

Monitoring activity of inpatient lower limb prosthetic users in rehabilitation using accelerometry: Validation study

Journal of Rehabilitation and Assistive Technologies Engineering
Volume 3: 1–5
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sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/2055668316642387
jrt.sagepub.com

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Abstract

Purpose: Due to limited accuracy of self-reported activities of lower limb prosthetic users, there is increasing interest in providing accurate walking time for those who are mobilising using their prosthesis in the rehabilitation ward. The aim of this study was to test the accuracy of a tri axial accelerometer (ActivPAL) in measuring walking activity of amputee patients while using their prosthetic limb.

Method: For the study, 21 subjects wore accelerometer devices taped to the thigh on both the amputated and non-amputated side. Each subject was asked to perform a set of activity routines: walking with prosthesis for 5 minutes, self-propelling in a wheel chair for 3 minutes and being pushed in a wheel chair for 3 minutes. Each activity was observed and timed by a physiotherapist and the observed times were compared with the output from accelerometer monitoring.

Results: Using the Bland–Altman method, the mean difference between observed and ActivPal monitor for total time spent walking for the non-amputated side was 0.004 seconds (limits of agreement -0.09 to 0.10 seconds) and for amputated side was 0.11 seconds (limits of agreement -0.43 to 0.66 seconds). An analysis between monitored and observed time found the sensitivity for the non-amputated side was 90.5% and 86% for the amputated side.

Conclusion: The use of ActivPAL accelerometers in measuring walking time for an individual using a prosthesis is within acceptable levels of accuracy for continuous ambulation monitoring. It has potentially important clinical application for prescribing prostheses.

Keywords

Age-related rehabilitation, amputees, disability, gait rehabilitation, limb prosthetics, rehabilitation

Date received: 8 October 2015; accepted: 8 March 2016

Introduction

The increasing incidence of diabetes and dysvascular disease due to population ageing has resulted in a proportional increase in lower extremity amputations.^{1,2} Global annual incidence of amputation ranges from 3 to 44 people per 100,000. In Australia it is estimated that a total of 8000 lower limb amputations occur each year.³

For lower limb amputee patients, walking with a prosthesis is an important goal of rehabilitation, to restore mobility and assist in performance of daily living activities. Due to limited clinical use of data provided by instrumental gait analysis performed in gait laboratories,⁴ real-life mobility monitoring offers prosthetists more insight about selection of suitable prostheses.^{5,6} Reliable and valid information about an

amputee patient's walking activity is an integral part of prosthesis prescription and can provide clinicians with a useful means of evaluating patient outcomes.⁷

To determine mobility levels while a patient is using their prosthesis outside clinical environments, we traditionally utilise information collected from self-reported

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walking time and/or infer from physical performance measurements completed during a visit to medical rooms.⁸⁻¹⁰ The ability to objectively measure walking time has become feasible with the introduction of accelerometers.¹¹ ActivPAL is a small activity monitoring device taped to the anterior thigh. The validity and reliability of this device in measuring time spent sitting, standing and walking has been examined in everyday activities for non-amputee subjects.¹² This study demonstrated good inter-device reliability, with inter-class correlation coefficient ranging from 0.79 to 0.99. The overall agreement of 95.9% was found between observer and monitor activities.¹² However, given the specific changes in the gait pattern of amputee patients,¹³ the ability of ActivPAL to accurately record walking time in prosthetic users is yet to be established.

The purpose of this study was to examine the use of a tri axial accelerometer (ActivPal) as a valid measure of walking time in amputee patients while using their prosthesis. A secondary aim was to compare agreement of walking time between devices attached to the amputated and non-amputated side.

Methods

Participants and setting

Prosthetic user patients admitted to a Geriatric and Rehabilitation Unit (GARU) or attending an

outpatient clinic in a metropolitan hospital in Brisbane, Australia during the period from April 2013 to November 2013 were invited to participate in the study. Eligible subjects were unilateral amputee patients capable of walking, with or without walking aids, while using their prosthesis. The study was conducted in the Rehabilitation Unit.

Accelerometer device

ActivPAL, produced by PAL Technologies Ltd of Glasgow (www.paltechnologies.com/), is a tri axial lightweight monitor. It weighs approximately 20 g and measures approximately 53 mm long, 35 mm wide and 7 mm thick. Two devices were used in this study, worn taped to the mid anterior thigh of both the amputated and non-amputated side.

Activities routine

Recruited subjects were requested to perform a structured activity routine while wearing the accelerometer devices, one on each thigh (see Figure 1).

The activity routine included walking for 5 minutes with prosthesis, self-propelling in a wheelchair and being pushed in wheelchair for 3 minutes, with a rest permitted between the different tasks. While the subjects performed this routine, the start and stop times of each observed activity were recorded manually by the research assistant (physiotherapist) using a digital



Figure 1. Both devices attached to amputated and non-amputated side.

stop watch. The time on the stop watch was synchronised with the time on the accelerometer device at the start of the activity routine. The accelerometer device recorded the amount of time in 15-second blocks spent walking, sitting, and standing over the duration of the activity routine. The amount of time for each activity recorded by the accelerometer device was compared with that recorded by the physiotherapist.

Ethical approval

The study was approved by the institutional human ethics and research committee, and subjects gave informed consent to participate.

Statistical analysis

For testing validity, the observed routine activities performed by prosthetic users were used as the reference standard and compared with ActivPal output to determine (1) if the device correctly classified the routine activity (as sitting or walking), and (2) the level of agreement between the observed time of the activity with that recorded by the accelerometer device for each leg. Sensitivity was calculated as the proportion of the occurrences of a particular observed activity category that was correctly detected by accelerometry data. Consecutive 15-second blocks of data were compared from observed and ActivPal data to measure sensitivity (number of identical walking samples of observations and ActivPAL/total number of observed walking samples \times 100). The Bland–Altman method was used to examine the agreement between observed and ActivPal measurements.¹⁴

Results

In total, 21 subjects participated in this study. The mean age was 59.4 (SD 11.5) years and the majority had a trans-tibial amputation ($n = 17$). The duration since fitting with prosthesis was variable, ranging from one to 36 years. Demographic characteristics are summarised in Table 1.

Validity

The levels of agreement between observed and ActivPal time spent in walking for amputated and non-amputated side are shown in Table 2. The average differences between the two methods were 0.11 s (SD 0.28) for amputated and 0.004 s (SD 0.005) for non-amputated side. The Bland–Altman limits of agreement for non-amputated side were narrower (-0.09 to 0.10 s) as compared with the amputated side (-0.43 to 0.66 s), indicating higher level of

Table 1. Study population characterisation ($n = 21$).

Characteristics	N (%)
Gender, male	15 (71.4)
Age mean (SD)	59.4 (11.5)
Range [median]	29–76 [61]
Amputation side	
- Right	11 (52.4)
- Left	10 (47.6)
Amputation level	
- TTA	17 (81.0)
- TFA	4 (14.3)
Reason for amputation	
- Traumatic	4 (19.0)
- Vascular	13 (61.9)
- Other	4 (19.0)
Peripheral sensory impairment	9 (42.9)
Walking aids	
- Nil	12 (57.1)
- 2 SPS	5 (23.8)
- SPS	3 (14.3)
- 4 WW	1 (4.8)
Recruited from OPD	17 (81)
Duration since fitting	
- 1 year (4–13 months)	10 (47.6)
- 1–4.7 years (13–57 months)	8 (30.1)
- 4.7–36 years (57–440 months)	3 (14.3)

SD: standard deviation; OPD: outpatient department; TTA: trans-tibial amputation; TFA: trans-femoral amputation; SPS: single point stick; WW: wheel walker

agreement. The sensitivity, although lower on the amputated (86%) compared with non-amputated side (90.5%), indicated that the device is accurate in detecting walking time.

Discussion

In this study we examined the validity of ActivPal in monitoring walking activities for amputee patients using their prosthesis. The results indicate that ActivPal accurately measures walking time for unilateral prosthetic users. The sensitivity of 90.5% when attached to the non-amputated lower limb is comparable with results from other studies examining validity of the ActivPal in measuring walking time for non-amputee patients.¹² The Bland–Altman analysis demonstrated narrow 95% limits of agreement between observed and activPAL, indicating a small difference between both methods.

Previous studies examining the accuracy of wearable devices showed variable results in detecting walking activities for lower limb prosthetic users. In two

Table 2. The agreement between the mean of the observers and activePAL monitor for time spend walking (5 minutes trial) from Bland–Altman analysis and sensitivity.

The side of the amputation	Bland–Altman analysis					Sensitivity
	Minimum	Maximum	Mean difference	SD	Limits of agreement	
Amputee side	3.91	5.08	0.11	0.28	−0.43 to 0.66	86%
Non-amputee side	4.95	5.1	0.004	0.05	−0.09 to 0.10	90.5%

SD: standard deviation

studies^{15,16} where monitoring devices were attached to the prosthesis, the accuracy ranged between 70.6 and 98.2%, while the accuracy for the device worn around the waist¹³ measuring different gait parameters was within 6.5%. In the clinical setting, for implementation of wearable devices measuring activity over a 24-hour period, an error of measurement within 10% is considered within acceptable limits for clinicians involved in providing prosthesis care.¹³ In our study the device used is small, can be made waterproof, and is wearable for a continuous period. Devices attached to the prosthesis or around the waist could potentially limit information provided about walking activities for 24 hours a day.

In this study we used two accelerometer devices to determine if positioning the device on the amputated or non-amputated side made a difference in detecting walking time. The gait speed of an amputee patient walking with a prosthesis is variable. Slower speed, reduction in number of steps and step length is expected in the early phase of gait retraining. In this study, subjects were asked to walk at a comfortable pace, and change in walking velocity was not required. Overall, the agreement between observed and ActivPal attached to the non-amputated side was better than amputated side. A possible explanation for this may be the difference in initiation and termination of velocity of walking on the prosthetic leg. Furthermore, the change in gait pattern and speed of movement of the amputated side, particularly in subjects using walking aids, could be interpreted by ActivPal software as standing rather than walking.

The difficulty in classifying short walking activities has been reported in previous studies examining validation of accelerometry.¹⁷ The potential delay to start and stop walking once a digital watch is activated could produce a small number of seconds of misclassified activities.

Limitations of this study merit comment. The validation of walking was performed on a level surface in the hospital setting; walking with prosthesis outside the clinical environment on uneven terrain, slopes and stairs was not examined in this study. Another limitation was that only unilateral prosthetic users were included in this study, so the results cannot be

generalised to bilateral prosthetic users, where major gait changes may impact on accelerometry accuracy.

Key points

- The ActivPal accelerometer has been shown to be a valid device for measuring walking time in unilateral amputee patients walking with prostheses.
- Objective data provided by ActivPal, allowing clinicians to examine activity profiles over prolonged periods, offer further information and assistance in appropriate prescribing of prostheses for lower limb amputee patients.

Declaration of interest

The authors declare that there are no conflicts of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors contribution

All authors contributed equally in the preparation of this manuscript.

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