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Technical note

Comparison of the performance of the activPAL™ Professional physical activity logger to a discrete accelerometer-based activity monitor

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Abstract

The aim of this study was to assess the accuracy of the 'activPAL™ Professional' physical activity logger by comparing its output to that of a proven discrete accelerometer-based activity monitor during extended measurements on healthy subjects while performing activities of daily living (ADL). Ten healthy adults, with unrestricted mobility, wore both the activPAL™ and the discrete dual accelerometer (Analog Devices ADXL202)-based activity monitor that recorded in synchronization with each other. The accelerometer derived data were then compared to that generated by the activPAL™ and a complete statistical and error analysis was performed using a Matlab® program. This program determined trunk and thigh inclination angles to distinguish between sitting/lying, standing and stepping for the discrete accelerometer device and amount of time spent on each activity. Analysis was performed on a second-by-second basis and then categorized at 15 s intervals in direct comparison with the activPAL™ generated data. Of the total time monitored (approximately 60 h) the detection accuracies for static and dynamic activities were approximately 98%. In a population of healthy adults, the data obtained from the activPAL™ Professional physical activity logger for both static and dynamic activities showed a close match to a proven discrete accelerometer data with an offset of approximately 2% between the two systems.

Keywords: activPAL™; Accelerometer; Mobility; Activity

1. Introduction

The knowledge of a subject's daily behavior allows clinicians and carers to determine whether levels of activity are sufficient or excessive, dependant on a subject's situation. This information may indicate a lack of exercise after a heart operation or excessive activity after a back operation, for example. Self-assessment of daily activity has shown to be variable and subjective, as patients own assessment can differ to that of a physician [1,2]. Thus, the use of an automatic monitoring system is proving to be the preferred choice for patient monitoring.

Several automatic monitoring techniques have been developed and used successfully in determining the mobility of patients in physiotherapy, psychophysiology and medicine [3]. Bussmann et al developed an accelerometer-based monitoring system to determine activities of daily living (ADL) which allowed sitting, standing, lying and moving to be distinguished [4]. This technique has been extensively validated and subsequently introduced into numerous studies where physical activity is important in aiding patient recovery from illness or improving patient mobility after severe trauma [5–7].

Regular physical activity is an important contributor to a healthy lifestyle and in the prevention of chronic disease [8] and numerous studies showed that an increased level of physical activity resulted in an improved physical fitness in elderly humans [9,10].

Lyons et al. used a discrete accelerometer-based activity monitor on older adults in a clinical setting to determine the various degrees of static and dynamic activity to a high

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level of accuracy [11]. The design of this particular system consisted of orientating one accelerometer on the trunk and one on the thigh according to Veltink et al. [12,13] with a data-logger attached to the waist, to determine the activities of patients in a clinical setting over numerous recording periods. However, such systems are unsuitable for long term monitoring due to the requirements of fitting two sensors and their associated cabling. Many modern commercial accelerometer-based mobility monitoring devices from different manufacturers have over come this problem.[1] One such popular device is the activPAL™,[2] this is a compact device that is easily attached to the thigh mid-way between the hip and the knee that monitors the ADL of patients for up to 1 week. The device is especially designed for long-term use with sufficient battery recording time and the facility to don and don off on a daily basis.

Numerous studies have used the device to record various degrees of mobility of elderly and sick patients [2,14–26]. Previous attempts have been made to validate of the accuracy of the activPAL™ [27–32], one which included video analysis to accurately compare the activities of test subjects while wearing the activPAL™ [28]. There were a number of faults with this study in that firstly the time allocated to video analysis was quite short (mean 38.7 min). Typically clinicians would like to have a prolonged recording period (>24 h) to develop a significant trend of patient behavior. The findings also did not show accurate agreement between the activities of standing and walking, two vital aspects of mobility monitoring (upper and lower limits of agreement 12.1% and −16.1%, respectively).

In another study, manual self-recording of the ADL of the subjects was used to compare the activPAL™ data [32]. However, this was found to be unsatisfactory due to the human error involved in taking such readings. Large periods of timing error were recorded, in some cases of up to 3 h. This large degree of inaccuracy is unacceptable.

In this paper we compared the activPAL™ to a proven accurate discrete accelerometer-based activity monitor while monitoring healthy young adults to determine if the activPAL™ is an accurate means to determine all the activities of ADL over extended measurement periods.

2. Method

The subjects recruited consisted of three female and seven male subjects and their age ranged between 22 and 27 years (mean: 24.9, S.D. 1.69). All the subjects wore the same equipment and were each monitored for a period of approximately 6 h. All subjects had the same degree of mobility and walked unaided. The monitoring environment consisted of the University of Limerick campus and all subjects were free to move throughout the campus while being monitored. Informed consent was obtained from all participants and ethical approval for the study was obtained from the University of Limerick Research Ethics Committee.

2.1. activPAL™ setup

During the course of the trial 3 different activPAL™ devices were used and attached to the subjects in repeated turns. Each activPAL™ was programmed through its computer interface and its internal clock synchronized to that of a personal computer. Initialization of recording was implemented to begin 30 min after it was unplugged from its computer docking cable. The activPAL™ (Fig. 1(a)) was attached directly to the thigh of the subject, mid-way between the hip and the knee in the correct orientation as outlined

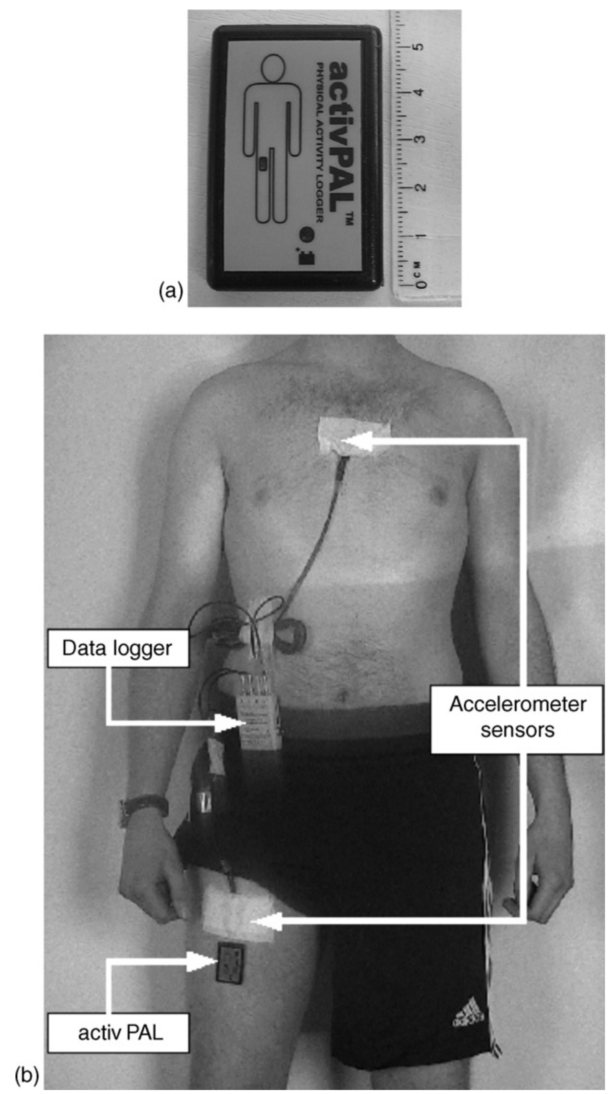

Fig. 1. (a) The activPAL™ Professional physical activity monitor from PAL Technologies and (b) as being worn by a subject with the discrete accelerometer-based system attached also.

[1] Ossur Patient Activity Monitor, PAM, Ossur, Grjothals, Reykjavik, Iceland; Dynastream AMP 211, Dynastream Innovations, Cochrane, Alberta, Canada; StepWatch3™, Cyma Corporation, Mountlake Terrace, WA, USA.

[2] PAL Technologies Ltd., Glasgow, UK.

by the manufacturer's guidelines underneath the subject's clothes (Fig. 1(b)). The device was easily attached with the manufacturer's recommended adhesive PALstickies™ (see Footnote 4) and covered with an additional recommended bandage for extra support (Medipore 3M surgical tape).

2.2. Discrete accelerometer activity monitor setup

The discrete accelerometer-based activity monitor comprised of two Analog Devices ADXL202[3] accelerometers that were attached to a portable, lightweight battery powered data logger (Biomedical Monitoring BM42).[4] The internal clock of the data logger was also synchronized to that of the personal computer. One accelerometer was located at the sternum and the other on the same thigh as the activPAL™. The accelerometers were attached underneath the subject's clothes using the same technique for attaching the activPAL™ as outlined. The two accelerometers were orientated with the active axis in the radial direction to the trunk and thigh. The data-logger fitted neatly to the subject's waist by using a belt attachment.

Initially the subject was asked to remain standing still for 1 min for calibration purposes and to remove any offset due to poor sensor alignment or due to the subject's incorrect posture during calibration. The discrete accelerometer-based system was switched on at the same time as the activation of the activPAL™.

2.3. Data analysis

Data from both the activPAL™ and discrete accelerometer were analyzed to obtain the duration of sitting/lying, standing and walking and compared directly for the total data set.

2.3.1. activPAL™

Upon the completion of the recording session the activPAL™ data were downloaded to the personal computer. The data were opened in the activPAL™ interface program and exported to an Excel[5] spreadsheet for further analysis. The data provided in the spreadsheet gives the corresponding time of day (as programmed by the personal computer) and the subsequent amount of time spent, sitting/lying, standing and stepping in increments of 15 s.

2.3.2. Discrete accelerometer

The trunk and thigh accelerometer signals were sampled at 50 Hz and a resolution of 12 bits. This data were saved to the data-loggers internal removable memory card, which had a total capacity of 256 MB, more than sufficient for 6 h monitoring.

At the end of the recording session the data were uploaded to a personal computer via a USB memory card reader and analyzed using a specially written Matlab® program. The Matlab® program read in the raw acceleration data then calibrated and low-pass filtered these signals. Using a 1 s moving window, the program analyzed the standard deviation values of the accelerometer signals to determine whether the activity was static or dynamic. When the data were deemed static, the mean acceleration over the 1-s window were converted to degrees of inclination of the trunk and thigh to establish the subjects posture. In the selection of the thresholds for the determination of the various static activities a 'best-estimate' approach was adopted as this was shown to be more accurate in uncontrolled circumstances during long term monitoring. When the data were deemed dynamic the mean and standard deviation accelerations determined the total stepping time if their respective thresholds were exceeded [11,33].

2.3.3. Comparison

Data from both systems were analyzed to perform a hit/miss percentage ratio. This determined how accurate the activPAL™ was when directly compared directly to the discrete accelerometer-based monitor.

Firstly the relevant activPAL™ Excel data were selected-based on the start and end of the recording session. This data were converted to a binary representation table. This was done automatically in Excel by placing a one (1) in the cell in each incrementing row with the greatest amount of time for the activity of sitting/lying, standing or stepping over the required recording time. The other cells in the same row were assigned a zero (0). The rows in this file contain data based on 15-s increments.

Secondly the discrete accelerometer-based activities of sitting/lying, standing and stepping for the 1-s window were determined. A table labelled 'Data' was created and a '1' placed in each incrementing row and in the necessary column where the activity headings of sitting/lying, standing or stepping were greatest. This binary table represents the total amount of time in 1-s increments and therefore was reduced in size so as to compare directly with the activPAL™ binary file. This reduction of table size was done by finding the sum of 1's in every 15 lines of the table 'Data' with a subsequent '1' being used to classify that activity which were greatest in the block of 15. The cells with least amount of ones were assigned zero.

The corresponding binary tables from the Matlab® program and Excel spreadsheet were compared on a line-by-line basis (15 s intervals) for direct comparison by the Matlab® program. The resulting hit/miss ratio was calculated to determine the accuracy of the activPAL™.

3. Results

Table 1 shows the total recorded time for each recorded activity for every individual subject using the discrete

[3] ADXL202, Analog Devices BV, Limerick, Ireland.
[4] Biomedical Monitoring Ltd., Wolfson Centre, Glasgow, UK.
[5] Microsoft Corp., Redmond, WA, USA.

Table 1
The actual amount of time spent at each activity for every subject for both the activPAL™ Professional and the accelerometer-based system and resulting percentage differences

Subject no.	activPAL™ Professional			Accelerometer			Difference		
	Sitting (m)	Standing (m)	Stepping (m)	Sitting (m)	Standing (m)	Stepping (m)	Sitting (%)	Standing (%)	Stepping (%)
1	280.84	62.63	26.53	280.78	62.42	26.85	0.02	0.34	1.19
2	216.57	78.87	60.55	216.45	79.00	60.05	0.06	0.16	0.83
3	220.99	85.09	35.92	220.32	85.17	35.80	0.30	0.09	0.34
4	258.47	60.54	41.99	258.57	61.04	41.27	0.04	0.82	1.70
5	281.78	39.65	29.57	281.85	40.75	28.70	0.02	2.70	3.03
6	304.13	32.41	32.47	303.43	33.86	31.85	0.23	4.28	1.95
7	160.05	162.32	52.63	159.70	163.13	52.22	0.22	0.50	0.79
8	227.35	108.10	25.64	227.65	107.85	25.51	0.13	0.23	0.51
9	300.15	36.17	30.93	300.25	35.87	31.12	0.03	0.84	0.61
10	295.87	34.57	40.31	295.66	34.80	40.11	0.07	0.66	0.50
Total	2546.20	700.35	376.54	2544.66	703.89	370.48	0.06	0.50	1.64

accelerometer compared to the activPAL™ physical activity monitor. The two sets of data show very little discrepancies from visual inspection. Of the total amount of time monitored, 60.38 h as measured by the activPAL™ and 60.32 h as measured by the discrete accelerometer-based activity logging system. The percentage difference in time measured between the two systems for sitting/lying, standing and stepping was 0.06%, 0.5% and 1.64%, respectively.

Table 2 shows the hit percentages from the resulting hit/miss ratio percentage analysis of the sitting/lying, standing and stepping activities for both the activPAL™ and the accelerometer-based activity system. This data gives a good representation of the accuracy of the activPAL™ when compared to the accelerometer-based system on a direct timed recording comparison.

The resulting hit/miss ratio based on the levels of recording accuracy for sitting/lying, standing and stepping between the two systems has been determined with an accuracy of approximately 98%. It has been shown that the activPAL™ and the discrete accelerometer-based monitor closely match in their analysis of the subjects static and dynamic measurements and subsequent activities of sitting/lying, standing and stepping. Data analysis based on a window of 15 s (based on activPAL™ output) proves to be accurate in distinguishing activities of ADL as is proven by the hit/miss percentage. The results found have proven the accuracy of the activPAL™ with an overall accuracy of comparison to a discrete accelerometer-based system of 98%.

Table 2
Resulting hit (success) percentages between the activPAL™ and the discrete accelerometer-based system

Subject no.	Sitting/lying (%)	Standing (%)	Stepping (%)
1	98.98	98.37	98.50
2	97.30	97.13	96.87
3	97.98	98.27	98.07
4	98.61	97.37	98.00
5	97.00	97.07	96.89
6	99.32	98.17	98.96
7	97.70	97.99	97.51
8	98.32	97.99	98.25
9	99.00	99.22	98.97
10	98.55	98.31	98.07
Average	98.28	97.99	98.01

This level of accuracy is very acceptable for the activPAL™ when compared to the validated accelerometer-based monitor technique. The activPAL™ is a long term monitoring device with activity recording capabilities of up to 1 week. Thus, the level of accuracy found in this paper validates its use for potential long term monitoring of patients outside clinical environments.

4. Discussion and conclusions

This paper describes the evaluation of the activPAL™ Professional by comparing it to a proven mobility monitoring system incorporating accelerometers and a data-logging device in a familiar environment, over an extended period of time. The system consisted of an activPAL™ Professional worn on the front of the thigh mid-way between the hip and the knee. The software analysis used the software package provided with the activPAL™ to determine its output and a Matlab® program developed by Culhane et al to determine the output from the accelerometers. The activities of the ten healthy subjects were monitored for a total of approximately 60 h of monitoring time.

The system used was lightweight and did not interfere with the subject's movement. The devices were worn under clothes and all subjects found the equipment comfortable, lightweight and un-obstructive.

It can be concluded that in a population of adults, the static activities of sitting/lying and standing and the dynamic activities of moving can be accurately determined by using the activPAL™ Professional when compared to a proven accelerometer technique, with accuracies of approximately 98%.

As the activPAL™ Professional physical logger monitor is good means of recording mobility, it can be used to monitor the activity of patients outside clinical environments where accelerometer/data-logging systems could prove to be unsuitable in long term monitoring situations particularly when consecutive 24 h monitoring may be required.

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