information can be vital to clinicians and researchers in understanding the development and progression of illness, as certain chronic disorders may be related to time spent in specific postures. For example, prolonged sitting may be associated with the development of obesity[8] and sustained postures may be implicated in work related injuries.[9] A detailed postural activity profile might allow for tailored interventions to change or increase the physical activity level. Repeated measurement of activity pre- and post-intervention would allow clinicians to determine the specific changes in physical activity level (frequency, duration, time and type) which could not be identified from a global measurement of energy expenditure.

In cases where the postural physical activity levels are of importance, observation is regarded as the criterion measure.[10–12] Direct observation has been employed in clinical practice,[13 14] however, this method is very time consuming and is not feasible for long-term monitoring in the home environment. Accelerometry has been proposed as a more viable alternative[15] and a number of accelerometer-based systems measure postural physical activity level.[9–11 16 17] These devices usually involve the application of a number of sensors to different parts of the body, for example, the trunk and thigh. Generally, the more sensors that are used, the greater the number of postures that can be distinguished[9–11 16] but the more cumbersome the device. The attachment of multiple sensors may inhibit free-living activity and may also affect compliance for long-term monitoring. For prolonged periods of measurement a small single unit device may be more acceptable to the wearer.

The *activ*PAL professional physical activity monitor (PAL Technologies Ltd, Glasgow, Scotland) is a single unit monitor based on a uni-axial accelerometer. It identifies episodes of walking, sitting and standing, allowing the measurement of both activity and inactivity. In addition, the monitor records step number and instantaneous cadence. The device has previously been used to measure posture[18] and has been validated for step count and cadence.[19] Currently there are no data available on the validity and reliability of this device for recording the time spent sitting, standing and walking or for identifying postural transitions.

The purpose of this study was to evaluate the validity and reliability of the *activ*PAL physical activity monitor as an objective measure of posture and postural transition in a simulated free-living setting using observational analysis as the criterion comparison.

METHODS

Overview

This study was divided into two testing sections, a controlled section and an activities of daily living (ADL) section. During the controlled section participants were asked to sit, stand and walk for periods of 2–9 min. During the ADL section the

Abbreviations: ADL, activities of daily living; ICC, intraclass correlation coefficients

Table 1 A selection of everyday tasks including a range of sitting, standing and walking activities

1. Remove clothes from washing machine and hang on clothes rack
2. Prepare and consume drink of choice
3. Remove clothes from clothes rack and fold in pile
4. Change bulb in table lamp
5. Remove clothes from basket and iron
6. Change fuse in plug
7. Put on duvet cover and pillowcases
8. Place lampshade on table lamp
9. Clean mirror
10. Watch video
11. Wash and dry dishes
12. Read newspaper
13. Remove rubbish from swing bin, put rubbish by door and replace bin liner
14. Word-process document using PC
15. Vacuum paper from floor
16. Make telephone call
17. Wash and dry hands
18. Write letter/list
19. Prepare and eat sandwich/biscuit

participants performed six everyday activities in a random order. Each testing section lasted 15–20 min. For the duration of the test, each participant wore three *activ*PAL activity monitors and the entire test was recorded by a digital camera. The information from the *activ*PAL monitor was then compared with the video observation (criterion measure) to establish the validity of the output of the monitor. The outputs of the three monitors were compared to investigate the interdevice reliability. In addition, the video recordings were classified by three researchers to establish the inter-observer reliability and ensure there was no observer bias in analysing the video recordings.

Participants

A convenience sample of 10 adults was recruited from staff and students at Glasgow Caledonian University. All participants were healthy individuals capable of undertaking the activities included in the study. Approval for the study was obtained from the School of Health and Social Care Ethics Committee and informed consent was obtained.

Instrument

The *activ*PAL professional (PAL Technologies Ltd, Glasgow, UK) is a light, credit card sized monitor worn midline on the anterior aspect of the thigh. It is a uni-axial accelerometer which produces a signal related to thigh inclination. Posture is inferred from the position of the thigh and is classified as sitting/lying, standing or walking using proprietary software. The *activ*PAL interfaces with a Windows compatible PC and the software package (*activ*PAL Professional Research Edition) analyses the activity record using proprietary algorithms. The software summarises activity over 1 h periods in graphical (fig 1) and numeric formats and data can be saved and exported to Microsoft Excel allowing a more detailed analysis. Three *activ*PAL activity monitors were used in this study. Before each test, the monitors were connected to a PC and synchronised using the proprietary software.

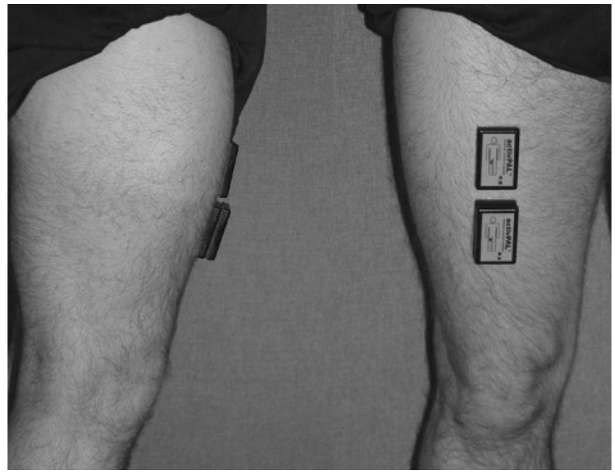

Figure 2 Side and front views of monitors placed mid thigh. Consent was obtained for publication of this figure.

Procedure

Three separate monitors were used in this study to investigate interdevice reliability. One monitor was placed mid thigh and a second positioned immediately distally. A third *activ*PAL was ''piggybacked'' on top of the distal monitor (fig 2). All monitors were attached by PAL*stickies* (double-sided hydrogel adhesive pads).

All testing was undertaken in a large open room with a treadmill and chair located at one end. The remainder of the room was arranged to allow the participants freedom of movement and provide a semi-natural location for the performance of the ADL. The household utensils required for the ADL were distributed around the room.

In the controlled section each participant was required to stand, sit and walk at a self-selected speed. Walking was performed on a treadmill to facilitate the video recording. Each posture was performed once by each participant, and the order and duration (between 2 and 9 min) of these controlled activities were randomised using a computer generated number system.

The ADL section consisted of the participants performing a range of everyday activities. As in previous protocols,[20 21] a list of activities representative of those performed in everyday living was compiled (table 1) and each participant was required to carry out six tasks from this list. The activities for the participants were randomly chosen using a computer generated selection procedure with numbers ranging from 1 to 19. Some tasks had a definite finishing point, whereas others were open-ended. The duration of open-ended tasks was randomised to between 2 and 9 min and participants were told when to move to finish the task. No instructions were provided as to how to perform the activities.

Following each test, data from the *activ*PAL monitors were downloaded to a PC which created an activity profile for the

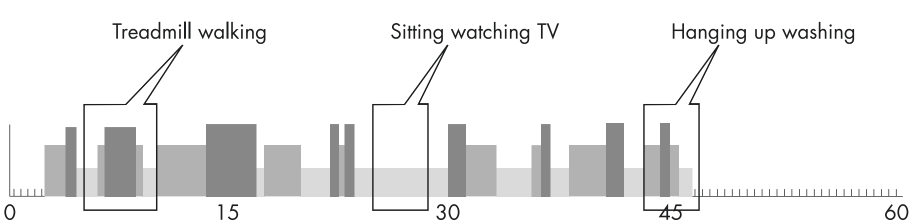

Figure 1 *activ*PAL activity profile for a 1 h period. In this figure the pattern of activity for the participant can be seen as he/she changes between the postures of sitting, standing and walking whilst doing everyday activities. The short vertical bars show sitting, the intermediate bars indicate standing and the tall vertical bars represent walking. These bars are shaded differently to facilitate interpretation.

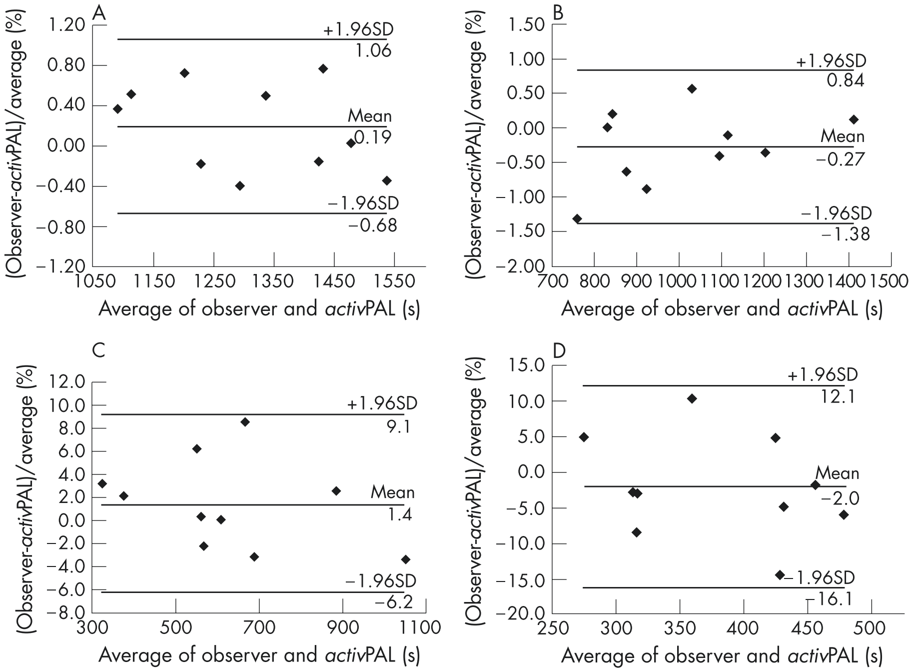

Figure 3 Bland-Altman plots demonstrating good agreement between the observer and *activ*PAL for the test duration: (A) sitting; (B) upright; (C) standing; and (D) walking.

period of measurement (fig 1). Further processing of the data produced a second-by-second output identifying the posture of the participant as either sitting/lying, standing or walking.

All tests were recorded on a digital video camera and observations of these recordings were used as the reference method. The images were downloaded to Windows Movie Maker (Version 5.1) and played on Windows Media Player. The digital recording of each participant was analysed independently by three observers in order to establish interobserver reliability and minimise observer bias. Activities were classified as sitting, standing or walking by each observer. In classifying the recordings, the observers were required to note the time at which a change in activity occurred and identify the change.

Data analysis

The total time spent sitting/lying, standing or walking in both the controlled and ADL sections and overall test time for each participant were calculated by each observer and each *activ*PAL activity monitor. The standing and walking times were also combined to provide data on total time spent upright. The number of transitions (sit-to-stand and stand-to-sit) for each observer and for the *activ*PAL were recorded.

Reliability

From the observational analysis data, the interobserver reliability was calculated using intraclass correlation coefficients (ICC) (3,1).[22] Calculations of the interdevice reliability using ICC (2,1) were made from the data recorded by the three *activ*PAL activity monitors. An ICC value of ⩾0.75 was considered good and ⩾0.9 was deemed excellent.[23]

Validity

In determining the validity of the device, data from one observer (CR) and one *activ*PAL (distal monitor attached directly to the thigh) were used. Agreement between observation (criterion measure) and the *activ*PAL monitor was assessed using two methods. In the first method, the mean value of total time spent in each posture (sitting, standing and walking) for observation was compared with the values obtained from the *activ*PAL monitor and agreement was determined using the method of Bland and Altman.[24] In the second method, data from observation and from the monitor were compared on a second-by-second basis and percentage agreement, sensitivity and predictive values calculated.[21]

- Agreement was defined as the percentage of agreement between all samples of observation and *activ*PAL (number of identical samples of observation and *activ*PAL×100/total number of samples).
- Sensitivity was the degree to which each observation activity category was detected correctly by the *activ*PAL (number of identical samples of observation and *activ*PAL

Table 2 The time spent in each posture when performing activities in the controlled and ADL sections for all participants

	Controlled activities				ADL activities			
	Sitting (min)	Upright (min)	Standing (min)	Walking (min)	Sitting (min)	Upright (min)	Standing (min)	Walking (min)
Mean	9.2	9.5	4.8	4.6	12.7	7.3	5.7	1.6
SD	2.8	2.0	1.8	1.4	2.4	3.5	3.4	0.4
Range	3.4–12.8	6.0–13.6	2.3–8.4	2.9–6.5	9.2–16.8	3.9–14.0	2.6–11.9	1.3–2.3
Total	92.4	94.8	48.4	46.5	126.7	73.1	56.9	16.2

Table 3 The percentage agreement level between the mean of the observers and the *activ*PAL monitor for time spent in all activities in the controlled and ADL sections from the Bland-Altman analyses

	Controlled section				ADL section			
	Sitting (%)	Upright (%)	Standing (%)	Walking (%)	Sitting (%)	Upright (%)	Standing (%)	Walking (%)
Mean difference	0.2	−0.2	0.5	−0.7	0.3	−0.6	3.7	−3.6
ULOA	0.9	0.5	3.8	2.7	1.6	2.2	25.9	52.6
LLOA	−0.6	−0.9	−2.8	−4.1	−1.1	−3.3	−18.5	−59.8

LLOA, lower limits of agreement; ULOA, upper limits of agreement.

for observation activity category A×100/total number of samples for observation activity category A) (categories relate to sitting, standing, walking or upright (combined standing and walking)).

- Predictive value was the degree to which each *activ*PAL activity category agreed with the observation activity category (number of identical samples of observation and *activ*PAL for *activ*PAL category A×100/total number of samples for *activ*PAL activity category A).

RESULTS

Ten participants (six female, four male; age 43±10.6 years; height 1.7±0.1 m; weight 73.7±10.1 kg (mean±1 standard deviation)) completed the study. The mean length of time for the controlled and ADL sections was 18.7 and 20.0 min, respectively. Total test time for each participant ranged from 34 to 47 min. Throughout testing no data were lost due to technical difficulties and all data were used in the analysis.

Reliability

The interobserver reliability ICC (3,1) was >0.97 for all individual postures (sitting, standing and walking) in both the controlled and ADL sections. With the exception of walking in the ADL section, the interdevice reliability ICC (2,1) for sitting/lying, standing, walking and upright, in both sections, was >0.99. The interdevice reliability for walking in the ADL section (ICC (2,1)) was 0.79.

Validity

Transition analysis

The total numbers of sit-stand and stand-sit transitions were identical between the observer and the *activ*PAL monitor for all tests.

Overall time analysis

Figures 3A–D illustrate the level of agreement according to the method of Bland and Altman[24] between observation and the *activ*PAL for the total time spent in each activity for the entire test (both controlled activities and ADL). The percentage difference between the mean of the observers and the *activ*PAL for total time spent in sitting and for total time spent upright was less than 0.3%. The percentage difference for total time spent standing and the total time spent walking were 1.4% and 2%, respectively.

Analysis of the controlled and ADL sections

A summary of the time spent in each activity category in the controlled and ADL sections is shown in table 2. The times are taken from the analysis performed by the observer.

The levels of agreement between observation and *activ*PAL for time spent in each activity for both sections separately are given in table 3. This table illustrates a high level of agreement for all activities in the controlled section. The results from the ADL section demonstrate excellent agreement for the sitting and upright postures but a low level of agreement for standing and walking.

Second-by-second analysis

The results of the second-by-second comparison of the observer and the *activ*PAL are shown in table 4. The overall level of agreement was 95.9% and the overall sensitivity and predictive values ranged from 88.1% to 99.6%. Sensitivity and predictive values were lowest for walking in the ADL section. Figure 4 illustrates the difference in walking activity pattern during the controlled and ADL sections. The controlled section consisted primarily of a small number of longer duration walking periods. In contrast, walking in the ADL section involved numerous very short periods of activity classified by the observer as walking.

DISCUSSION

The results demonstrate excellent interobserver reliability for the video analysis (ICC ⩾0.97) and are comparable to the results in other similar studies.[25] The interdevice reliability

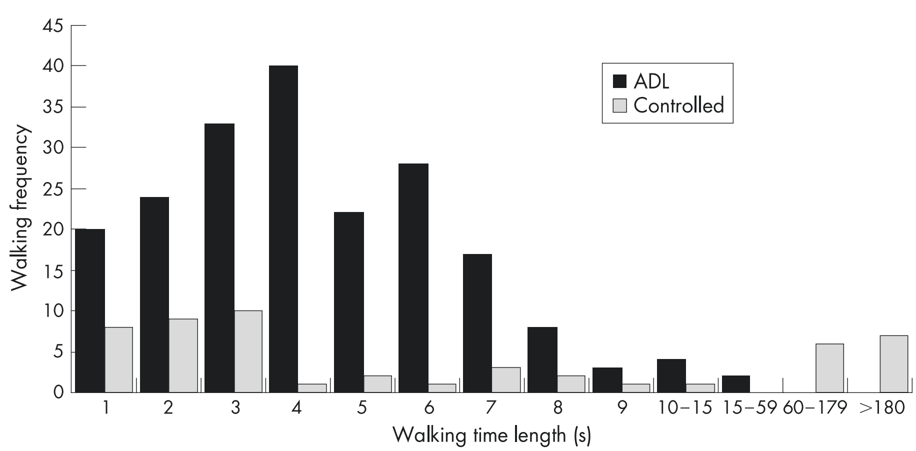

Figure 4 Walking frequency and time in the ADL and controlled sections.

Table 4 The percentage agreement, sensitivity and predictive value for the *activ*PAL monitor for sitting, upright, standing and walking with one of the observers

Activities section	Agreement (%)	Sitting S (%)	Sitting PV (%)	Upright S (%)	Upright PV (%)	Standing S (%)	Standing PV (%)	Walking S (%)	Walking PV (%)
Controlled	98.5	99.7	99.8	99.8	99.7	97.1	97.1	97.3	97.1
ADL	93.6	99.4	99.5	99.0	98.6	84.9	88.0	67.4	63.7
Combined	95.9	99.5	99.6	99.6	99.3	89.9	91.3	90.0	88.1

PV, predictive value; S, sensitivity.

was good to excellent (ICC (2,1) = 0.79 to 0.99) indicating that the monitors and the placement positions were interchangeable, which allowed one *activ*PAL to be used for the comparison with one observer.

The lowest interdevice reliability was found for walking in the ADL section. A possible explanation for this may be the small between-subject differences for time spent walking as illustrated by the values for the time range of 1.3–2.3 min in table 2. It has previously been noted when calculating reliability that the smaller the between-subject difference, the lower the ICC value.[26]

The Bland-Altman plots (fig 3A–D) demonstrate good agreement between observer and *activ*PAL for the test duration. The lowest agreement existed for walking and standing in the ADL section of the study (table 3). Figure 4 clearly shows that this section involved a high number of very short duration periods classified by the observers as walking, which often had short time intervals (between 1 and 2 s) of standing between them. For some of these periods, this walk interrupted by a pause was interpreted by the *activ*PAL software as one long continuous walking period, leading to a larger estimation of walking and a lower estimation of standing when compared with the observer. Additionally, discrete single steps recorded by the observer were sometimes not classified by the *activ*PAL as walking. This would produce only a small number of seconds of misclassification. However, the mean walking time during the ADL section was small (table 2), and this resulted in a large percentage difference in the levels of agreement. Very short duration walking activities are difficult to classify whatever the methods used for detection. Other authors have found these short duration periods difficult to classify using accelerometer-based monitors and to overcome the problem have rejected postures and movements below a specified duration. For example, Bussmann *et al*[27] discounted activities lasting less than 5 s. Such filtering was not undertaken in this study.

Sensitivity and predictive values (table 3) compare well with other studies where agreement ranged from 87% to 90% and sensitivity and predictive values ranged from 58% to 100%.[11 21 25 28] Sensitivity and predictive values for the *activ*PAL were lowest for walking in the ADL section. This may again be attributed to the high number of short duration walks in this section (fig 4). At times there were minor time phase shifts (1–2 s) between the *activ*PAL and observation which resulted in slight asynchrony. This resulted in decreased sensitivity and predictive values during the self-directed activities, where numerous standing periods were interspersed with short walks. Although the tasks were relatively typical of those undertaken in a normal day, it is highly unusual to complete this number of activities within a 20 min period. Many of the self-directed activities would normally be undertaken over a longer time period and would result in fewer postural transitions. Consequently, the design of this study ensured that the *activ*PAL was evaluated under fairly rigorous testing conditions.

The *activ*PAL compares well with other devices in identifying the primary postures of sitting/lying, standing and walking in terms of reliability and validity.[25 28] As a single unit, the *activ*PAL monitor is unobtrusive and, since it requires no calibration by the user, can be applied easily by any individual. Multi-sensor monitors require careful placement and calibration when in position.[16 27] A limitation of the *activ*PAL is that posture can only be defined as sitting/lying, standing and walking and the level of postural detection, for example lying on the side, climbing stairs and cycling, which other monitors with multiple sensors purport to identify,[16 29] cannot be achieved.

The *activ*PAL provides meaningful data presented in a simple manner for the immediate interpretation of results (fig 1), allowing clinicians to examine activity profiles over prolonged periods. Clinicians attempting to alter sedentary behaviour could use this information to identify patterns of inactivity and plan behaviour modification strategies. Activity monitoring during treatment could indicate adherence to the strategy and, following intervention, could be used to measure success.

There were some limitations to this study:

- in order to facilitate accurate filming, the test was performed in a semi-constrained environment;
- undertaking six activities in 20 min could be considered unusually high, and not necessarily fully reflective of daily life; and
- it is recognised that a small sample size was used and this may have artificially widened the limits of agreement in the Bland and Altman analyses. However, these conservative estimates of *activ*PAL validity still illustrate a good level of agreement with observation.

What is already known on this topic

- Many chronic health problems are attributable to a lack of physical activity.
- Although various methods have been employed to measure components of activity, objectively quantifying habitual movement and sedentary behaviour remains challenging.

What this study adds

- This study establishes the validity and reliability of a novel activity monitor in recording posture and positional change in a healthy adult population which can provide a measure of both activity and sedentary behaviour.

CONCLUSION

This study found that the *activ*PAL is a valid and reliable device for measuring posture and motion during everyday activities in a healthy population. This, combined with its small size and ease of use, makes it a convenient instrument for measuring physical activity.

Authors' affiliations

P M Grant, C G Ryan, W W Tigbe, M H Granat, Glasgow Caledonian University, Glasgow, UK

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Consent was obtained for publication of figure 2.

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