

**TITLE**

Physical activity of ICU survivors during acute admission: Agreement of the activPAL<sup>3</sup> with observation

**ARTICLE TYPE**

Brief report

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## ABSTRACT

**Purpose:** To estimate the agreement of a thigh-worn accelerometer to measure activity and sedentary parameters with an observed mobility assessment of intensive care unit (ICU) survivors.

**Method:** Prospective comparison of the activPAL to direct observation during assessments at ICU or acute hospital discharge, in eight participants with a median (1<sup>st</sup>-3<sup>rd</sup> quartile) age of 56(48-65) years and APACHE II score of 23(17-24). Frequency of sit-to-stand transitions, time spent standing, stepping, upright (standing+stepping) and sedentary (lying/sitting), and total steps were described, with analysis including Bland-Altman plots and calculation of the absolute percent error.

**Results:** All sit-to-stand transitions were accurately detected. The mean difference (95% confidence limit) on Bland-Altman plots suggested overestimation of standing time with the activPAL of 31(-9 to 71) seconds and underestimation of stepping time by 25(-47 to -3) seconds. The largest median absolute percent errors were for standing time (21.9%) and stepping time (18.7%), with time spent upright (1.7%) or sedentary (0.3%) more accurately estimated. The activPAL underestimated total steps/session, with the largest percent error (70.8%).

**Conclusion:** With the underestimation of step count, stepping time was likely incorrectly recorded as standing time by the activPAL such that time spent upright was the measure of activity with least error. Sedentary behaviours including frequency of transitions were validly assessed.

## Keywords

physical therapy, accelerometry, critical illness, validation studies

## INTRODUCTION

Wearable activity monitors can be used in hospitalised patients to objectively quantify daily activity levels and sedentary behaviours. However data on the validity of activity monitoring in the acute hospital setting is limited to older medical/stroke inpatients<sup>1-3</sup> and is specific to the monitoring protocol, such as the device used, wear location and recording/analysis method. Studies in acute populations most commonly cite device validation as established in community dwelling participants,<sup>4-6</sup> which may not be generalisable to the acutely unwell due to the influence of the hospital environment and acute illness on physical activity patterns and movement quality. Survivors of a critical illness present with a unique pattern of muscle dysfunction that exacerbates immobility induced changes, affecting their short and long term activity levels that may be quantified by accelerometer monitoring.<sup>7-9</sup> Within the intensive care unit (ICU), behavioural mapping suggests that patients rarely ambulate outside of rehabilitation sessions<sup>10</sup> such that therapy sessions are the main contributor to cumulative daily activity. As health care staff may overestimate active and underestimate inactive time, objective activity/inactivity assessments such as accelerometry may provide a more accurate assessment of activity.<sup>11</sup> Accelerometry is advantageous in that it is less intrusive and labour intensive than behavioural mapping or video observation, and has potential use for routine monitoring or in larger studies of activity dose on outcomes. Existing studies of accelerometry of ICU patients are limited in that the accuracy of monitoring protocols have either not been tested<sup>9,12</sup> or validated for out of bed activities.<sup>13</sup> As part of a larger study of activity monitoring in people admitted to an ICU (NCT 02881801), this study sought to use concurrent measurement with the activPAL and direct observation, to test the hypothesis that there would be agreement between methods to classify sit to stand transitions, time spent standing, stepping, upright (standing plus

88 stepping) and sedentary (sitting or lying), and total number of steps during an unstructured  
89 mobility assessment of survivors of a critical illness on acute hospital wards.

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## **METHODS**

Procedures were approved by the relevant institutional ethics review committees and conducted in a single tertiary ICU/hospital in Bedford Park, South Australia. Patients aged  $\geq 18$  years who required mechanical ventilation for  $\geq 5$  days were eligible for inclusion. Patients who were unable to ambulate independently  $\geq 10$  meters prior to admission, unable to provide informed consent or were for palliative management were excluded. Fifteen participants provided written informed consent at awakening from mechanical ventilation within a larger prospective study of activity monitoring, for potential recording of an unstructured mobility assessment concurrently by direct observation and accelerometry at the a priori defined milestones of discharge from ICU or acute hospital. Eligible participants in the larger study were consecutively sampled, yet to overcome limitations of previous work,<sup>13</sup> we purposively sought to assess a sub-set of patients who were capable of transitioning from sit to stand with maximal assistance from two people (no mechanical lifters) and were able to attempt stepping with/without a walking frame<sup>5</sup> at ICU discharge. Twelve of the 15 potential participants met this minimum mobility criteria between October 2015 and April 2016. However, assessments were only able to be completed with  $n=8$ , with the choice of milestone (ICU or acute hospital discharge) based on the availability of the treating physiotherapist, the participant and the research observer for a scheduled mobility assessment. Each patient was assessed to their best functional capacity, while wearing their accelerometer to quantify daily physical activity and sedentary behaviours at discharge from the ICU or acute hospital.

Participants were fitted with a waterproofed activPAL3 (PAL technologies, Glasgow, UK) on their non-dominant anterior mid-thigh with strips of adhesive tape (Hypafix, BSN medical, Hamburg, Germany). A thigh-worn accelerometer was chosen as used in previous

studies,<sup>2,5,6</sup> as this attachment site is less likely to be compromised by dressings, attachments or invasive lines in acutely unwell patients, thus facilitating monitor wearability. Minor variations to the mid-thigh position do not appear to impact the accuracy of outcome measurement.<sup>14</sup> Unlike ankle worn devices, the thigh-worn device enables differentiation of posture and sit-stand transitions,<sup>15</sup> although the latter may be more accurate for determining step count at slower gait speeds.<sup>5</sup> The activPAL determines posture (sitting/lying and upright), stepping and transitions between postures from accelerometer-derived information about thigh position and accelerations.<sup>16</sup> Further details of the activPAL algorithm are unknown as it is proprietary.<sup>16</sup> The default setting for minimum upright period recording was reduced to two seconds while the minimum sitting period was 10 seconds,<sup>17</sup> based on the expectation that severely deconditioned patients may only stand for short periods. Each device was first waterproofed with a latex finger cot and dressing (Opsite, Smith & Nephew Medical Ltd., Hull, UK). Data were transferred to a PC for processing (v.7.1.18, PAL technologies, Glasgow, UK) before export of raw data to Microsoft excel.

Observational data were recorded and transcribed by a single physiotherapist with 10 years of clinical experience in the acute tertiary hospital setting and with the early rehabilitation of ICU patients. The physiotherapist used a digital voice recorder (Sony IC recorder, ICD-P28, New Jersey, USA) to report changes in patients body posture in real-time using a priori determined definitions for standing and stepping to determine time spent upright, and, sitting to determine time spent sedentary (Appendix 1). Standing was determined when the patient was in their most upright posture and a step as when the foot of the patient completely lifted off the ground. Sitting was determined when the patient reached a seated position either from lying, or, when the patient's bottom contacted the seated surface after a period of standing. In real-time and with the above definitions in mind, the observer spoke the words

'sit', 'stand', 'step' (for anticipated small numbers of steps such as in transfers) into the  
 voice recorder, but numerically counted each series of steps when the patient was  
 specifically marching on the spot or walking. A standardised form was used to transcribe  
 observations to the nearest second using timing from the playback file (Appendix 1), with  
 activities then coded consistent with the activPAL for each session prior to viewing  
 accelerometer results.

Data on the time interval and cumulative step count for each change in activity code (0  
 sedentary, 1=standing, 2=stepping) was summarised from the activPAL event file to the  
 nearest second for the corresponding period of observation and entered into SPSS (IBM  
 v.21.0, New York, NY). This was done by the same physiotherapist, once accelerometer  
 data had been obtained from all study participants. The frequency of sit to stand transitions,  
 time spent standing, stepping, upright (standing plus stepping) and sedentary (sitting or  
 lying), and, total number of steps over the session were noted. Descriptive data were  
 reported as median (1<sup>st</sup>–3<sup>rd</sup> quartile) unless otherwise stated, with full summary data for time  
 and step count outcomes from both methods in Table E1 (Appendix 2). The Bland-Altman<sup>18</sup>  
 method was used as consistent with other studies that have compared observation (without  
 video) to the activPAL<sup>5,6</sup> to assess the differences between device and visualised  
 measurements, plotted against the average of these measures; horizontal lines at the mean  
 difference, +/-1.96 standard deviations (limits of agreement) were also plotted. The  
 precision of the mean differences and limits of agreement were determined by calculating  
 95% confidence intervals, as described by Bland and Altman.<sup>18</sup> Table E1 (Appendix 2) also  
 includes summary data for the difference between methods (activPAL-observation) and the  
 absolute percent error ((activPAL-observation) / observation) x 100, calculated per  
 participant. For total number of steps, method agreement was also represented by a scatter

166 plot with lines of perfect agreement and best fit (with pearson correlation ( $r$ ) and 95%  
167 confidence interval), due to a systematic difference between methods (Fig. E1, Appendix 2).

168

## RESULTS

Eight participants completed the study, n=6 females, aged 56(48-65) years, admission APACHE II score of 23(17-24) and ICU length of stay of 16(12-38) days. The assessments occurred 18(15-47) days post ICU admission, with five participants at ICU discharge and three participants at hospital discharge. The duration of observed sessions was 24 minutes 57 seconds (12 minutes 44 seconds – 37 minutes 14 seconds), with 2(1-3) sit to stand transitions per session (16 across all sessions), which were identified on 100% of occasions by the activPAL. Across all sessions there were a total of 11 stepping bouts (retrospectively defined from observed step counts as  $\geq 10$  consecutive steps) observed with 1(1-2) bouts per participant and 58(42-95) steps/bout, achieved as both marching on the spot (55% of bouts) and walking (45% of bouts).

Participants were observed to spend most their time sedentary, being a median (1<sup>st</sup>–3<sup>rd</sup> quartile) of 20 minutes 41 seconds (10 minutes 39 seconds – 31 minutes 59 seconds)(Table E1). In terms of active time, participants were observed to spend a median (1<sup>st</sup>–3<sup>rd</sup> quartile) of 3 minutes 1 second (1 minute 52 seconds – 5 minutes 30 seconds) upright, consisting of more time standing (1 minute 41 seconds (1 minute 7 seconds – 4 minutes 18 seconds)), than time stepping (1 minute 16 seconds (34 seconds – 2 minutes 55 seconds))(Table E1). Figure 1 shows the mean [95% confidence interval] differences between the activPAL and observation, with time spent standing overestimated by 31[-9–71] seconds (Fig. 1A), time spent stepping underestimated by 25[-4–3] seconds (Fig. 1B), such that the smallest mean difference between measures was for time spent upright (overestimated by 7[-33–48] seconds, Fig. 1C) and time spent sedentary (underestimated by 10[-59–39] seconds, Fig. 1D). The limits of agreement were +/-1 minute 34 seconds for time spent standing, +/-51 seconds for time spent stepping, +/-1 minute 36 seconds for time spent upright and +/-1

194 minute 54 seconds for time spent sedentary. The largest absolute percent errors were for  
195 time spent standing and stepping, being a median [interquartile range] of 21.9%[101.1%]  
196 and 18.7%[73.1%] respectively, as compared to the more accurate measures of time spent  
197 upright (1.7%[23.5%]) or sedentary (0.3%[5.9%]) (Table E1, Appendix 2).

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199 There were 85(27-158) total steps observed per session that were consistently  
200 underestimated by objective monitoring, seen as all points on the scatterplot of total steps  
201 detected by activPAL monitoring versus observation fell below the line of perfect agreement  
202 (Fig. E1, Appendix 2). For the line of best fit,  $r = 0.997$  (95% confidence interval 0.823–  
203 0.994). The absolute percent error for total steps was a median [interquartile range] of  
204 70.1%[28.6%].

## DISCUSSION

Similar to the study of Taraldsen et al<sup>2</sup> the activPAL correctly identified the number of sit to stand transitions. The point of equality (zero) for the mean difference between methods was within the 95% confidence intervals on Bland-Altman plots for all time based variables, except time spent stepping, suggesting acceptable agreement. More specifically, time spent upright and time spent sedentary had the smallest absolute percent error. Still, it appeared that the activPAL tended to overestimate time spent standing, possibly due to the activPAL incorrectly registering time spent stepping as time spent standing, with the underestimation of step count. The underestimation of total step count with the activPAL is consistent with other studies of activPAL step detection in participants with slower walking speeds,<sup>2,5</sup>

The clinical relevance of a difference in methods remains to be determined. However, given confidence intervals for mean differences were within +/-41 seconds and limits of agreement were within +/-1 minute 36 seconds for the time based activity outcomes, equivalent to between 4-12% of the time spent active/walking reported in previous studies of ICU patients (16.8 minutes at/over 5 days in the ICU<sup>12</sup> to 13.7 minutes prior to discharge<sup>9</sup>), we think that the activPAL provides a sufficiently valid estimate of time spent upright in people recovering from an ICU admission. As a positional device (rather than one that uses activity cut-points), the activPAL is capable of recording sedentary time and the transition between sedentary postures and quiet standing. This is important because quiet standing may indeed be therapeutic for deconditioned patients, and changes in response to treatment may first be seen in patterns of sedentary behaviour<sup>15</sup> such as breaks from sitting to standing. The measurement of transitions was 100% consistent between the activPAL and observation in the present study.

There appeared to be lower method agreement with a systematic difference in step detection in this sample of ICU survivors than in other populations that may mobilise with a slow gait speed or walking aid<sup>5</sup>. This may have been due to the smaller number of occasions or shorter duration of stepping observed per participant. However, unlike a previous study that compared an accelerometer to direct observation of ICU patients<sup>13</sup> but in which therapeutic activity was only observed in a bed or chair, out-of-bed mobilisation (standing/stepping) was attempted by all participants. While our observed mobility sessions were longer than those noted with behavioural mapping of ICU patients, it is not clear whether the time spent undertaking activities associated with ambulation within sessions was comparable.<sup>10</sup> The median (1<sup>st</sup>–3<sup>rd</sup> quartile) proportion of observed time spent stepping in the present study equated to 6.3%(2.2%-9.5%). Alternatively, the low rate of step detection could have occurred in relation to how the steps were accumulated across different parts of an unstructured assessment (in transfer, marching on the spot or walking) or differences in the stepping motor pattern of deconditioned patients following critical illness reflected in accelerations as detected by the activPAL. The accurate measurement of step count is likely to be clinically important in that walking during hospital admission for older adults is emerging as a measure of greater predictive ability than other measures of activities of daily living to predict 30-day readmission.<sup>19</sup>

## **Limitations**

We employed a technique of direct observation<sup>1,13</sup> for method comparison rather than video recording.<sup>2,4</sup> While video recordings enable inter and intra-rater reliability assessment of activity classifications and may limit errors in notation, it is challenging to achieve appropriate camera positioning within acute hospital and open ward settings. The reliability of the direct observation process used in the present study was not formally assessed

although we sought to mitigate sources of error by use of set definitions for activities and a single experienced investigator. The use of direct observation of position/activity according to pre-defined categories is an established method,<sup>10</sup> with high inter-observer agreement when assessed against video scenarios.<sup>1,6,20</sup> Unlike previous validation studies in acutely ill patients,<sup>1,2</sup> we chose to use a single monitor. While this simplified the procedure, it limited the possibility of differentiating sitting from lying.<sup>2</sup> The limits of agreement and confidence intervals for differences between methods on Bland Altman plots would be smaller with a larger sample, allowing more confidence in interpretation. While small samples of specific clinical groups have been used in previous validation studies of accelerometry,<sup>2,4,7</sup> sample sizes of studies of acutely hospitalised ICU survivors that have used accelerometer monitoring reflect the research challenges with the critically ill and the need for further evaluations of accelerometry in the acute setting.

## **Conclusion**

This study compared the agreement of the activPAL to direct observation for measures of activity and sedentary variables during mobility assessments of ICU survivors as they recovered on acute hospital wards, which enhances the transferability of results to real clinical situations. The comparability of the activPAL to other models of accelerometers used with ICU patients remains unknown.<sup>9,12</sup> Nonetheless, the single thigh-worn activPAL most consistently detected sit to stand transitions and time spent upright and sedentary, although total steps was underestimated and should be interpreted with caution.

## KEY MESSAGES

- (1) What is already known on this topic: Accelerometry can provide a valid measure of measure physical activity and sedentary time in stable healthy and clinical populations, but it has not been validated for the assessment of survivors of a critical illness in the acute hospital setting.
- (2) What this study adds: Agreement between the thigh-worn activPAL and observation to detect sit to stand transitions within unstructured mobility assessments of ICU survivors was excellent (100%). The agreement between methods for time-based variables was best for time spent sedentary and upright (standing and stepping), with the smallest percentage error. However, the device underestimated step count, the clinical relevance of which remains to be determined.

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## **AUTHOR CONTRIBUTIONS**

All authors contributed to the conception and design of the study. CEB completed data collection, analysis and drafted the manuscript. All authors contributed to data interpretation, subsequent manuscript revisions and gave final approval for this work, agreeing to be accountable for its accuracy and integrity.

## **CONFLICT OF INTEREST STATEMENT**

The author(s) declare that there is no conflict of interest. No financial support was provided to participants or individuals of the research team.

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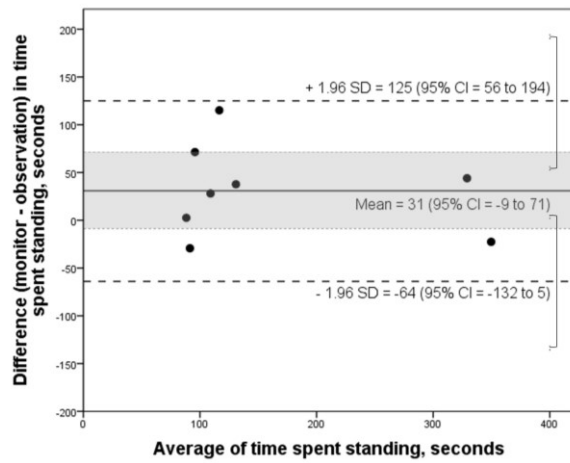
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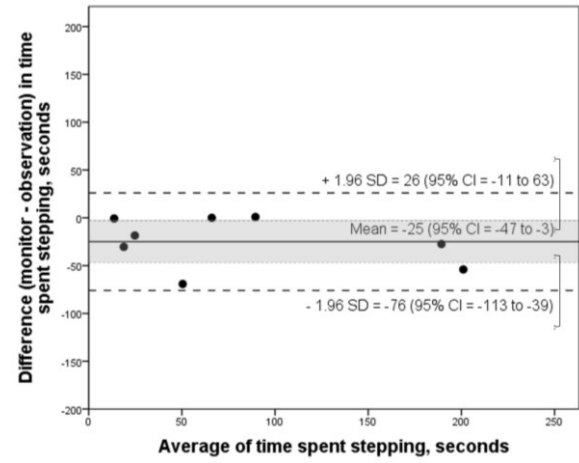
**FIGURE CAPTION**

**Figure 1.** Bland Altman plots of differences between objectively measured and observed time spent in seconds a) standing, b) stepping, c) upright and d) sedentary. Grey shading represents the 95% confidence interval for the mean difference; error brackets on the right of each plot represent the 95% confidence intervals for the limits of agreement.

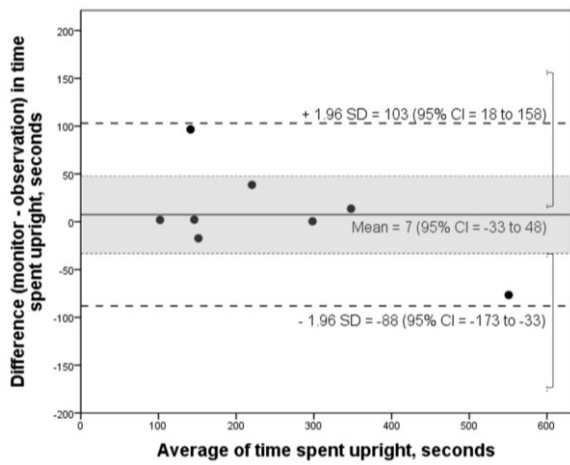
**FIGURE**



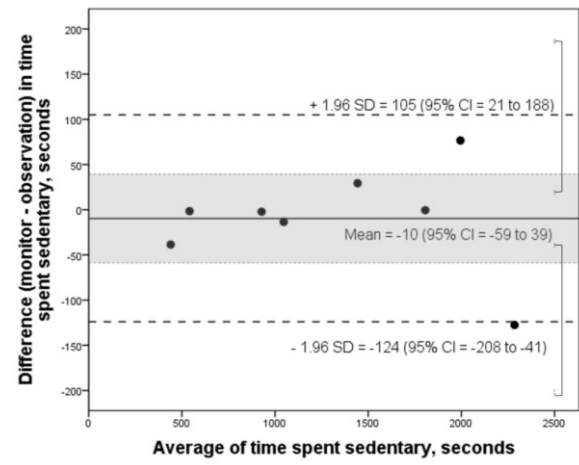
(a)



(b)



(c)



(d)

## ONLINE CONTENT

### APPENDIX 1: Observational data transcription form

#### VALIDATION DATA

**Time point:** ICU discharge / hospital discharge

**Session number:** \_\_\_\_\_

**Physiotherapist initials:** \_\_\_\_\_

#### ACTIVITY MONITORING

##### ActivPAL

Serial number of device: \_\_\_\_\_

Time applied (24 hour time): \_\_\_\_\_

Date applied: \_\_\_\_\_ / \_\_\_\_\_ / \_\_\_\_\_

Applied to leg: left / right

Time set to start recording: \_\_\_\_\_

#### OBSERVATION

Date: \_\_\_\_\_

Start time: \_\_\_\_\_

End time: \_\_\_\_\_

Direct observation / audio transcript

#### Instructions:

*Sequentially note the time (minutes:seconds) of each change in body position in a new row of the table overleaf.*

#### Position/activity definitions:

**Sit:** the time when the patient has reached a seated position with the trunk upright ( $\geq 45^\circ$ ), and legs lowered on the edge of the bed from lying, (not sitting up in bed, only can be sit on edge of bed); or following weight bearing transfer, the time when the patients bottom contacts the seated surface (supported in any type of chair or unsupported on the edge of the bed) after a period of standing

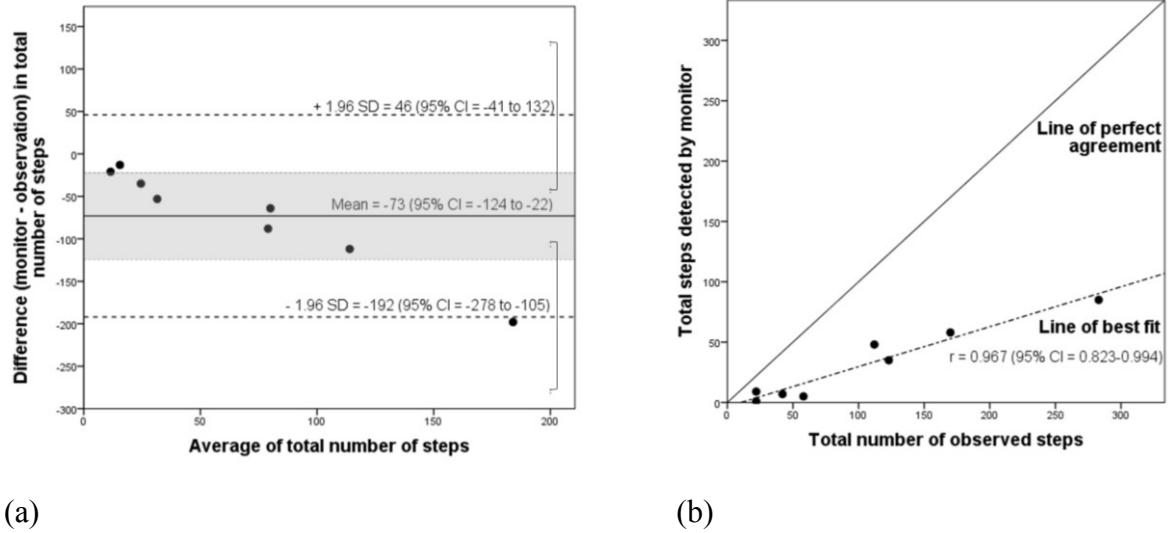
**Stand:** time when the patient is in their most upright position in standing

**Stepping:** when the foot of the patient completely lifts off the ground (i.e. either steps in transfer, marching on the spot or walking).

**Other movements:** can be described at discretion of observer (e.g. whether sitting in chair, wheelchair, etc.)

Time	Body position				Other notes
Commenced observation -----	Lie	Sit	Stand	Stepping	i.e. note number of steps (step counts) on transcription

## APPENDIX 2: Additional results



**Figure E1. (a)** Bland Altman plot of differences between objectively measured and observed total number of steps. Grey shading represents the 95% confidence interval for the mean difference; Error brackets on the right of the plot represent 95% confidence intervals for the limits of agreement. **(b)** Scatterplot of observed versus objectively measured total number of steps with a line of perfect agreement and best fit.

**Table E1.** Summary data for observed and objectively monitored variables, difference between methods and absolute percent error

Parameter	Observation	Activity monitor	Difference between methods <sup>a</sup>	Absolute percent error <sup>b</sup>
	Mean (SD) <i>Median [1<sup>st</sup>–3<sup>rd</sup> quartile]</i>	Mean (SD) <i>Median [1<sup>st</sup>–3<sup>rd</sup> quartile]</i>	Mean (SD) <i>Median [1<sup>st</sup>–3<sup>rd</sup> quartile]</i>	Mean (SD) <i>Median [1<sup>st</sup>–3<sup>rd</sup> quartile]</i>
Time spent standing (s)	148 (117) <i>101 [67 - 258]</i>	179 (107) <i>141 [98 - 297]</i>	31 (48) <i>33 [-16 – 65]</i>	45.1 (74.4) <i>21.9 [-3.9 – 97.2]</i>
Time spent stepping (s)	94 (80) <i>76 [34 - 175]</i>	69 (72) <i>41 [14 - 153]</i>	-25 (26) <i>-23 [-48 – 0]</i>	-33.6 (36.4) <i>-18.7 [-74.9 – -1.8]</i>
Time spent upright (s)	241 (166) <i>181 [112 - 330]</i>	248 (136) <i>215 [144 - 341]</i>	7 (49) <i>2 [-13 – 32]</i>	13.5 (38.0) <i>1.7 [-7.9 – 15.6]</i>
Time spent sedentary (s)	1315 (685) <i>1241 [639 - 1919]</i>	1305 (679) <i>1248 [637 - 1976]</i>	-10 (58) <i>-2 [-32 – 22]</i>	-1.2 (4.0) <i>-0.3 [-4.4 – 1.5]</i>
Total steps (n)	104 (90) <i>85 [27 - 158]</i>	31 (31) <i>22 [6 - 56]</i>	-73 (60) <i>-59 [-106 – -25]</i>	-74.2 (14.4) <i>-70.8 [-89.4 – -60.8]</i>

s = seconds

<sup>a</sup> activPAL – observation<sup>b</sup> ((activPAL – observation)/observation) x 100, calculated for each set of measurements

