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Reliability and Criterion-Related Validity of the activPAL™ Accelerometer When Measuring Physical Activity and Sedentary Behavior in Adults With Lower Limb Absence

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Introduction: Accurate measurement of physical behavior in adults with lower limb absence is essential to report true patterns of physical behavior and the effectiveness of interventions. The effect of placing accelerometers on prostheses may also affect the reliability and validity. **Purpose**: To assess reliability and criterion-related validity of the activPAL for measuring incidental and purposeful stepping, and reclining and stepping time in adults with unilateral lower limb absence. **Methods**: 15 adults with unilateral lower limb absence completed simulated lifestyle activities in a laboratory setting that were retrospectively scored via video analysis. Objective data were obtained simultaneously from two activPAL monitors placed on the sound and prosthetic side. Data were analyzed using one-way intraclass correlation coefficients (ICC), paired *t*-tests and Cohen's *d*. **Results**: Reliability (prosthetic side vs. sound side) was poor for incidental steps (ICC = .05, $d = 0.48$) but acceptable for all other measures (ICC = .77–.88; $d = .00–.18$). Mean activPAL measures, although highly related to the criterion, underestimated, on average, stepping and time-related variables. Differences were large for all stepping variables ($d = .38–.96$). **Conclusions**: The activPAL is a reliable measurement tool in adults with lower limb absence when used in a laboratory setting. Placement of the monitor on the sound side limb is recommended for testing. The activPAL shows evidence of relative validity, but not absolute validity. Further evaluation is needed to assess whether similar evidence is found in free-living activity and sedentary contexts.

Keywords: amputation, physical activity, prosthesis

Being physically active is one of the most important components of successful health promotion. Physical activity has long been a priority for public health, rising to greater prominence with the publication of the Global Recommendations on Physical Activity for Health (World Health Organization, 2011). Mobility limitation can be typically defined as reported difficulty walking for one-quarter mile or climbing one flight of stairs (Verbrugge & Jette, 1994). Increasing physical activity and reducing sedentary behavior among those with mobility limitations has also been shown to improve health outcomes and control the economic and social burden of lifestyle-related disease (Loprinzi, Sheffield, Tyo, & Fittipaldi-Wert, 2014). Measuring physical behavior in people with limb absence is necessary to identify those at risk of health deterioration. Further, understanding where and how best to direct physical behavior interventions aimed at increasing physical activity and reducing sedentary behaviors is important. The term *physical behavior* in the context of this research encompasses both sedentary behavior and physical activity. The Sedentary Behaviour Research Network defined sedentary behavior as "any waking behaviour characterized by energy expenditure ≤1.5 METs while in a sitting or reclining posture" (Sedentary Behaviour Research Network, 2012). Similarly, this research study does not encompass sleeping behavior. This research focuses on sedentary and physical activity concepts of the movement continuum and patterns of sedentary and physical activity behavior during waking hours. Understanding patterns of behavior is also of increasing value in moving towards reducing the negative physiological effects of prolonged bouts of sedentary time, and increasing daily movement (Chastin & Granat, 2010; Healy et al., 2011; Owen et al., 2011; Thorp, Owen, Neuhaus, & Dunstan, 2011).

Outcomes of physical behavior interventions must be evaluated to determine effectiveness, and measurement is an important aspect of evaluation (Sallis, 2010). Selection of an appropriate measurement tool is multi-factorial and consideration should be given to cost, resources, ease of use, data management, and reliability and validity of the tool. Establishing a reliable and valid tool for measuring physical behavior patterns is important to ensure accurate reporting of habitual behavior and intervention effects. Reliability reflects the consistency of measurement under two or more conditions. When measuring physical behavior objectively, inter-instrument reliability pertains to the extent that two devices provide similar scores when worn concurrently. Criterion validity (or criterion-related validity) assesses how well the device measures the construct of interest by comparing it against a criterion measure. Validity of measurement indicates the degree to which an instrument measures what it purports to measure. Notably, an instrument cannot be valid without being reliable (Rowe & Mahar, 2006).

Amputation is the surgical removal of all or part of a limb or extremity such as an arm, leg, foot, hand, toe, or finger. Major lower limb amputation refers to any amputation performed above the level of the ankle. Congenital absence describes all or part of a limb/extremity missing due to disease or physical malformation present from birth. Amputation performed without an attempt at

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limb salvage (for example revascularization, bony repair, soft tissue coverage) is termed primary amputation, whereas amputation following a failed attempt at revascularization is termed secondary amputation (Dillingham, Pezzin, & Shore, 2005).

During 2011–2012, 5906 people were referred to United Kingdom (UK) prosthetic rehabilitation services, of whom the majority were male ($n = 4121$). Of this total number of referred people, 5389 had lower limb absence (91.2%). Almost 70% of those with lower limb absence were referred due to compromised vascular causes (impaired circulation) and were over 54 years of age (United National Institute for Prosthetics Orthotics Development, 2011–2012). There are no known studies that provide data on the physical behaviors of this subgroup of the limb-absent population. However, with the etiology in mind, it might be reasonable to assume that there are low levels of physical activity attainment.

The activPAL™ accelerometer (PAL Technologies Ltd., Glasgow, UK) has demonstrated reliability and validity in measurements of walking activity and posture in healthy adults (Ryan, Grant, Tigbe, & Granat, 2006). Few studies have examined walking and posture in people with limb absence. A systematic review was conducted on instruments and methods for the assessment of physical activity in people with amputation (Piazza, Ferreira, Minsky, Pires, & Silva, 2017). These methods included the use of surveys and questionnaires, pressure monitors, and instruments such as the StepWatch™ Activity Monitor. The researchers concluded from 12 studies that validated measurement tools are used in the assessment of physical behavior, despite these tools not being originally designed for use in the research of people with limb absence. The authors additionally suggested that physiological parameters such as energy expenditure and movement pattern may be different in people with limb absence, and may not be taken into account by these measurement tools.

An early study of activity monitor validity and reliability in people with limb absence examined an unnamed activity monitor for measuring normal daily activities in five males. Video recordings were used as the criterion reference in order for direct observation to be possible. The rating of the video recordings by two raters had a percentage agreement of 99.7% demonstrating the reliability of the criterion reference. The overall percentage agreement between the activity monitor output and direct observation was 90% (Bussmann, Reuvekamp, Veltink, Martens, & Stam, 1998). Another study described how a prosthesis mounted ActiGraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL) could accurately identify general postures and movements of eight participants with transtibial amputation (Redfield, Cagle, Hafner, & Sanders, 2013). The identification of these movements and postures were compared to visual observation by study researchers. The Actigraph was shown to be 96.6% accurate compared to the observers.

Salih, Peel, and Burgess (2016) conducted a laboratory-based study with 21 participants with limb absence (of whom $n = 17$ had transtibial absence). The number of males in the sample was 15. ActivPAL accelerometers were placed on participants' amputated and non-amputated sides whilst performing lifestyle simulated tasks (walking, and sitting in and propelling a wheelchair). Sensitivity was calculated as the proportion of each observed activity category that was correctly detected by the activPAL. Using the Bland-Altman method, the mean difference between directly observed and activPAL monitor measures for total time spent walking over a five minute trial for the sound, non-amputated side was <0.01 seconds (95% limit of agreement –0.09 to 0.10 seconds), and for the amputated side was 0.11 seconds (95% limit of agreement –0.43 to 0.66 seconds). The Bland-Altman analysis between monitored and observed time found the sensitivity for time spent walking for the non-amputated side was 90.5% and for the amputated side was 86%. No recommendations were made on which side (limb absent or sound side) to attach the monitor for optimal recording.

In another study, researchers measured daily standing and stepping of adults with lower limb absence to help in determining optimal prosthetic socket prescription (Buis et al., 2014).The inter-device reliability of the activPAL monitor was established in only one participant who wore two monitors attached just above the ankle for 20 trials. Inter-device reliability in this single subject observation study was ICC (intraclass correlation coefficient) = .99, which the authors considered to be excellent. A number of studies have shown that activity monitors can be reliable and valid in measuring physical activity in people with limb absence. Additionally the activPAL has been used for establishing various outcomes such as sensitivity of the device and optimal socket prescription in people with lower limb absence. However, based on this limited evidence of reliability and validity of the activPAL accelerometer in adults with lower limb absence, there are obvious gaps in the knowledge-base. Therefore, the aims of this study were to:

1. assess reliability of the activPAL accelerometer for measuring physical behavior in a controlled setting; and
2. determine the criterion-related validity of the activPAL accelerometer for measuring incidental and purposive walking, and walking and sedentary time.

Methodology

Participants

Adults with unilateral lower limb absence at either transtibial or transfemoral level who routinely wore and used a prosthesis for free-living activities were recruited to the study. Adults who used walking aids or a wheelchair were not excluded although the final sample did not include such individuals. Potential participants were identified from an attendance list of volunteer patients who had previously been invited to assist with academic training and education at the University of Strathclyde. Although this was a convenience sample from volunteer patients, the authors are mindful that habituation to the prosthesis following amputation may have influenced individual gait patterns and the results. However, all participants had similar levels of functional classification i.e., they all had the ability or potential for variable cadence ambulation over most environmental barriers such as kerbs, stairs or uneven surfaces. On arrival at the testing location, study information was presented to 20 potential participants by a departmental receptionist who was independent of the study. The list of potential participants included 18 males and two females. Those who wished to participate provided signed consent prior to commencement of the laboratory-based study. For the participants' convenience, testing was carried out during one visit to the test center.

Measurement Device

The activPAL is a tri-axial accelerometer-based posture and activity device. It is a small device ($53 \times 35 \times 7$ mm) weighing approximately 15 grams that is typically attached to the anterior mid-thigh using transparent waterproof film dressing (e.g., 3M™ Tegaderm™, 3M Healthcare, St Paul, MN). The activPAL monitor measures

posture and classifies free-living activity into time spent sitting/lying, standing, and stepping. The activPAL also records sit-to-stand transitions and stepping events and produces a step count. Notably, the monitor registers each step taken with the leg to which the activPAL is attached, and the inbuilt software doubles this in order to obtain a total step count.

Procedure

Participants were asked to complete three brief (ca. two minutes) controlled trials in a laboratory setting, consisting of four activities of daily living performed in a pre-determined order. Figure 1 illustrates the laboratory layout and equipment positioning, and the route taken by participants. Digital video recordings of each trial from two synchronized cameras were subsequently classified by three trained researchers. Each participant wore two activPAL Mini accelerometers (PAL Technologies Ltd., Glasgow, UK; www.paltechnologies.com/). One activPAL was attached to the sound, non-amputated side, and the other was attached to the prosthetic, limb-absent side at the level of the anterior thigh mid-point. To establish validity of the accelerometer output, data from each activPAL were compared to the observer rated data derived from the digital recordings. Finally, data from the two accelerometers worn by each participant were compared to establish the

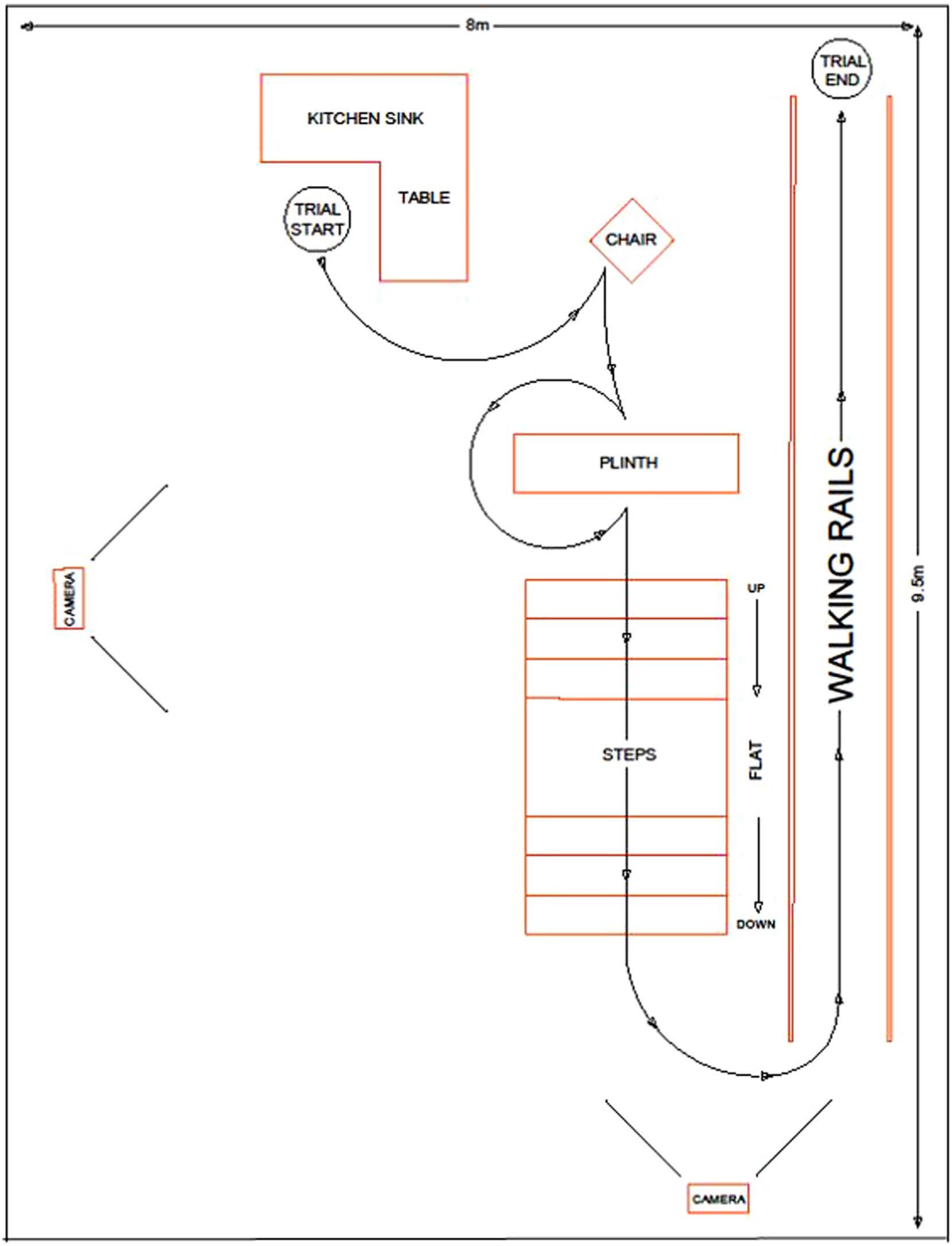

Figure 1 — Illustration of laboratory and equipment layout and participant trial route.

effect of the placement of the monitors on participants' sound or prosthetic side limbs.

Before the trials commenced participants completed a questionnaire to collect demographic and other relevant information such as pre-existing medical conditions. The questionnaire also asked about habitual locomotor modes in the home. Participants were briefed on the equipment including the activPAL monitors, the room layout, and the sequential tasks to be performed during each trial.

For consistency, an identical equipment set up was ensured over each data collection day by marking the laboratory floor with tape on the first day of testing. Walking speed was self-selected by each participant. Participants were shown where to stand for the start of the trial. The trial route was then demonstrated by a researcher who moved through the stations in the following order: (a) setting a table in a mock kitchen; (b) sitting in a chair; (c) lying down on a plinth; (d) negotiating six stairs (three stairs up, a flat section of one meter, and three stairs down); (e) walking the length of the room between walking rails; and (f) standing at ease at the trial end. These were all activities which were familiar to participants and were selected for simplicity and ease of mastery for those with lower limb absence. Participants were prompted when to move from station to station by a researcher. It was important for the participants to self-select their walking speed in order for them to mimic their normal gait patterns and for them to remain physically and emotionally comfortable during the trials.

Clinical judgment by a qualified prosthetist was used to determine each participant's tolerance for standing and incidental stepping, and ambulatory walking. With this in mind, when the participant adopted and was comfortable in the stipulated posture, each activity was performed for a minimum of five seconds and no more than seven seconds as measured by one of the researchers.

Equipment

Two digital cameras (HRD-CX115E, Sony Corporation, Tokyo, Japan) were used to record the movements of participants during each trial. The cameras were placed at points in the laboratory to record sagittal and coronal views of performance. Using data analysis software (PnO Data Solutions, The Tarn Group, Dunedin, New Zealand), videos were downloaded and converted to .wmv files for analysis using Windows Media Player (Microsoft Corporation, Redmond, WA). Windows Media Player has an upwards counting timer and displays video time length. This was an important feature in helping the researchers ensure the trials were of consistent length across participants, and when raters assessed the video footage.

ActivPAL time of initialization was noted for later identification of the beginning of each of the three trials in the continuous data output. The activPAL monitors were placed at the anterior midpoint of each thigh of the participant using film dressing. If the participant had transfemoral limb absence, then the prosthetic side activity monitor was positioned on the outer prosthetic socket at the same level as the monitor positioned on the middle of their sound side thigh. In doing this, there may have been the potential for a signal artefact from the activity monitor. However, due to the close fitting nature of the stump-socket interface, it was not possible to attach the monitor directly to the skin of the transfemoral prosthesis users. The study procedures were given ethical approval by the University Ethics Committee.

Data Processing and Data Analysis

The activPAL software (PAL Technologies Ltd., Glasgow, UK) is an agreeable system for initializing, downloading, and exporting data. Researchers can visualize data such as bouts of sitting/lying, standing, and stepping in various formats from individuals' files. Data can be viewed by week, by day, or by hour. Data produced by the activPAL monitors were downloaded and saved as .csv files in numerous formats. Raw data from the activPAL is converted to a variety of summary files. More detailed summaries of importance in this study, such as the order of occurrence of the activity bouts are produced in events files. These are a chronological list of all bouts of sitting/lying, standing, and each step, with the time each bout begins and ends, and the duration of each event. Events files have a separate row for each period of uninterrupted sitting/lying and standing, and each individual step. Events files detail the recording of individual steps from the leg to which the monitor is attached. To be clear, events files produce data related to all activity bouts on the sound side, or the amputated side. As such, each activPAL monitor measures a step only on the worn leg which is recorded in the events file, yet individual step values are doubled when recorded in the summary file. The events files were used for all analyses in this study related to physical behavior. All analyses were conducted using SPSS 22.0 (IBM Corp., Armonk, NY).

Reliability and Criterion-Related Validity of the activPAL Accelerometer

Upon completion of the three trials by each participant, data from the two monitors were downloaded. Manual calculations were made for total incidental stepping time, total reclining time and total purposive stepping time in each trial. Various events were identified and highlighted on the events file output to indicate the following: trial start showing first standing event followed by incidental stepping events; chair sitting and plinth lying reclining events; purposive stepping event; and trial end showing final standing event.

Inter-Rater Reliability of a Video-Rated Criterion

All participants successfully completed three laboratory trials and a total of nine sets of video scores were produced per participant (three raters assessing three video recorded trials per participant). Two types of scores were recorded: step counts; and time elapsed in seconds. Analysis was carried out on three types of behavior namely standing, sitting/lying, and stepping. The time points at which these behavior types occurred in the videos were used to cross-reference with the same time points in the events files. A hand held mechanical tally counter was used by each of the three raters for counting steps. Prior to the rating of the videos, instructions were provided to each rater; several practice video reviews were also performed by each rater. This allowed raters to be consistent in defining the start and end of different activities. Two different angles/views of the participant were taken simultaneously by two cameras creating one multi-angle video file; raters were able to verify specific and individual events from sagittal and coronal views. The instructions also clarified to the raters one step as being the point at which one foot leaves the ground (toe off) and the same foot making contact with the ground (heel contact). The following step and time values were derived by each rater, for each trial, for each participant:

- total incidental steps—all steps taken from video start until the participant reached the plinth;
- total purposive steps—all steps taken from leaving the plinth until the participant stood at the trial end;

- total steps (the sum of incidental and purposive steps);
- reclining time; and
- purposive stepping time.

A separate, multi-angle video file with split views in the sagittal and coronal planes was created per trial, resulting in three videos per participant. All three videos for each participant were observed and counted by each rater and used for the analysis. The rater values for each of the above variables were summed across the three trials, and the median of the three raters' values was used as the criterion measure. In the current study, the raters were the same across all participants and data were continuous, therefore inter-rater reliability was calculated using the two-way intraclass correlation coefficients (ICC) model (Shrout & Fleiss, 1979). All results were adjusted for a single rater. For time variables, the time spent in each activity was recorded by each monitor. For reclining and purposive stepping time variables, the raters' values derived using the media player file clock were compared to those from the prosthetic side monitor output, and then repeated for the sound side monitor output. Results for criterion-related validity for reclining and purposive stepping time, and for incidental, purposive and total steps is presented as raters versus the sum of prosthetic and sound side devices for observed and measured stepping.

For all data analyses, ICC values of between .75 and .90 were considered good, and values ≥.90 were deemed to show excellent reliability (Koo & Li, 2016). Nunnally (1994) described an ICC = .70 and above as being minimally acceptable (Nunnally, 1994). Paired *t*-tests were used to compare the mean measures between devices. No significant or meaningful differences would be detected if the values yielded by the raters or the devices were identical. The effect size indicates whether that difference is large enough to be practically meaningful. Cohen suggested that $d = 0.2$ be considered a small effect size, 0.5 a medium effect size, and 0.8 a large effect size (Cohen, 1988). Finally, a modified Bland-Altman plot was used to inspect patterns of systematic difference between the activPAL and the criterion or possible outliers (Bland & Altman, 1986). The differences between methods (*y* axis) were plotted against the criterion (*x* axis). This was performed for raw scores, and for scores expressed as a percentage of the criterion. The aim was to determine whether proportional bias was monotonically related to magnitude of the criterion score, and also to standardize any mean bias across the different variables having a different metric/magnitude to each other.

Results

Characteristics of the Participants

Table 1 presents characteristics of the participants of study. All results are based on a convenience sample of 15 participants (13 males and two females), which is atypical of the population with limb absence. The split of males and females in the UK national limb-absent population during 2011–2012 was 69.9% and 30.2%, respectively (United National Institute for Prosthetics Orthotics Development, 2011–2012). Of the sample, four participants had transfemoral absence, and 11 participants had transtibial absence, also representative of the UK national limb-absent population. Trauma was the most common reason for limb absence ($n = 8$). Also of note was the fact that 13 of the 15 participants in the sample were classified as being overweight or obese (a body mass index equal to or greater than 25).

Table 1 Characteristics of Study Participants

Measurement	All ($N = 15$), *M* (*SD*)	Male ($n = 13$), *M* (*SD*)	Female ($n = 2$), *M* (*SD*)
Age (yr)*	59.20 (12.03)	62.60 (8.56)	37.00 (2.83)
Height (m)*	1.74 (0.11)	1.76 (0.09)	1.58 (0.04)
Weight (kg)*	84.90 (18.77)	89.50 (15.35)	54.80 (1.77)
Body mass index (kg/m^2)*	27.80 (3.68)	28.70 (3.08)	22.10 (0.38)
Level			
Transtibial	11	10	1
Transfemoral	4	3	1
Side of limb absence			
Right	10	9	1
Left	5	4	1
Cause of limb absence			
Trauma	8	8	
Cancer	3	2	1
Infection	1	0	1
Congenital	1	1	
Peripheral arterial disease	2	2	
Employment status			
Retired	9	8	1
Full-time	3	2	1
Part-time	2	2	
Unemployed	1	1	
Wheelchair user			
No	14	12	2
Yes	1	1*	

* This participant used a wheelchair outdoors and infrequently, and did not use a wheelchair during the study trials.

Inter-Rater Reliability of Directly Observed Stepping, and Reclining and Purposive Stepping Time

One video trial file capture failed due to equipment malfunction, therefore 44 video files from a possible total of 45 video files were analyzed. Missing step count and time data values for the failed video trial data capture were substituted using the average of the values from the two successfully recorded video trials for this participant. This was considered an appropriate and accurate approach based on a study on individual information-centered imputation of missing data (Kang, Rowe, Barreira, Robinson, & Mahar, 2009). The total time to complete all three trials ranged from 207.32 to 384.93 seconds ($M = 243.85$, $SD = 46.49$). Table 2 shows the inter-rater reliability of directly observed stepping, and reclining and purposive stepping time. All intraclass correlations for all measures are .95 or higher, indicating excellent reliability for the criterion measures.

Reliability of the Prosthetic Side Device vs. Sound Side Device for Stepping and Time

Table 3 shows the results of paired *t*-test analyses for prosthetic and sound side placed devices. There were no significant differences for

any of the variables although the difference for incidental steps is notably a medium-sized effect (*d = 0.48)*. Inter-device reliability was adjusted for a single rater.

Intraclass correlation coefficients for incidental steps ICC = .05 (95% CI = –.46 to –.53) indicated no consistency in the measurement between devices. For purposive steps and total steps the intraclass correlation coefficients were ICC = .88 (95% CI = .67 to .96) and ICC = .77 (95% CI = .44 to .92), indicating that the activPAL was reliable in measuring these variables. Inter-device reliability was adjusted for a single rater. Time-based measurements showed the activPAL to be reliable in measuring reclining time ICC = .99 (95% CI = .96 to 1.00), and for purposive stepping time ICC = .99 (95% CI = .97 to 1.00).

Table 2 Inter-Rater Reliability of Directly Observed Stepping, and Reclining and Purposive Stepping Time

		95% CI	
Measurement	**ICC**	**LL**	**UL**
Incidental steps	0.95	0.89	0.98
Purposive steps	1.00	0.99	1.00
Total steps	0.99	0.98	1.00
Reclining time (s)	0.98	0.96	0.99
Purposive time (s)	0.99	0.97	1.00

Note. All measures have been adjusted for a single rater. ICC = intraclass correlation coefficient; CI = confidence interval; LL = lower limit; UL = upper limit.

Criterion-Related Validity of activPAL vs. Directly Observed Time and Stepping Variables

The intraclass correlation coefficients between the directly observed values and activPAL measures for time were found to be excellent for reclining time, and were good for one of the measures. The values were as follows: for reclining time ICC = .99 (95% CI = .98 to 1.00); and for purposive stepping time ICC = .88 (95% CI = .69 to .96). Table 4 displays the results of the paired *t*-tests comparing raters' values to the activPAL recorded values for all time and stepping variables. Directly observed values and activPAL measures for incidental, purposive and total number of steps is also presented. Notably, mean activPAL scores were significantly lower than raters scores for all stepping and time variables. The results were: incidental steps ($t_{(14)} = -18.26$, $p = <.0001$, $d = 0.96$), purposive steps ($t_{(14)} = -8.24$, $p = <.0001$, $d = 0.38$), and total steps ($t_{(14)} = -17.02$, $p = <.0001$ $d = 0.46$).

Table 3 Paired *t*-Test Comparing Prosthetic Side Device vs. Sound Side Device for Stepping and Reclining and Purposive Stepping Time

Measurement	**Statistic**	**Prosthetic**	**Sound**	**Paired Differences**	***t***	***p***	***d***
Incidental steps	*M*	10.07	12.20	2.13	1.36	.20	0.48
	SD	3.61	5.09	6.08			
Purposive steps	*M*	45.13	45.13	0.00	0.00	1.00	0.00
	SD	9.55	9.06	4.61			
Total steps	*M*	55.20	57.33	2.13	1.00	.34	0.18
	SD	11.36	12.98	8.29			
Reclining time (s)	*M*	78.67	77.78	0.89	1.40	.18	0.06
	SD	16.72	15.13	2.48			
Purposive time (s)	*M*	65.39	65.61	0.21	0.24	.81	0.01
	SD	21.89	23.06	3.42			

Note. Values were summed for prosthetic and for sound sides across the three trials. *M* = mean, *SD* = standard deviation.

Table 4 Criterion-Related Validity of activPAL vs. Directly observed Time and Stepping Variables

				Paired Differences						95% CI	
Variable	**Measure**	***M***	***SD***	***M***	***SD***	***t***	***p***	***d***	**ICC**	**LL**	**UL**
Reclining time (s)	Raters	82.82	14.84	–4.59	1.80	–9.86	<.0001	.12	.99	.98	1.00
	activPAL	78.23	15.90								
Purposive stepping time (s)	Raters	70.39	16.84	–4.89	9.60	–1.97	.07	.49	.88	.69	.96
	activPAL	65.50	22.02								
Incidental steps	Raters	59.84	10.17	–37.58	7.97	–18.26	<.0001	.96	.56	.09	.83
	activPAL	22.27	6.40								
Purposive steps	Raters	105.70	20.27	–15.42	7.24	–8.24	<.0001	.38	.93	.80	.98
	activPAL	90.27	18.03								
Total steps	Raters	165.47	29.12	–52.93	12.04	–17.02	<.0001	.46	.89	.72	.96
	activPAL	112.53	22.94								

Note. *n* = 15; ICC = intraclass correlation coefficient; CI = confidence interval; LL = Lower Limit; UL = Upper Limit.

The authors performed criterion-related validity analyses when the sample was split by level of limb absence into transtibial and transfemoral groups. There were no meaningful differences; the results were ostensibly similar to each other, and similar to the sample as a whole ($n = 15$). Further, the modified Bland-Altman method for stepping variables showed there was a significant and meaningful negative fixed bias (the activPAL underestimated directly-observed scores by 63% [incidental steps], 15% [purposive steps], and 32% [total steps]), with no proportional bias. For time-related variables, the results were less clear. When converted to percentage scores, there was a significant and meaningful negative fixed bias (the activPAL underestimated directly observed scores by 8% [purposive stepping time], and 6% [reclining time]), though the results for proportional bias were different. There was no proportional bias for purposive stepping time, and a significant positive proportional bias for reclining time, albeit bias was negative across the whole range of scores. The results of the analyses by level of limb absence, and the complete Bland-Altman analyses, are available from the primary author on request.

Discussion

The aims of this study were to 1) assess reliability of the activPAL accelerometer for measuring physical behavior in a controlled setting; and 2) determine the criterion-related validity of the activPAL accelerometer for measuring incidental and purposive stepping, and stepping and reclining time.

Reliability of the activPAL Accelerometer for Measuring Stepping and Time

Inter-rater reliability of directly observed stepping, and reclining and purposive stepping time was examined to establish a criterion reference. All intraclass correlation values were considered excellent and the authors concluded that multiple raters are not needed to obtain reliable data in criterion validity studies that use direct observation as the criterion measure. This is of course in the context of this study where trials were short (approximately two minutes in duration), and included a small number of activities.

Reliability between the measurements from the sound and prosthetic side placed monitors was found to be poor in measuring incidental steps. However, each monitor consistently measured total steps due to the accuracy of each device in accurately measuring purposive steps. The higher agreement for purposive steps over incidental steps is understandable as the monitors in conjunction with the underlying firmware and software, irrespective of placement side, were able to detect continuous bouts of purposive stepping. This is due to adequate acceleration of the limb segment, in this case the thigh.

A possible explanation for poor reliability in measuring incidental steps could be the nature of the participants' clinical condition. Due to the fact that participants walked with prostheses, some may have walked with a more hesitant or faltering gait. Reduced participant cadence and velocity may not be detected by the activPAL due to the algorithms being designed to be more suitable for healthy adults rather than those with clinical conditions affecting posture and movement (Ryan et al., 2006). Further, the incidental stepping during the trial requires turning or pivoting movements when compared with the purposive stepping. Given the mobility of these individuals could be compromised, it may be possible that the prosthetic side is used more as a stabilizing pivot thereby allowing the sound limb to maneuver more freely. This may account for the differences between sound side and prosthetic side results during incidental stepping.

The laboratory conditions may have contributed to the restriction of normal gait patterns which influenced the results. For example, the participants took fewer incidental steps relative to purposive steps on both the prosthetic and sound sides. This can also be described in terms of the number of purposive steps dominating over incidental steps taken and therefore influencing the number of total steps taken. To clarify, incidental steps ($M =$ 59.8 steps) constituted 36% of total steps ($M = 165.07$), whereas purposive steps ($M = 105.53$ steps) constituted 64% of total steps. This may not be representative of a free-living situation where a relatively higher proportion of total steps taken by people with lower limb absence may be purposive steps. This is further supported by a study examining reliability of the activPAL in $N = 20$, non-prosthesis wearing healthy adults (Ryan et al., 2006). This study showed that inter-device reliability of the activPAL was excellent for both step number and cadence.

The activPAL monitors were reliable in measuring time, despite an individual trial length time of between one and two minutes. This may be considered short when other studies have assessed posture and stepping over periods of up to 30 minutes (Sellers, Dall, Grant, & Stansfield, 2016).

Criterion-Related Validity of the activPAL Accelerometer for Measuring Incidental and Purposive Stepping, and Total Stepping and Reclining Time

Based on the findings, the activPAL is valid in detecting purposive stepping, and for recording reclining and purposive stepping time in a sample of people with limb absence. This study has shown that the activPAL monitor is not valid in the measurement of incidental stepping in those with unilateral limb absence who use a prosthesis.

The optimal side of placement of an accelerometer in a population of people with unilateral absence was considered for all variables. Generally across participants, the monitors recorded similar values for time spent reclining, purposive stepping, and step number. The prosthetic side monitor more inconsistently measured stepping to a greater degree than the monitor placed on the sound side when measuring incidental stepping. This corresponds to the findings from a similar study where researchers tested the accuracy of the activPAL featuring adults with lower limb absence (Salih et al., 2016). Here, measurements compared more favorably between the observed raters and the sound side placed monitor ratings (90.5% agreement), than between the observed raters and the prosthetic side monitor (86% agreement). However, recommendations on preferred side of attachment of the monitor were not made by the authors.

Strengths, Limitations, and Future Work

There were limitations to the study. Participants had either transtibial or transfemoral limb absence. Those with transfemoral absence had the prosthetic side activPAL monitor positioned on the external prosthetic socket rather than the usual protocol of attaching the monitor directly onto the skin of the thigh. The monitor is designed to record data when attached directly to the skin and it is possible that, with placement on the prosthetic socket, the ability of the monitor to accurately record time and steps may have been adversely affected. However, this is inherent to studying the

activPAL in this population rather than being a weakness of the study design *per se*.

The authors explored the differences between transtibial and transfemoral groups within the whole sample. However, the limited sample size, especially for the transfemoral sub-group (n = 4) suggests the separated results should be viewed cautiously. Preliminary results indicate that those with transtibial and transfemoral absence showed similar patterns. Further research on larger sub-groups is required to test whether this finding is robust. For this study it was felt important to include both transtibial and transfemoral groups in the analysis to help the findings be extrapolated to all levels of unilateral lower limb absence.

Future work could yield information on optimal positioning of activity monitors in those with different levels of limb absence. In addition, the cohort was non-representative in terms of cause of amputation due to only two participants of the 15 stating the reason for amputation being peripheral arterial disease. In the UK, peripheral arterial disease is the most common aetiology in people with limb absence with more than 75% of lower limb amputations being performed due to this condition (United National Institute for Prosthetics Orthotics Development, 2011–2012). This could be addressed by recruiting randomly from a prosthetic-centered clinical facility rather than from a convenience sample.

Further, potential artefact accelerations may have been introduced due to monitors being attached to the outer prosthetic socket in the case of the participants with transfemoral absence. Future work could explore optimal ways of assessing physical activity and sedentary behavior using the activPAL in people with transfemoral absence.

The controlled laboratory environment in which the study took place may have been limiting for the participants in being able to realistically perform the simulated free-living movements. Gait patterns may have also been affected by the limited space in the laboratory. Short distances between the chair and the plinth for example may have led to participants taking proportionally more incidental steps than purposive steps at walking cadences slower than usual. Replication of the study using longer trial lengths and walking routes which encourage more purposive gait at greater cadence might be conducive to the activPAL being more sensitive in recording incidental and purposive steps (Sellers et al., 2016). The converse may have also arisen whereby participants' self-selected gait may have been influenced by the presence of the observers in the laboratory. The underlying algorithm from each activPAL monitor translated the measured accelerations into metrics. It is proposed that not all accelerations were detected by the monitors attached to sound and prosthetics sides; indeed there was greater sensitivity in recording of steps by the raters than those recorded by the activPAL monitors. The authors infer that the magnitude and pattern of dynamic accelerations during slower cadences may have been insufficient for the algorithm to detect a step.

Improvement in device validity may be seen in replication research with longer sampling periods and a true real time environment for performing activities. The design of this controlled study resulted in limitations to the ecological validity especially in terms of the number of postural transitions that occurred in a short period of time. There was also the limitation of one activPAL monitor recording steps in a small environment over a short course of time on one limb side.

Finally, in this study the activPAL appeared to be valid in detecting short duration activity. However, the data were reprocessed for 0.1 second increments in order that incidental steps were not rejected, nor those events occurring at faster speeds such as purposive walking. In the current study, the simulated free-living activities included in each trial could be regarded as being abnormal in daily living patterns. Specifically, it would be unlikely that a short bout of kitchen activities would be followed by a sitting bout, which is in turn immediately followed by a lying bout.

Although direct observation of free-living activity is becoming more feasible, other observational monitoring methods could also be considered. For example, wearable cameras such as the SenseCam (Microsoft Corporation, Redmond, WA), which includes an on-board triaxial accelerometer for recording and contextualizing physical behaviors, could be used. Objective measurement of free-living activities for time periods up to the maximum recording period for the activPAL monitor of 14 days could be explored. In this way, a better understanding of realistic posture and movement, and patterns of movement could be gained. Monitoring week day and weekend time periods when it is known that physical behavior patterns can be altered could be studied (Drenowatz et al., 2016). Conducting studies which test other accelerometers, such as the ActiGraph GT3X (ActiGraph, LLC; Ft. Walton Beach, FL) should be prioritized. This would aid researchers in determining the optimal movement, sedentary behavior, and posture measurement device for use in this clinical population.

Conclusions

This study has shown that multiple raters can be used to obtain reliable data in criterion validity studies that use direct observation as the criterion measure. Further, the activPAL accelerometer is a valid instrument for measuring purposive stepping and reclining events over a short period in a laboratory setting. It can be considered a useful tool by clinicians and researchers in measuring simulated activities of daily living in people with lower limb absence, and may be valid for use in lifestyle physical behavior studies subject to further investigation. Placement of the accelerometer on the sound leg of people with limb absence is more accurate in recording than a monitor placed on the prosthetic side.

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