

Review

# Considerations when using the activPAL monitor in field-based research with adult populations

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## Abstract

Research indicates that high levels of sedentary behavior (sitting or lying with low energy expenditure) are adversely associated with health. A key factor in improving our understanding of the impact of sedentary behavior (and patterns of sedentary time accumulation) on health is the use of objective measurement tools that collect date and time-stamped activity information. One such tool is the activPAL monitor. This thigh-worn device uses accelerometer-derived information about thigh position to determine the start and end of each period spent sitting/lying, standing, and stepping, as well as stepping speed, step counts, and postural transitions. The activPAL is increasingly being used within field-based research for its ability to measure sitting/lying via posture. We summarise key issues to consider when using the activPAL in physical activity and sedentary behavior field-based research with adult populations. It is intended that the findings and discussion points be informative for researchers who are currently using activPAL monitors or are intending to use them. Pre-data collection decisions, monitor preparation and distribution, data collection considerations, and manual and automated data processing possibilities are presented using examples from current literature and experiences from 2 research groups from the UK and Australia.

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**Keywords:** Inclinometer; Measurement; Physical activity; Posture; Sedentary behavior; Sitting

## 1. Introduction

Over the past decade, there has been substantial, and growing, scientific interest in sedentary behavior.<sup>1–3</sup> In 2012, an expert consensus defined sedentary behavior as “any waking activity characterised by an energy expenditure  $\leq 1.5$  metabolic equivalents and a sitting or reclining posture”.<sup>4</sup> It is now recognised that sedentary behavior is common (on average adults spend 46%–73% of waking hours sedentary),<sup>5–10</sup> and that too much time spent sedentary may be detrimental to health both in the short term<sup>11–14</sup> and long term.<sup>3,15–17</sup>

The availability of objective measurement tools with date and time-stamped information about activity is a key factor in improving our understanding of the impact of sedentary behavior and patterns of sedentary time accumulation on health. Most of the evidence on the associations of objectively assessed sedentary time and health has been derived from tools that infer sedentary time from a lack of movement.<sup>8,10,18–20</sup> However, this can lead to misclassification of low-intensity non-sedentary behaviors as sedentary behaviors.<sup>21</sup> A key example of this is standing. Like sitting or lying, standing involves minimal movement and low energy expenditure.<sup>22</sup> However, unlike sitting or lying, this behavior is characterised by its upright posture which elicits higher muscle contractile activity<sup>23</sup> with associated beneficial impacts on physiological processes such as glucose metabolism.<sup>11,13–24</sup>

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Notably, while the 2012 definition of sedentary behavior includes both energy expenditure and postural elements,<sup>4</sup> no field-based tool as yet directly and accurately captures both of these elements. The thigh-mounted activPAL monitor (activPAL™, activPAL3™, and activPAL3™ micro; PAL Technologies Ltd., Glasgow, UK) is 1 measurement device that directly measures the postural aspect of sedentary behavior. The activPAL device (referring to all models) is a small and slim thigh-worn monitor. Via proprietary algorithms (Intelligent Activity Classification), accelerometer-derived information about thigh position and acceleration are used to determine body posture (i.e., sitting/lying and upright) and transition between these postures, stepping, and stepping speed (cadence), from which energy expenditure is inferred indirectly. The activPAL has almost perfect correlation and excellent agreement with direct observation for sitting/lying time, upright time, sitting/lying to upright transitions and for detecting reductions in sitting.<sup>21,25–27</sup> Additionally, it accurately distinguishes standing from stepping<sup>26</sup> and identifying stepping speed (cadence);<sup>28</sup> however, accuracy for detecting stepping is compromised at very slow (i.e., <0.5 m/s) walking speeds.<sup>29</sup> As such, the use of the activPAL device in physical activity and sedentary behavior research has increased rapidly in recent years (460% increase from 2008 to 2014 on the Scopus citation database).

With the increasing use of activPAL monitors to address important questions in sedentary behavior research, it is timely to consider some of the methodological and practical considerations specific to these monitors. Existing best practice recommendations for objective activity monitoring, such as those outlined by Matthews et al.,<sup>30</sup> provide an excellent starting point. However, these are either general, or focused on other monitors that have key differences to activPAL devices, from the method and location of attachment, to the properties of the resultant data. Accordingly, some existing recommendations may not be applicable, and the unique opportunities and challenges specific to activPAL monitors warrant consideration and further elucidation.

This report provides an overview of the key data collection and processing issues to consider when using the activPAL activity monitor in physical activity and sedentary behavior field-based research with adult populations. The considerations discussed are categorised under: pre-data collection, monitor preparation and distribution, data collection, data processing, and data reporting. The considerations are mainly based on the procedures and protocols reported in the current literature (free-living adult studies identified from the PAL Technologies' bibliography (September 2014) and by searching the term "activPAL" in PubMed (October 2015)). Only those accessible in full-text form were included (Table 1). However, given the paucity of detail in the published literature, we also based considerations on the experiences from 2 international research groups (Table 2). These experiences span across both epidemiological and intervention study designs, various adult population groups and settings. It is intended that these findings and discussion points be informative for researchers who are both currently using activPAL monitors or are intending to use such

devices. It is not intended that the practices employed to date should be taken as best practice for the field.

## 2. Pre-data collection considerations

### 2.1. Wear period: number of days of monitoring

The number of days of monitoring ideally depends on the study design and purpose. The majority of studies (71%) that we considered in the literature (Table 1) and those in Table 2 have asked participants to wear the activPAL for 7 full days. To our knowledge only 1 study has reported how many days of monitoring are required to provide adequate reliability for several activPAL outputs (sitting, standing, stepping, and transitions) in adults.<sup>31</sup> Applying the Spearman–Brown Prediction Formula,<sup>32</sup> Reid et al.<sup>31</sup> showed to achieve intra-class correlations (ICCs) of 0.8 and 0.9, respectively, 5 days and 11 days respectively were needed for sitting, 5 days and 10 days respectively for standing, and 7 days and 15 days respectively for stepping in a population of older adults living in residential care. However, this approach has limitations, as each day is treated as randomly sampled (but they consecutive) and no distinction is made between particular days of the week. In reality, mean activity levels and correlations are likely to vary by day of the week.<sup>33</sup>

More recently, generalisability theory has been applied to investigate the reliability of activPAL measured sitting time and moderate-to-vigorous physical activity (MVPA).<sup>34</sup> Generalisability theory gives a better indication of repeatability than the ICCs, particularly when more sources of variation, including seasonality, are considered.<sup>35</sup> Barreira et al.<sup>34</sup> showed that in women, to achieve G-coefficients (interpreted identically to an intra-ICC value) of 0.8 and 0.9, respectively, 4 and 9 wear days were needed for sitting and 7 and 21 wear days were needed for MVPA. Achieving an acceptable degree of repeatability, whether by ICC or G-coefficients, indicates that within-individual variation is low in proportional to other sources of variation. The number of days required to achieve a particular ICC or G-coefficient relates to both properties of the measure and the population, and therefore should be reported for a wider range of outputs and populations using up-to-date methods.

From a practical perspective, researchers are also limited by the 16 MB (32 MB for activPAL3 micro) memory capacity of the activPAL3 monitor, which with a sampling frequency of 20 Hz (80 Hz available in research mode) allows up to 14 days of monitoring. The activPAL3 micro has a larger memory capacity, yet still only allows for up to 14 days of monitoring. Pending better recommendations, for a single assessment, studies should use a protocol that is at least 7 days and ideally up to the 14 days limitation of the monitor. This recommendation takes into consideration that the number of days requirements are largely unknown, but at times exceed 7 days. Multiple assessments, including covering multiple seasons, have been shown to improve reliability and better estimate long-term activity over single-season assessments.<sup>35</sup>

### 2.2. Wear period: time of wear

In studies where the wear protocol was clear (Table 1, 38/55 studies), 32% asked participants to wear the monitor during

Table 1  
Summary of activPAL use reported in full-text accessible articles of free-living studies in adults.

Reference	Study design	Intended wear period				Attachment		Periods of interest analysed, with any corroborating data, and by what method of ascertainment		
		Model	File	Day	Hour	Method	Location	Other data	Analysed	How achieved
Aadahl et al., 2014 <sup>40</sup>	RCT	activPAL3	Events	7	24/7	PAL stickies (removed during water activities)	Anterior upper right thigh	Log of bed, wake, removal, other sleep times	Waking wear Valid: removed <2 h	NA
Aguilar-Farias et al., 2015 <sup>42</sup>	Cross-sectional <sup>a</sup>	activPAL3	Events <sup>b</sup>	7	24/7	Waterproofed and Tegaderm	Middle-anterior right thigh; written instructions	Log of wake, sleep, and removal times	Waking wear Valid <sup>a</sup>	Matching to other monitor; “non-wear” based on unspecified method
Aguilar-Farias et al., 2014 <sup>50</sup>	Cross-sectional <sup>a</sup>	activPAL3	Events	7	24/7	Waterproofed and Tegaderm	Middle-anterior right thigh	Log of wake, sleep, removal times	Waking wear Valid: ≥10 h	“Semi-automated” filter to merge log data
Alkhajah et al., 2012 <sup>57</sup>	Non-randomised trial	activPAL3	15 s epoch	7	24/7	NA	NA	Log of awake, asleep, removal, and work times	Waking wear/working wear Valid: removed <90 min/<10%	Periods identified from log
Barreira et al., 2016 <sup>34</sup>	Cross-sectional	NA	NA	NA	Wake	NA	NA	Log of on and off times	Waking wear Valid: ≥10 h	Non-wear determined by log and data file, i.e., >3 h continuous lying/sitting with 0 or 1 count in the accelerometer channel
Barreira et al., 2015 <sup>47</sup>	Cross-sectional	Uniaxial	NA	7	24/7	NA (removed during water activities)	Right thigh	NA	7:00 a.m.–10:00 p.m. Valid: NA	NA
Barry et al., 2015 <sup>41</sup>	Cross-sectional	Uniaxial	Events	7	24/7	PAL stickies and Hypafix (removed during water activities)	Upper thigh	NA	NA	NA
Berendson et al., 2014 <sup>43</sup>	Cross-sectional <sup>a</sup>	activPAL3	Events <sup>b</sup>	≥3	24/7	Waterproofed and Tegaderm	NA	Time use diary collected every 15 min during waking hours	NA	“Matched” with time use diary; limited detail
Chastin et al., 2011 <sup>77</sup>	Cross-sectional	NA	Events <sup>b</sup>	7	24/7	NA	NA	NA	All hours NA Valid: NA	Wear
Chastin et al., 2014 <sup>69</sup>	Cross-sectional	NA	NA	7	24/7	NA (removed during water activities)	NA	NA	Waking wear Valid: worn continuously for 3 weekdays and 1 weekend day	Waking defined as first standing event after ≥2 h of non-upright posture between midnight and 9:00 a.m. to last standing event before >3 h of non-upright posture after 10:30 p.m.
Chau et al., 2014 <sup>78</sup>	RCT	activPAL3	NA	5	Work time	NA	Front mid-thigh	Log of work start and end times	NA	Work time data determined by the log
Craft et al., 2012 <sup>36</sup>	Cross-sectional	NA	NA	7	Wake	Hypafix	Front of right thigh, midway between knee and hip; written instructions	Log of time on and off each day	Waking wear Valid: ≥10 h	Wake time determined by log and activPAL data; treats all overnight removal as sleep

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Table 1 (continued)

Reference	Study design	Intended wear period				Attachment		Periods of interest analysed, with any corroborating data, and by what method of ascertainment		
		Model	File	Day	Hour	Method	Location	Other data	Analysed	How achieved
Di Fabio et al., 2015 <sup>79</sup>	Longitudinal	Uniaxial	NA	7	24/7	Unspecified adhesive (removed during water activities)	Right leg over quadriceps	NA	All wear hours	Matched to other monitor for non-wear
Dollman et al., 2016 <sup>58</sup>	Cross-sectional	Uniaxial	15 s epoch	3	24	Waterproofed and unspecified tape	Mid-anterior right thigh	Log of removals, time going to and getting out of bed	All hours (controlling for time in bed but not removing it) Valid: all hours	Time in bed identified in event files using log, corrected based on monitor data
English et al., 2016 <sup>80</sup>	Cross-sectional	activPAL3	Events	7	24/7	Waterproofed and NA	Anterior thigh, unaffected leg	Log of sleep, wake, and removals	Waking wear Valid: NA	Waking hours determined from the log, incorrect data (identified using heat maps) adjusted using events file data
Esbensen et al., 2015 <sup>81</sup>	RCT protocol	activPAL3	Events	7	24/7	Unspecified waterproof dressing and adhesive tape	Anteriorly on upper right thigh	Diary of resting and sleeping time	NA	Sleep time determined by the diary
Evans et al., 2012 <sup>59</sup>	RCT	NA	Events <sup>b</sup>	5	Work time	NA	NA	Log of monitor on and off each work day	Work hours: NA Wear Valid: $\geq 4$ h (work)	Sitting/lying bouts included if <10 min was outside the log reported work period
Fitzsimons et al., 2013 <sup>82</sup>	Pre–post study	NA	NA	7	24/7	NA	NA	NA	All hours: NA Wear Valid: full days	NA
Gardner et al., 2014 <sup>83</sup>	RCT protocol	activPAL3	NA	7	24/7	Unspecified waterproof dressing	NA	NA	NA	NA
Gennuso et al., 2016 <sup>84</sup>	Cross-sectional	NA	Events <sup>b</sup>	7	Wake	Medipore tape	Midline of thigh	Log of wear time	Waking wear Valid: $\geq 10$ h	Matched to other monitor and wear log
George et al., 2014 <sup>71</sup>	Cross-sectional	NA	Events	7	Wake	NA	Mid-right thigh	Log of time got up/into bed and monitor wear	Waking wear Valid: $\geq 10$ h	NA
Godfrey et al., 2014 <sup>51</sup>	Cross-sectional	Uniaxial	Both: NA	7	24/7	PAL stickies and Hypafix (removed during water activities)	Upper thigh	NA	All wear hours for sedentary and ambulatory time: NA Valid: NA	Non-wear: periods >8 h; sedentary bouts 8:00 a.m.–8:00 p.m.
Gorman et al., 2013 <sup>60</sup>	Pre–post study	activPAL3	Events	7	24/7	Waterproofed and unspecified adhesive	Right anterior thigh	Log of awake, asleep, removal, and work times	Working wear Valid: removed <20%	Bouts assigned the log classification that mostly ( $\geq 50\%$ ) applies
Granat et al., 2015 <sup>85</sup>	Cross-sectional	Uniaxial	Events	7	24/7	NA	Anterior aspect of thigh	NA	NA	NA
Júdice et al., 2015 <sup>72</sup>	RCT	NA	15 s epoch	14	24/7	Unspecified adhesive (removed during water activities)	Middle anterior line of right thigh	Log of waking/sleeping hours and removals	Waking wear Valid: $\geq 10$ h	Matched to other monitors for waking period and checked with log
Klenk et al., 2015 <sup>86</sup>	Cross-sectional	Uniaxial	NA	7	24/7	NA	NA	NA	All hours	NA

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Table 1 (continued)

Reference	Study design	Intended wear period				Attachment		Periods of interest analysed, with any corroborating data, and by what method of ascertainment		
		Model	File	Day	Hour	Method	Location	Other data	Analysed	How achieved
Kozey-Keadle et al., 2012 <sup>21</sup>	Pre-post study	Uniaxial	15 s epoch	7	NA	Unspecified adhesive	Anteriorly on right mid-thigh	Log of wake/bed time, monitor on/off times, removals >10 min	Waking wear Valid: ≥10 h	NA
Kunkel et al., 2014 <sup>39</sup>	Longitudinal	NA	NA	NA	Staff work	NA	Unaffected leg	NA	NA	NA
Lord et al., 2011 <sup>87</sup>	Cross-sectional	Uniaxial	Events <sup>b</sup>	7	NA	NA	NA	NA	NA	NA
Lowe et al., 2014 <sup>88</sup>	Cross-sectional	activPAL3	NA	≤7	24/7	PAL stickies (removed during water activities)	Anterior mid-thigh	NA	All hours: NA Wear Valid: NA	NA
Lyden et al., 2015 <sup>89</sup>	Pre-post study	Uniaxial	Events	7	Wake	Unspecified adhesive pad	Midline of right thigh	Log of monitor wear times and removals	Waking wear Valid: ≥10 h	Wear time determined from log
Martin-Borras et al., 2014 <sup>90</sup>	RCT protocol	NA	NA	NA	NA	NA	NA	NA	NA	NA
Matthews et al., 2013 <sup>67</sup>	Cross-sectional <sup>a</sup>	NA	Events	7	Wake	NA (removed during water activities)	Mid-right thigh	Log of time out of/into bed and time when monitor worn	Waking wear Valid <sup>a</sup>	Log data and Choi algorithm applied to activPAL movement
Mau-Moeller et al., 2014 <sup>91</sup>	RCT	Uniaxial	NA	5 and 7	24/7	NA (removed during water activities)	Anterior thigh, middle of knee and hip	NA	All hours: NA Wear Valid: NA	NA
Mutrie et al., 2012 <sup>75</sup>	RCT	NA	NA	7	24/7	NA	Anterior thigh	NA	NA Valid: ≥1000 steps	NA
Neuhaus et al., 2014 <sup>74</sup>	RCT	activPAL3	Events	7	24/7	Adhesive (breathable) and waterproofing	Anterior midline right thigh	Log of wake/sleep, work, and removal times	Wear at work Valid: worn ≥80% of time at work	NA
Paul et al., 2015 <sup>49</sup>	Cross-sectional	Uniaxial	NA	7	24/7	Tegaderm and waterproofing	Anterior thigh, unaffected leg	NA	NA	NA
Pontt et al., 2015 <sup>92</sup>	Cross-sectional	Uniaxial	Event	3	24	Adhesive and waterproofing	NA	Log of removals, bed, wake, and work times	All hours	Time in bed identified by log and refined by event data
Reid et al., 2013 <sup>31</sup>	Cross-sectional	activPAL3	Both	7	24/7	Hypafix and waterproofing	Anterior midline right thigh	Log of awake/sleep/nap and removal times	Waking wear Valid: ≥80% of waking hours	Log periods (15 s epoch); bouts assigned the log classification that mostly (≥50%) applies (events); days defined by sleep/wake cycle
Reid et al., 2015 <sup>93</sup>	Cross-sectional	activPAL3	15 s epoch	7	24/7	Tegaderm and waterproofing	Mid-thigh	Log of sleep and removals	Waking wear Valid: ≥22 h	Log data used to isolate waking wear using MATLAB
Rosenberg et al., 2015 <sup>94</sup>	Pre-post study	Uniaxial	NA	7	Wake	Mild-gel	Front of thigh	Log of wear times	Waking wear Valid: NA	Non-wear determined by log times
Ryan et al., 2011 <sup>95</sup>	Cross-sectional	NA	Events <sup>b</sup>	7	NA	NA	NA	Working and non-working days indicated	Wear at work Valid: visual inspection	Bouts mostly ≥50% in work period (assumed 09:00–17:00); visual non-wear method

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Table 1 (continued)

Reference	Study design	Intended wear period				Attachment		Periods of interest analysed, with any corroborating data, and by what method of ascertainment		
		Model	File	Day	Hour	Method	Location	Other data	Analysed	How achieved
Sande et al., 2014 <sup>96</sup>	Pre–post study	NA	NA	14	NA	NA	Anterior thigh	NA	NA	NA
Smith et al., 2014 <sup>68</sup>	Cross-sectional	NA	NA	7	24/7	Waterproofed and Tegaderm	Midway between right hip and knee	NA	Waking hours: NA Wear. Valid: NA	Waking hours determined by 07:00–23:59; non-wear method
Smith et al., 2015 <sup>52</sup>	Cross-sectional	activPAL3	15 s epoch	5	24	Waterproofed and adhesive dressing	Middle of thigh	X	Valid: all hours	Waking hours determined by 07:00–23:00
Stephens et al., 2014 <sup>56</sup>	Non-randomised trial	activPAL3	Events	7	24/7	Waterproofed and breathable dressing	Anterior midline of right thigh	Log of wake/sleep and work times	Wear at work Valid: removed <20%	Bouts that were mostly (≥50%) sleep, non-wear or not at work according to log excluded; days from wake to wake
Stewart et al., 2014 <sup>97</sup>	Pre–post study	NA	NA	7	NA	NA	NA	NA	NA	NA
Swartz et al., 2014 <sup>37</sup>	Pre–post study <sup>a</sup>	Uniaxial	15 s epoch	3	Work time	PAL stickies and athletic tape	Midline of right thigh	Log of monitor on/off times	Wear at work Valid <sup>a</sup>	Matched with log; limited detail
Swartz et al., 2014 <sup>38</sup>	RCT	Uniaxial	15 s epoch	3	Work time	PAL stickies	Midline, anterior right thigh	Log of start/end of workday	Wear at work Valid: ≥6 h (work)	Matched with log; limited detail
Thomas et al., 2014 <sup>98</sup>	RCT protocol	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tieges et al., 2015 <sup>73</sup>	Longitudinal	NA	Events <sup>b</sup>	7	24/7	NA	Unaffected leg	NA	Valid: all 24 h	Sleep time not removed
Tigbe et al., 2011 <sup>99</sup>	Cross-sectional	Uniaxial	NA	7	24/7	PAL stickies (removed during water activities)	Anterior mid-thigh	Work/non-work days and hours	All hours/work: NA Wear Valid: 24 h periods	Matched with work hours; non-wear method
Watne et al., 2014 <sup>100</sup>	RCT	NA	NA	In hospital	24/7	NA	Anterior non-affected thigh	NA	NA	NA
Wilmot et al., 2011 <sup>76</sup>	RCT protocol	NA	NA	10	NA	Unspecified adhesive	NA	NA	NA	NA
You et al., 2015 <sup>101</sup>	Cross-sectional <sup>a</sup>	NA	15 s epoch	7	NA	NA	NA	GPS and travel diary	NA Valid <sup>a</sup>	Accepted all data (noted problems after)

<sup>a</sup> Study is for measurement (e.g., validity); other data collected for measurement study purposes; “valid” data included related to multiple methods due to measurement study.

<sup>b</sup> Events file implied from description of activPAL data “bouts” or uses data clearly not obtainable from the 15 s epoch file.

Abbreviations: GPS = global positioning system; NA = not available; RCT = randomized controlled trial; X = did not collect.



Table 2  
Summary of the studies used to inform the report—all of which used activPAL3.

	STAND <sup>76</sup>	Walking away from diabetes <sup>102</sup>	PROPELS <sup>103</sup>	AusDiab <sup>104</sup>	Stand Up Victoria <sup>61</sup>
Study design	Randomised controlled trial	Cluster randomised controlled trial	Randomised controlled trial	Longitudinal	Cluster randomised controlled trial
Data collection points	Baseline, 3 and 12 months	Baseline, 12, 24, and 36 months (activPAL only at 36 months)	Baseline, 12 and 48 months	Waves 1, 2, and 3 (activPAL only at Wave 3)	Baseline, 3 and 12 months
Total sample size ( <i>n</i> )	187	808	1308	782	231
Study population/setting	At risk of type 2 diabetes/free-living	At risk of type 2 diabetes/free-living	At risk of type 2 diabetes/free-living	General adult population/free-living	Office workers/free-living overall and at the workplace
Age group	18–40 years (mean: 33 years)	30–75 years (mean: 63 years)	24–75 years (mean: 60 years)	36–89 years (mean: 58.4 years)	23–65 years (mean: 45.6 years)
Men (%)	31	64	51	43	32
Country	UK	UK	UK	Australia	Australia
Years of study	2011–2012	2013	2014–2019	2011–2012	2012–2014
Wear protocol	activPAL3 10 days Continuous (24 h) Waterproofed Distributed at examination center, returned by mail Self adhered to thigh by hypafix/tegaderm and checked by nurse	activPAL3 7 days Continuous (24 h) Waterproofed Distributed at examination center, returned by mail Self adhered to thigh by hypafix/tegaderm and checked by nurse	activPAL3 7 days Continuous (24 h) Waterproofed Distributed at examination center, returned by mail Self adhered to thigh by hypafix/tegaderm and checked by nurse	activPAL3 7 days Continuous (24 h) Waterproofed Distributed at examination center, returned by mail Staff adhered to thigh by hypafix/tegaderm	activPAL3 7 days Continuous (24 h) Waterproofed Distribute/returned via workplace Adhered by staff (baseline only) or self to thigh with hypafix/tegaderm
Concomitant data	Paper diary (sleep and wear)	Paper diary (sleep and wear)	Paper diary (sleep and wear)	Paper diary (sleep and wear)	Paper diary (sleep, wear and work)

Note: Sample sizes reported are not necessarily reflective of all data available.

waking hours only (e.g., Ref. 36), working hours only (e.g., Refs. 37, 38) or during periods based on researcher convenience (i.e., staff working hours; e.g., Ref. 39). In these studies, the activPAL was usually attached with PAL stickies (PAL Technologies Ltd.) or an unspecified adhesive. A slightly smaller percentage of studies (26%) employed a 24 h protocol while requested that participants remove the monitor for showering/bathing (e.g., Refs. 40, 41). Again these studies tended to use PAL stickies for attachment. A higher percentage (42%) of the studies we examined requested participants to wear the activPAL monitor 24 h per day during waking and sleeping hours and water-based activities (e.g., Refs. 42, 43); therefore, it appears that researchers are favoring this type of wear protocol for this monitor. This is in contrast to the ActiGraph device where researchers have mostly employed a waking wear protocol.<sup>30</sup> A continuous wear protocol can easily be achieved with the activPAL monitor by waterproofing the device with a small flexible sleeve to cover the monitor, wrapping it in 1 piece of waterproof medical grade adhesive dressing (e.g., Tegaderm, Hypafix, or Opsite) and then attaching to the leg using adhesive dressing. A continuous wear protocol like this may increase wear time compliance.<sup>44</sup>

### 3. Monitor preparation and distribution

#### 3.1. Initialisation

The activPAL software allows researchers to select an immediate start time for recording (from the time the device is unplugged from the docking station until the battery runs out,

the memory is full, or the device is plugged into the docking station again), or a future date and time, along with the stop date and time. Unfortunately, there is only a 4-day limit on initialisation. For example, to begin recording on a Monday morning, the earliest that the device could be initialised would be on the previous Thursday morning.

The default sampling frequency in the software is 20 Hz for the activPAL3, but 80 Hz can be selected in research mode, or 10 Hz for the activPAL (uniaxial version). The software also gives researchers the option of changing the minimum sitting/upright time period to define a new posture from 1 s to 100 s. The default of 10 s (i.e.,  $\geq 10$  s of sitting/lying or upright data is needed to register as a new event) is recommended by the manufacturer. In the studies in Table 2, and in other published studies (e.g., Ref. 45), the default of 10 s has been selected; however, research suggests that this may not be appropriate for all populations.<sup>46</sup> In a sample of very young children (mean age of 4.5 years), Alghaeed et al.<sup>46</sup> found that a 2 s, in comparison to 1 s, 5 s, and 10 s, minimum sitting/upright time period had the smallest error in detecting the number of breaks performed against direct observation. This suggests that young children transition rapidly between postures and the default of 10 s to register a new event may not be appropriate for this age group. Therefore, it is important that researchers apply the appropriate settings for their population, and report the settings in publications. However, to our knowledge, similar studies have yet to be conducted with other populations so the extent to which this setting impacts on the number of breaks in adult populations, for example, remains unclear.

An important, and often overlooked, consideration when initialising the monitors is to be aware of the system used to record the date/time-stamped data, especially when intending to match the monitor data with date–time stamped data from other monitors and diaries, or when collecting data in a time-zone that involves discontinuities (such as “losing” or “gaining” 1 h with daylight savings). Furthermore, when dealing with activPAL data as part of a multi-sensor data collection that requires matching output on fine time scales, clock drift should be considered.<sup>47</sup>

### 3.2. Attachment location and method

The algorithm used by the activPAL software uses information from static acceleration (due to gravity) and angle of the thigh to classify posture (lying/sitting *vs.* upright) and dynamic acceleration (due to body movement) to determine stepping.<sup>48</sup> Accordingly, it is important that the activPAL device is worn on the midline anterior aspect of the upper thigh as recommended by the manufacturer. An example of correct placement for the activPAL is shown in the example instruction sheet (the example instruction sheet can be found as [Supplementary File 1](#)). Of the studies in [Table 1](#) that did report information on the exact activPAL location (i.e., where on the leg and which leg), they all reported attaching the activPAL to the right thigh apart from studies conducted in stroke populations where it was attached to the unaffected leg (e.g., Refs. 39, 49). While it can be useful to standardise which leg the activPAL is attached to, participants involved in the studies in [Table 2](#) occasionally experienced slight irritation from the adhesive dressing. In this situation they were advised to attach the activPAL to the opposite leg. This enabled the participant to attach the monitor in the same optimal location on the opposite leg in preference to using a sub-optimal location on the same leg (e.g., too far away from the midline) or ceasing to wear the monitor completely. Two studies<sup>42,50</sup> in [Table 1](#) mentioned collecting the times and reasons from participants of every occasion when the monitor was removed from the indicated position.

The orientation in which the activPAL monitor is worn is critical to how the software classifies posture. The correct orientation is indicated by the figure on the front of the activPAL monitor ([Fig. 1A](#)), but this can be obscured when using waterproof coverings. In this case, we have redrawn the orientation figure on the waterproof covering ([Fig. 1B](#)). If, however, participants wear the device upside down, the activPAL software (from Version 7.2.32) allows researchers to reprocess the data as though it were worn in the correct orientation. There is no automatic function within the software to determine when the device has been worn in the incorrect orientation so it may be useful to ask participants to record this in a wear log.

As stated in [Section 2.2](#) the activPAL monitor is attached using various different adhesives (i.e., PAL stickies, medical dressing, e.g., Hypafix); the type of adhesive being largely dependent on the wear protocol. Some of the adhesives are designed to be short lasting (i.e., 1 day) and some longer term (i.e., 5–7 days). Although manufacturers state that a piece of the hypoallergenic waterproof dressing can stay attached for 5–7 days, participants involved in the studies outlined in [Table 2](#) preferred to change their dressing every 2–3 days. Therefore, for

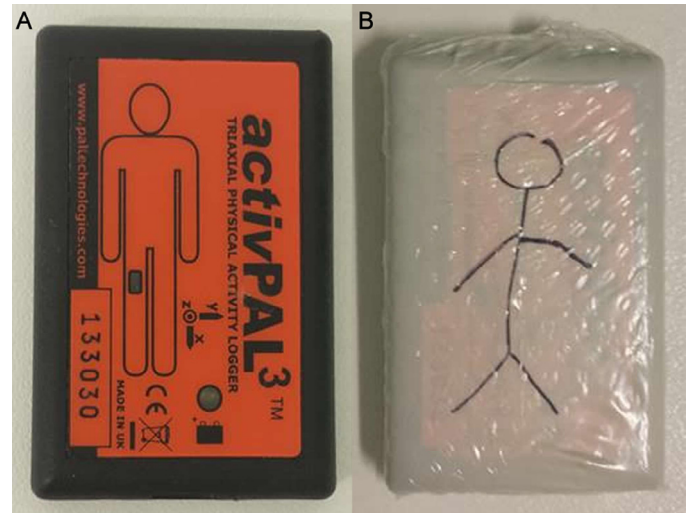


Fig. 1. (A) The figure on the front of the activPAL indicating the correct orientation of the device. (B) An activPAL with waterproof coverings and a stick man to indicate correct orientation.

a 7-day monitoring period, participants were provided with 4 dressings for re-attachment and 4 alcohol wipes to assist in the attachment and removal of the dressing. This has cost implications, but may enhance wear time compliance. The provision of additional dressing was also reported in 3 studies<sup>41,51,52</sup> in [Table 1](#).

### 3.3. Instructions to participants

Only 3 studies in [Table 1](#) reported providing participants with written placement instructions to take away with them in addition to the standard verbal instructions.<sup>36,42,50</sup> To our knowledge, no evidence exists on various instructional techniques and their impact on correct monitor attachment/reattachment or compliance. Example written instructions as used in the studies in [Table 2](#) are provided in [Supplementary Files 1 and 2](#). Media could also be used for participants to access at home, such as these instruction videos posted on YouTube ([http://youtu.be/BuaRHZ\\_BOA4](http://youtu.be/BuaRHZ_BOA4) and <https://www.youtube.com/watch?v=CHCCX2GW3DM>).

## 4. Data collection

### 4.1. activPAL wear, sleep, and key periods of interest log/diary

Over half of the studies (55%) in [Table 1](#) reported collecting some form of log/diary data (e.g., working hours, sleep, and wake times) to assist them with isolating key periods of interest such as worn waking hours during data processing (see [Section 5](#)). Requesting that participants complete a wear diary/log may act as a reminder to participants to keep wearing the monitor and to re-attach the monitor each day in a waking hours only protocol. Recording removal reasons and “other comments” from participants (e.g., reactions to dressing, device not flashing, worn upside down) via a diary/log can also be informative, particularly for a new population group and/or pilot data collection. General measurement principles suggest that instructions should be aimed at shifting the diary/log



reporting towards “recording” rather than “recalling” and “estimating” for better accuracy, and that pilot testing should be used to ensure usability of the diary/log for your target population.

The studies in Table 1 reported limited detail about the content of their logs/diaries. In the studies in Table 2, diaries/logs were paper-based and ranged from a single page to detailed page-per-day booklets with accompanying instructions (the example instructions sheet can be found as Supplementary Files 2 and 3). All were tailored to the interests of each study (e.g., work-based studies included work details). The paper-based diaries (both short and long) have been well received by our participants but have typically entailed much missing data and high amounts of time entering data. Recently we have developed and trialled electronic diaries in a sample of office workers with the aim of reducing turn-around time, data entry costs, and missing data (by setting some fields as mandatory). Depending on the electronic approach used, the data can be available to the researcher on a daily basis, enabling the researcher to query issues of missing or questionable data and request clarification from participants in a timely manner. This may be more important for information, such as work times, that are essential for analysis and cannot be inferred from the monitor

data alone. The electronic diary method shows promise, but may not be universally suitable. What works best is likely to depend on the study population, study size and requirements, and the resources and skills available in the research team.

#### 4.2. Compliance

In accelerometer studies generally, compliance is typically considered in terms of the amount of time the monitor is worn during the period of interest (e.g., waking hours) and the number of valid wear days provided (i.e., the number of days on which wear time was adequate to consider that monitoring has sufficiently captured most of the period of interest). Table 3 presents the compliance figures for 4 of the studies outlined in Table 2. These data may be helpful in indicating the degree to which the sample size should be inflated to allow for missing data due to non-compliance. For comparison, we also present compliance figures for the hip-worn ActiGraph accelerometer (ActiGraph, Pensacola, FL, USA) worn in the same studies but with a waking hours only and removal during water-based activities protocol. Both provided a similar number of “valid” days, but activPAL showed longer waking wear days than the ActiGraph, possibly due to different wear protocols and attachment methods.

Table 3  
Number of valid wear days and wear/wake time (on valid days) for the activPAL and ActiGraph monitors in some of the research studies outlined in Table 2.

	STAND <sup>76</sup> Baseline data (n = 187)		Walking away from diabetes <sup>102</sup> Final follow-up data (n = 530)		AusDiab <sup>104</sup> 2011–2012 (n = 782)		Stand Up Victoria <sup>61</sup> Baseline data (n = 231)	
	activPAL	ActiGraph	activPAL	ActiGraph	activPAL	ActiGraph	activPAL	ActiGraph
Period	Waking hours	Waking hours	Waking hours	Waking hours	Waking hours	Waking hours	Waking hours	Waking hours
Protocol	Continuous	Waking hours	Continuous	Waking hours	Continuous	Waking hours <sup>a</sup>	Continuous	Waking hours <sup>a</sup>
Definition	10+ h estimated from the monitor data, <95% in any one behavior, <500 steps	10+ h estimated wear time	10+ h estimated from the monitor data, <95% in any one behavior, <500 steps	10+ h estimated wear time	≥10 h worn waking hours (monitor-corrected diary)	10+ h estimated wear time	≥10 h worn waking hours (monitor-corrected diary)	10+ h estimated wear time
Participated in monitor wear (%)	100	100	99.2	99.6	77.1	77.1	100 <sup>b</sup>	100 <sup>b</sup>
Valid days <sup>c</sup> (%)								
0	31.0 <sup>d</sup>	11.2	13.1	0	5.2	4.7	0.4	1.3
1	1.1	1.6	2.3	0.4	0.5	1.2	0	0.4
2	3.2	1.6	1.1	2.5	0.8	0.8	0	0.4
3	1.1	1.6	0.8	1.7	1.5	1.4	0	0.9
4	2.7	3.7	2.9	4.2	1.0	1.8	1.3	1.3
5	9.1	6.4	3.4	5.9	2.6	3.1	1.3	5.6
6	7.0	7.0	9.5	13.6	9.6	7.8	6.5	14.7
7+	44.9	66.9	66.9	71.7	78.8	79.3	90.5	75.3
Wear during waking hours (h) <sup>e</sup>	15.3 ± 1.9	14.4 ± 1.4	15.8 ± 2.2	14.3 ± 1.3	15.7 ± 1.1	15.6 ± 2.5	15.8 ± 1.8	15.0 ± 1.2

<sup>a</sup> For days on which participants deviated from the protocol and wore the monitor to bed, estimated time in bed (sleep) was also removed using an approach based on the Sadeh algorithm<sup>105</sup> and visually checking/manual reclassification of erroneous data.

<sup>b</sup> Monitor wear was a study requirement.

<sup>c</sup> Percentage of participants providing a certain number of valid wear days (as a percentage of participants assigned the monitor). Figures exclude study participants who refused to wear the monitor at all (did not participate), but include those with no data due to faulty downloads or lost data in addition to non-compliance.

<sup>d</sup> This includes a high percentage of monitor malfunction that we experienced at the start of the study associated with the “future start time” function during the initialisation process.

<sup>e</sup> mean ± SD.

## 5. Data processing

### 5.1. *activPAL software and files available*

The activPAL software (PAL Technologies) provides a quick and easy-to-use system for initialisation, downloading and exporting data (in raw form and pre-classified by proprietary algorithms), and enabling researchers to visualise pre-classified data (i.e., sitting/lying, standing, stepping) in various formats (e.g., hour by hour, by day, or by week) from individual files. However, it is not a comprehensive, interactive data processing or analytic tool, and therefore even fairly routine requirements, such as isolating sitting/lying during waking hours, excluding periods of non-wear, and linkage to other time-stamped data (e.g., logs), requires processing the data outside of the activPAL software in other software packages (e.g., SAS, STATA, Excel, R). To assist researchers, in the following sections we provide: an overview of the data available from the activPAL; describe ways that our research groups and others have isolated key periods of interest in the activPAL data, identified non-wear and invalid data; and applied external limiters to the data (e.g., analysed only work hours).

When data from the activPAL device are downloaded, they can be saved as csv files in numerous formats. A 15 s epoch summary file shows the number of seconds spent in various activities, number of steps and sit-to-upright transitions occurring during that 15 s time window. These files do not indicate the order in which multiple activities occurred within the 15 s window. Such precise information is available from the event based summaries (“Events” files). These are a chronological list of all bouts of sitting/lying, standing, and each step, with the time each bout begins and bout duration. The “Events X Y Z” files also include triaxial acceleration data. These event-based summaries offer more precise data for the amount of each activity (less rounding error) and are ideally suited for extracting information on bout frequency and duration. The raw data can also be output; these were not reportedly used in the studies we examined (Table 1). Raw data files are currently being used in the context of methods development, including exploring the recognition of activity types not currently available through the activPAL software, such as distinguishing lying from sitting<sup>53</sup> and identifying wake time and number of awakenings during sleep<sup>54</sup> and cycling.<sup>55</sup>

### 5.2. *Defining a day*

Researchers often define days as calendar days (i.e., midnight to midnight). However, all time-based definitions are problematic when examining “bouts” of behavior or events because a single bout of behavior may begin in one day and end in the next. This poses problems in examining issues such as sitting accumulation because segmenting the bout at the day boundary means systematically underestimating bout duration. A simple modification could be to use calendar days but assign entire bouts to the day or date the bout begins.

The person-oriented day approach, from one wake time to next day wake time (Table 1),<sup>56</sup> offers a behaviorally relevant approach that also avoids sub-dividing activity bouts across multiple days and further may increase the number of valid

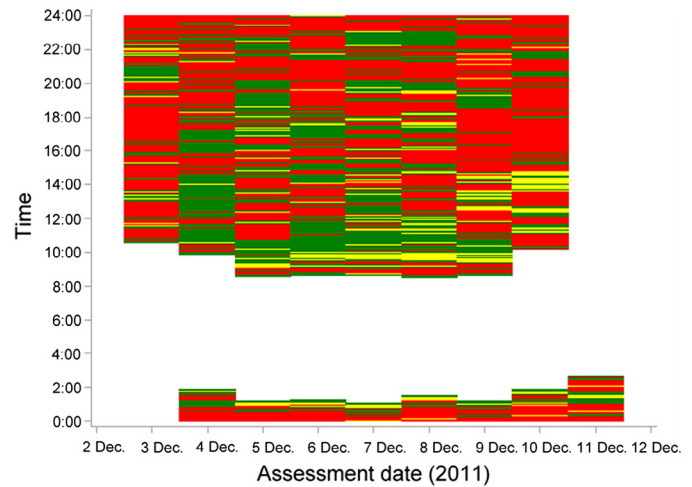


Fig. 2. Heat map of waking hours (“sleep” has been removed) activity (green, stepping; yellow, standing; red, sitting; white, sleep or not worn) from a participant showing bouts of behavior after midnight on 4–10 December, 2011.

days or amount of waking wear. It reduces the likelihood of pockets of valid data being removed and considered “invalid” just because they occur after an arbitrary time (e.g., midnight) and the following day does not include enough wear to be labelled as valid. For example, in Fig. 2 (which displays only valid waking hours data), a participant was still moving around from late on the 10th of December until the early hours the next morning (11th of December), which was not a valid wear day. A calendar day would discard all data from the 11th of December because it occurs after midnight but the person-oriented day approach would not. Person-oriented day durations are not always 24 h; the practical impact is often non-existent as waking day durations are variable under most definitions.

### 5.3. *Isolating key periods of interest in the data*

activPAL monitors provide continuous streams of data, regardless of whether the monitor is being worn or placed on a bedside table, for example. Isolating only the periods reflective of actual participant behavior during the period of interest (e.g., waking hours or working hours) is a necessity for high quality data. The process for differentiating these periods requires researchers to determine from the data, or from other sources of information (e.g., diary), when the monitor was put on in the morning and taken off in the evening (waking hours protocol), what time the participant woke up (or arose out of bed) and went to sleep (or went to bed), or the start and end of work. At present, there is an absence of validated, accurate methods to isolate these periods of interest and studies to date (Table 1) seldom describe in detail the methods they have employed. Methods that have been reported, as well as ones we are currently employing in the studies outlined in Table 2, are described in the following sections.

#### 5.3.1. *Time intensive methods*

Most (75%) of the studies we examined (Table 1) that described how they isolated data for their period of interest

(such as waking wear, time at work) reported using external information collected, typically self-reported logs/diaries. However, this is time intensive to implement. The exact procedure used to match up the diary with the activPAL data is rarely described, but 2 main approaches are apparent from those studies that have included detail. Sometimes, the literal log/diary-reported period is analysed, especially when using 15 s epoch files (for which this approach is easy) (e.g., Ref. 57). Other times, log/diary-reported periods are matched with “bouts” of activity (it is not unreasonable to assume that a change in period, location, or context would coincide with a change in activity), especially when using the events files, and a rule is implemented as to whether to include or exclude an entire bout of activity from the period of interest (e.g., Refs. 58–60). This method has the advantage of not segmenting bouts when examining bout durations or accumulation. One rule used involved choosing whether including a bout would include too much time outside of the period of interest. For example, sedentary periods crossing the start/end of each workday were included if most of the sedentary period was within the stated work hours and no more than 10 min was outside.<sup>59</sup> An alternative rule employed in several studies involved including bouts which crossed the period of interest (e.g., working hours) if  $\geq 50\%$  of that bout was within the period of interest.<sup>61</sup> Internal validation work showed excellent agreement (95% of observations within  $\pm 5$  min) between our events-modified start and finish work times and participants’ originally reported times.<sup>62</sup>

A common occurrence with self-reported logs/diaries is they are often not fully completed. Participants may still wear the activPAL monitor but how these missing data are dealt with is again not described. An example of how this is dealt with is provided by the Stand Up Victoria and AusDiab studies (Table 2). When participants failed to report a time of waking or sleeping for a particular day, these were visually identified from the events files by research staff. The method the staff used was to examine the events files, starting with times around late evening or early morning, for an extremely long bout of sitting/lying or standing. Then depending on this bout duration, the duration and degree of movement observed in the surrounding bouts, either just this long bout or also some of the surrounding bouts, were selected as the likely unreported sleep or wake time.

### 5.3.2. Low burden methods

Low burden approaches may be preferable for studies that are large, require quick turn-around of data in bulk, and/or have other staffing and resource issues. Low burden approaches have had limited use, especially for continuous wear protocols, until recently (Table 1). As yet validation of such approaches is yet to appear in the peer-reviewed literature but is likely to be forthcoming based on conference abstracts.<sup>63–65</sup>

For waking wear protocols, examples of low burden approaches reported in the literature (Table 1) for isolating waking hours data from non-wear data include the classification of very long bouts ( $>8$  h) of sitting/lying as non-wear (e.g., Ref. 51), the application of the Choi method<sup>66</sup> (commonly

applied to ActiGraph accelerometer data), i.e., 60 min of no movement with an interruption allowance of 2 min or less<sup>67</sup> and  $>3$  h of continual sitting/lying with 0 or 1 count in the accelerometer channel.<sup>34</sup>

For the 24 h protocols, methods also need to be employed to distinguish between sleep and waking hours. A very simple method that has been used is to limit data to time periods when it is assumed participants are awake (e.g., between 07:00 and 23:59, e.g., Ref. 68). The simplicity of this method is appealing but may result in low data quality. Our diary data show that adults’ sleep and wake times are highly variable and not well approximated by any single time period. Chastin et al.<sup>69</sup> took a similar approach but allowed for individuals to have varying waking periods by classifying the first standing event after  $\geq 2$  h of sitting/lying between midnight and 9:00 as the beginning of wake, and the last standing event before  $>3$  h of sitting/lying after 22:30 as the beginning of sleep. This latter method is less restrictive about when sleep occurs but still presupposes a nocturnal sleep pattern, which may not always be the case, such as in shift workers.

### 5.3.3. Future possibilities

Viewing activPAL data via heat maps from studies outlined in Table 2 suggests that for adults, an automated approach to isolating waking wear from sleep ideally ought to avoid placing assumptions on when sleep occurs and consider that any period identified as sleep may be part of a larger fragmented sleep pattern, i.e., that periods immediately before and after may also be part of what should be isolated from the main waking wear day. For example, sleep rarely occurs as 1 large uninterrupted bout of sitting/lying (Fig. 3A). Many participants have some small amounts of movement (stepping and/or standing) registered throughout sleep (Fig. 3B); these can be genuine waking movements involving arising from bed but in the case of standing can simply reflect leg positioning in bed while asleep, for example if someone has their leg hanging out of the bed. This fragmentation occurs to a lesser extent (but may still occur) when participants have removed their monitors overnight. We are in the process of trialling an approach that considers these factors.<sup>63,65</sup>

It has been contended that an integrated approach considering all movements over a whole day, combining issues relevant for the sedentary, physical activity, and sleep research fields, while acknowledging the inter-dependent nature of these movements may yield relevant insights and opportunities to improve health.<sup>70</sup> Continuously worn activity monitors that can also measure parameters of interest to sleep researchers have potential as a cost-effective means of achieving this. It would be useful to develop more sophisticated methods that involve distinction within this broad time period that we have loosely termed sleep (i.e., time in bed asleep, time in bed awake, brief periods out of bed) and can indicate sleep quality. Preliminary attempts in this direction have shown promise.<sup>54</sup>

### 5.4. What constitutes a valid day?

The criteria used for the minimum number of hours constituting a valid day or valid time period of interest are irregularly

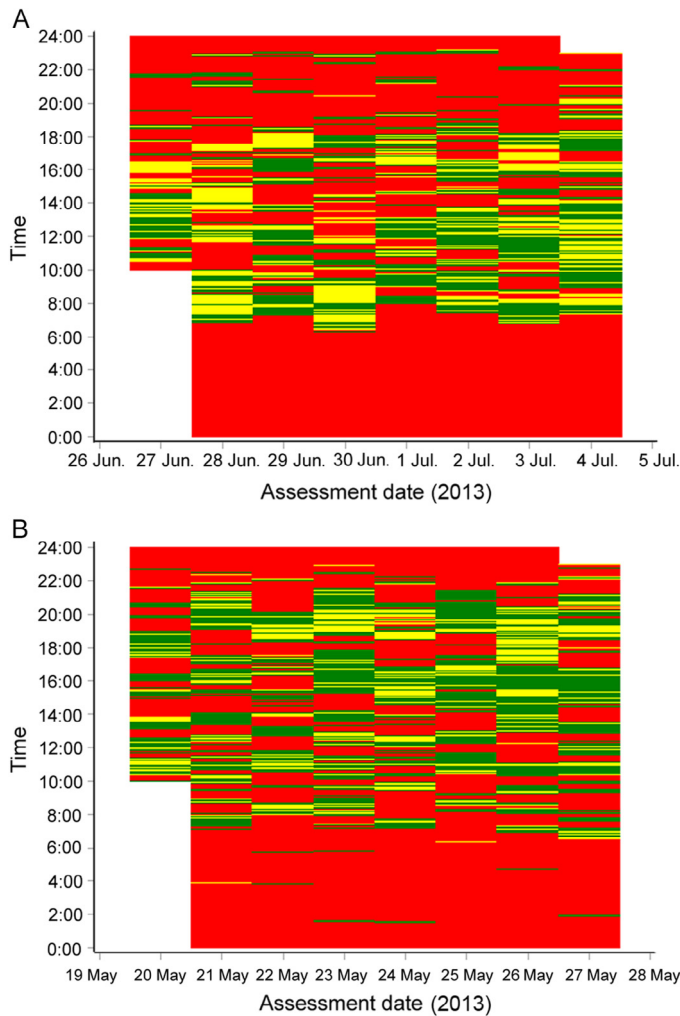


Fig. 3. Heat map of activity for the total monitoring period (green, stepping; yellow, standing; red, sitting/lying; white, pre- and post-study). (A) Uninterrupted sleep and (B) interrupted sleep.

reported (Table 1, 49% reported valid criteria). Those researchers who have reported criteria have used either a minimum of 10 h of wear or waking hours (e.g., Refs. 71, 72), required the full 24 h period (e.g., Refs. 58, 73), considered a day as valid if wear time comprised  $\geq 80\%$  of waking hours,<sup>31</sup> or if the monitor had been removed for  $< 2$  h in the 24 h time period (e.g., Ref. 31). These criteria have been applied when the full day is of interest. When working hours have been the time period of interest, researchers have applied either a minimum of 4 h or 6 h of valid data per working day (e.g., Refs. 38, 59), or the monitor had to be worn  $\geq 80\%$  or  $\geq 90\%$  of work time (e.g., Ref. 74). For variable duration periods in particular (such as work hours), the percentage approach avoids systematically excluding observations that were short (but were sufficiently complete and therefore valid).

While automated identification of specific non-wear periods is difficult, the identification of entire non-wear days is much simpler. Accordingly, one study<sup>75</sup> excluded days with  $< 1000$  steps. Similarly in the STAND<sup>76</sup> and Walking away studies (Table 2), days with  $< 500$  steps were excluded. The optimal

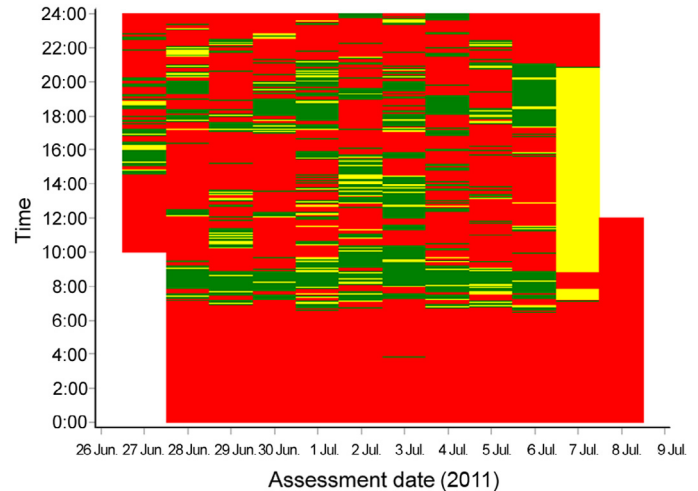


Fig. 4. Heat map of activity for the total monitoring period (green, stepping; yellow, standing; red, sitting/lying; white, pre- and post-study) showing an “invalid” day due to the majority of the day standing (indicated by yellow color) on 7th July.

cut-offs are likely to depend on the study population (e.g., 1000 steps may be too high for older adults). Additional rules may also be beneficial for activPAL data specifically. Prolonged bouts of standing can occur during the daytime if the activPAL is removed and propped up against something (Fig. 4). It is important that this type of activity is not included in the valid data. We are trialling the identification of a day as “invalid/non-wear” if the vast majority (e.g.,  $> 95\%$ ) of the day is spent in any one posture, e.g., standing or sitting/lying.

## 6. Data reporting

Broader reporting issues and guidance when using physical activity monitors have been previously covered by Matthews et al.<sup>30</sup> These should be considered for studies using the activPAL. Due to space constraints, researchers typically cannot provide the full level of detail required to replicate studies and judge comparability in study results in their manuscript. They could instead report their methodology as Supplementary material. We present an example table template in Appendix 1.

## 7. Summary, key recommendations, and future research

The activPAL monitor has demonstrated excellent reliability and validity for use in both physical activity and sedentary behavior research and the device offers exciting possibilities to advance sedentary behavior research specifically. This report provided an overview of the issues to consider, before, during, and after data collection, when using the activPAL monitor in physical activity and sedentary behavior field-based research with adult populations.

Based on the experiences of our research groups with adult populations in the UK and Australia, and the practices observed across a diverse array of epidemiologic studies in free-living adults, we suggest the following key recommendations when using the activPAL monitor in field-based research:



- Employ a 24 h wearing protocol if possible.
- Deploy for at least 7 days.
- Provide verbal, visual, and written instructions to participants on how to wear the device correctly and change dressings; and, if possible, have a study researcher attach the monitor (or demonstrate and check self-attachment).
- Provide a diary (paper or electronic) to collect information on wake and sleep time, time in and out of bed, any removal times, and other contexts of interest (e.g., work times).
- Use events files for data processing, especially if reporting measures relating to bout durations.
- No waking wear identification method is universally accurate and accepted. Use quality controls (e.g., visual examination heat maps) to check classifications, ideally against an external source of data, such as a diary.
- Be transparent when reporting activPAL collection and processing methods.

Future research should focus on the following areas in order to bridge the gaps in our understanding related to the use of the activPAL for measuring physical activity and sedentary behavior:

- Limited research exists on the intra- and inter-individual variability of physical activity and sedentary behavior as measured by the activPAL. This would increase understanding around which populations and measures may require longer observation periods.
- Current literature has employed a variety of wear protocols including waking hours with removals for water activities, waking and sleep hours with removals for water activities and continuous 24 h monitoring. It has been suggested in previous research with ActiGraph accelerometers that wear time compliance increases with continuous wear protocols compared to waking wear protocols. This has yet to be confirmed with the activPAL monitor.
- The accuracy of the minimum sitting/upright period default setting of 10 s (i.e.,  $\geq 10$  s of sitting/lying or upright data is needed to register as a new event) for detecting the number of breaks in sitting needs to be tested in adult populations.
- Studies have used a variety of attachment methods and it is not clear whether the type of attachment (e.g., PAL stickies vs. piece of Hypafix) may influence wear compliance.
- Most studies reported giving participants verbal instructions on how to wear the activPAL with a small number also providing written instructions for participants to refer to during the wear period. Instruction techniques such as online videos are emerging. However, it is not known to what extent these various methods of instruction impact on correct monitor attachment, re-attachment and wear compliance.
- As noted by Matthews et al.,<sup>30</sup> lack of compliance is a source of lost data and can increase cost in research studies. The percentage of participants providing at least 4 days of valid data was reasonable (Table 3) but could still be improved. Research (e.g., qualitative) exploring how to maximise compliance in different populations is needed.

- Studies have employed a variety of methods to isolate key periods of interest from the continuous data that are collected by the activPAL and to define a valid day. The extent to which this impacts on data outputs and therefore comparability between studies is unclear.
- There is currently an absence of validated, accurate methods to isolate key periods of interest (e.g., waking hours) from the continuous data that are collected by the activPAL. The development and validation of automated processes that consider the fragmented sleep patterns that are frequently observed in activPAL data collected continuously is a priority.
- The development of accurate identification methods for additional activity types beyond the current classifications is an important emerging area, both in terms of waking activities (e.g., differentiating lying from sitting, identifying cycling) and sleep (e.g., awakenings during sleep).

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### Authors' contributions

CLE conceived of the idea for the review, reviewed existing research, and wrote the first draft of the manuscript; GNH conceived of the idea for the review along with CLE and reviewed/edited of the manuscript; EAHW reviewed existing research and wrote the first draft of the manuscript with CLE; DHB helped draft some sections of the manuscript and reviewed/edited the full manuscript; TY, MJD, and DWD reviewed/edited the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

### Competing interests

The authors declare that they have no competing interests.



## Appendix 1

Template table (which expands on the reporting recommendations made by Matthews et al.<sup>30</sup>) for reporting use of activPAL monitors completed for an example study (STAND<sup>76</sup>).

Item	Example response
Monitor version	activPAL3
Rationale for selecting activPAL monitor	The STAND intervention aimed to reduce sitting time; objective device required
Which behavioral characteristics were of primary interest in making the measurements	Time spent sitting and standing and sit to upright transitions
Reliability (inter- and intra-instrument) for the device selected (if available)	Interdevice reliability for the activPAL device ranged from 0.79 to 0.99 (Grant et al. <sup>26</sup> )
Validity information for the activity estimates of interest (e.g., direct measures of predicted values)	A mean percentage difference of 0.19% (limits of agreement from -0.68% to 1.06%) and 1.4% (limits of agreement from -6.2% to 9.1%) between the activPAL monitor and observation for total time spent sitting and standing has been reported (Grant et al. <sup>26</sup> )
Method and location of monitor attachment	Device was waterproofed by covering in nitrile sleeve and wrapped fully in 1 piece of waterproof dressing (Hypafix transparent). Self-adhered to mid-thigh anterior aspect using 1 piece of Hypafix dressing following visual demonstration, with attachment checked by research staff Additional dressings supplied for reattachment during wear period
Wear period and number of days	24 h/day for 10 consecutive days
activPAL software version	Version 7.2.29
Settings used: <ul style="list-style-type: none"> <li>• Sampling frequency</li> <li>• Minimum sitting period</li> <li>• Minimum upright period</li> </ul>	20 Hz (default) 10 s (default) 10 s (default)
Diary data collected and details collected	Time woke up, time got up, time went to bed, time went to sleep, and any removal times each day
Type of file used for data processing	Events file (X, Y, Z version)
Goal for the sampling periods observed (i.e., number of hours per day; number and type of days); state whether a priori	At least 10 h of data per day and 4 days of data ( <i>a priori</i> )
Method(s) for estimating wearing time/removing time in bed/sleep (report in sufficient detail so that others can replicate the method)	“Sleep”/prolonged removals were removed using an algorithm developed using the study data, which identified the longest sitting/lying and any sitting/lying/standing bouts >5 h in a 24 h period as coded these as sleep, and then searched either side of that sleep bout to identify other bouts to be incorporated into the sleep bout using the following rules: (1) sedentary bouts of ≥2 h within 15 min of sleep plus any interceding movement are considered as sleep time, (2) sedentary bouts of ≥30 min within 15 min of sleep bout and <20 steps in interim plus any interceding movement are considered as sleep time, and (3) sedentary bouts where the only movement between the sleep bout and the sedentary bout is standing are considered as sleep time along with the interceding standing bout <sup>b</sup>
What quality control checks were implemented	Heat maps of included and excluded data visually checked (side by side) for probable errors classification of data to include/exclude. Any likely errors were checked against diaries (when available) and the most plausible classification (subjectively determined) was chosen and applied considering diary data and the typical movement patterns on all days
Specify type of action taken when data were determined to be invalid	Data deemed invalid were excluded from analysis of worn waking hours.
Compliance criteria to define a valid day of observation <sup>a</sup>	Day has ≥10 h of worn waking hours, <95% of time spent in any one behavior (i.e., sitting, standing, or stepping) and ≥500 steps
Number and type of days required to be included in final analytic sample <sup>a</sup>	Any 4 days of data
Definition of a day <sup>a</sup>	Midnight to midnight
Data processing package used and methods used to generate key summary variables	activPAL software Version 7.2.29 to create events files. STATA Version 13 was used to perform quality checks and determine valid data

<sup>a</sup> The criteria should be chosen with view to the needs of a particular study’s research questions (e.g., whether individual reliable estimates or an unbiased group estimate is most desired), the activity measures, and the study populations and context.

<sup>b</sup> Algorithm still under development.

## Appendix: Supplementary material

Supplementary data to this article can be found online at [doi:10.1016/j.jshs.2016.02.002](https://doi.org/10.1016/j.jshs.2016.02.002).

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