Title: Minimum Wear Duration for the activPAL™ Professional Activity Monitor in Adolescent Females.

Running Head: Minimum activPAL Wear Time

Competing Interests: The authors declare no conflict of interest.

Abstract:

Objectives: This study aims to determine the minimum number of days of monitoring required to reliably predict sitting/lying time, standing time, light intensity physical activity (LIPA), moderate-to-vigorous intensity physical activity (MVPA) and steps in adolescent females.

Methods: 195 adolescent females (mean age=15.7 years; SD=0.9) participated in the study. Participants wore the activPAL activity monitor for a seven day protocol. The amount of time spent sitting/lying, standing, in LIPA and in MVPA and the number of steps per day were quantified. Spearman-Brown Prophecy formulae were used to predict the number of days of data required to achieve an intraclass correlation coefficient of both 0.7 and 0.8.

Results: For the percentage of the waking day spent sitting/lying, standing, in LIPA and in MVPA, a minimum of 9 days of accelerometer recording is required to achieve a reliability of ≥0.7, while a minimum of 15 days is required to achieve a reliability of ≥0.8. For steps, a minimum of 12 days of recording is required to achieve a reliability of ≥0.7, with 21 days to achieve a reliability of ≥0.8.

Conclusion: Future research in adolescent females should collect a minimum of 9 days of accelerometer data to reliably estimate sitting/lying time, standing time, LIPA and MVPA, while 12 days is required to reliably estimate steps.

Keywords: activPAL, Minimum, Adolescent, Wear Time, Physical Activity, Sedentary Behaviour.

Introduction:

The elimination of physical inactivity has the potential to reduce the incidence of major non-communicable diseases by 6-10% (12). Increasing the prevalence of individuals achieving the recommended daily amount of moderate-to-vigorous physical activity (MVPA) is a key behaviour to target when addressing the prevalence of non-communicable disease (12). Furthermore, evidence has accumulated on the deleterious effects of sedentary behaviours (SB) on health outcomes (23). Consequently, reducing the amount of time spent sedentary is becoming an increasingly important component of public health recommendation development globally (24).

Accurate and reliable measures of physical behaviours (including sitting/lying time (SLT), standing time (StT), light intensity physical activity (LIPA) and MVPA) in free-living environments are essential when identifying associations between specific physical behaviours and health outcomes, identifying determinants that may influence participation in physical behaviours, informing interventions that target specific physical behaviours, and evaluating the effectiveness of interventions and improving public health surveillance (28). The selection of which measure to employ is often a trade-off between feasibility and validity in field-based research (26, 30). Reviews of the literature have highlighted the advantages and disadvantages of a wide range of field-based measures of physical activity (PA) and SB (26, 30, 31). These reviews suggest that motion sensors, such as accelerometers, are currently the measure of choice (26, 31).

Free-living activity behaviours across given monitoring periods are characterised by large amounts of inter-individual and intra-individual variability (15), which can significantly impact measurement reliability. Reliability is a prerequisite to validity and the reliability of a device must be determined to ensure valid estimates of free-living physical behaviours (3). By determining the inter- and intra-individual variability across days of measurement, researchers can define the number of days of monitoring required to reliably estimate such behaviours. The minimum number of days required to assess PA and SB with a suitable level of reliability vary substantially across age, population and accelerometer (27). In young children, highly variable findings have been observed, with research suggesting that between 2-7 days of accelerometer wear time provide a reliable estimate of total PA and SB (1, 9). There is also debate in relation to the necessity of the inclusion of weekend data for the reliable estimation of typical activity in young children (8, 18). In adults, it has been recommended that a minimum of seven consecutive days of accelerometry wear time is required for a reliable estimate of time spent inactive and in MVPA (13), while any 3 days of measurement is appropriate for examining steps per day (29).

When establishing the minimum number of days required to reliably estimate sedentary time, researchers have historically relied on devices that require count-to-activity thresholds to estimate sedentariness. A count-to-activity threshold is a threshold that relates arbitrary accelerometer count values to an estimate of energy expenditure. The most typical sedentary threshold utilised is that for the ActiGraph, whereby <100 accelerometers counts per minute signifies sedentary time. The use of sedentary thresholds relies on the lack of ambulation to estimate SB rather than examining the postural allocation of the individual (11, 17). Such estimates may under/over-estimate sedentary time due to the inclusion of standing or low ambulatory activities (11, 17). Device developments have enabled the examination of postural allocation to accurately distinguish between SLT and StT, and have been encouraged over count-to-activity thresholds (17). One such device, the activPAL™ (PAL Technologies Ltd, Glasgow, UK), has previously been identified as a valid measure of SLT in children (19) and adults (11) and as a measure of MVPA in adolescent females (6).

To the author's knowledge, the minimum number of days of monitoring required when examining free-living SLT, StT, LIPA, MVPA and steps when using the activPAL in an adolescent population has not been defined. The purpose of this study was to determine the number of days of activPAL monitoring required to reliably estimate SLT, StT, LIPA, MVPA and steps in an adolescent female sample.

Methods:

Data were collected from a cross-sectional sample of students from 13 schools in the mid-western region of Ireland between 2009 and 2011. Participants were randomly selected from all 13-18 year old female students in each school. To be eligible for inclusion, participants were required to have no injuries or illnesses which impact their participation in PA. Written informed participant and parental consent were obtained prior to data collection. All procedures were reviewed and approved by the researchers institute research ethics committee. Data collection on all participants was completed during school term, meaning all data on weekdays presented were schooldays.

Objective examination of physical behaviours over a seven day period was obtained using the activPAL. The activPAL is a thigh mounted accelerometer-based activity monitor, measuring 53×35×7mm and weighing 20g. The activPAL samples at 10 Hz and measures bodily accelerations using a uni-axial accelerometer (5). The monitor provides information on whether the wearer is in a sitting/lying position, standing position or if the wearer is stepping, while activity counts and step counts are also provided. The monitor communicates with a Windows (Microsoft Corporation, One Microsoft Way, Redmond, WA, USA) compatible PC via a USB interface. All monitors were initialised on the morning of distribution to each participant. The activPAL was worn on the midpoint of the anterior aspect of the right thigh and was attached to the skin using a hydro-gel adhesive pad (PAL*stickie*™). Monitors were distributed to the participants by the investigators, while every student was provided with detailed instructions on how the monitor was to be worn. Participants were then asked to attach the device as instructed. Finally, investigators examined the location of attachment to ensure that the monitor was worn appropriately. Participants were instructed to wear the device at all times (24 hour wear protocol), and to only remove the device when bathing or for water-based activities. Participants were supplied with extra PAL*stickie*™ to reapply the device if it was removed. The device was worn for a seven day wear protocol. At the end of data collection, the devices were collected by investigators, and the activPAL data was downloaded to the same PC via USB interface.

Prior to detailed examination of accelerometer data, all activPAL output was visually inspected using the activPAL software to identify potential erroneous data from monitor malfunction, prolonged periods of non-wear time and to identify the earliest and latest time the monitor registered movement over a typical 24 hour measurement period. To determine the number of valid days of accelerometry required to reliably estimate SLT, StT, LIPA and MVPA, a criteria for a valid measurement day was defined. A valid measurement day was classified as a day with <4 hours of non-wear time during waking hours (defined below) (5). Non-wear time was defined as a period with ≥60 minutes of consecutive zero activity counts (25). The non-wear periods for each day were summed, and all measurement days with ≥4 hours of non-wear time during waking hours were removed from this analysis. For all remaining participants, the daily non-wear time was summed, and the non-wear time was subtracted from both the waking day time and the sitting/lying time to ensure that only wear periods were included for analysis.

All components of PA and SB were presented as a percentage of waking hours (5). The amount of waking time was calculated as waking hours = bed time - rise time. To estimate the number of bed hours, the first registered non-sedentary epoch after 7:00 a.m. was identified as rise time. This time was chosen as no participant was identified to have risen from bed prior to 7:00 a.m. during visual inspection of the data. The last registered non-sedentary epoch, which was followed by an uninterrupted sedentary period (>2 hours), was identified as the time the participants went to bed (5).

The activPAL was used to estimate daily SLT, StT, LIPA, MVPA and steps. A detailed description of the methodologies applied to examine the activPAL output for these physical behaviours has previously been provided (5, 6). Briefly, SLT was defined as all time spent in a sitting/lying posture during a waking day. Standing time was defined as time spent in a standing position with no stepping (i.e. standing still), and was calculated by summing the total number of seconds spent standing. LIPA was defined as all time spent in stepping at an intensity of <3 metabolic equivalents (METs) (e.g. slow walking, household chores, etc.), while MVPA was defined as all time spent stepping at an intensity of >3 METs. For MVPA, a threshold of 2997 counts per epoch (15 s) was used to estimate METs for each 15s period, where MVPA was defined as >3 METs (6). Steps were determined from the activPAL output, and were summed over the measured day to provide steps per day. Sitting/lying time was adjusted by subtracting non-wear time from SLT. This method of examining non-wear time data was completed as 1) non-wear time would otherwise be categorised as SLT and 2) no records for the types of activity completed during non-wear time were collected. Total wear time during the waking day was calculated by subtracting non-wear time from the identified waking measurement period. Finally, SLT, StT, LIPA and MVPA were then presented as a percentage of the total wear time during the waking day.

Descriptive statistics are presented as mean (SD), median (25th percentile, 75th percentile) or number (percentage) as appropriate. All numeric data were assessed for skewness by visual inspection of histograms and formal tests of normality. The distributions of the sedentary and PA variables were found to be skewed so Box-Cox transformations were used to transform the data to normality prior to analyses. Linear mixed models (LMM) were used to model the transformed daily data, accounting for the different number of days of recorded data across the sample. Single day intraclass correlations (ICC) values were computed from the LMM models, where the ICC is defined as the ratio of between-individual variance to the sum of the between- and within- individual variance. The reliability of the activPAL daily measurements of physical behaviours and steps was assessed using the Spearman-Brown prophecy formula (22). The number of required days to reach the target average ICC was computed using the Spearman-Brown prophecy formula: $N=ICC_T(1-ICC_S)/(ICC_S(1-ICC_T))$, where ICCs=single day ICC, N=number of required days and ICC_T=target average measures ICC. Although an average measures ICC (computed as the ICC of an average measure across N days) of ≥0.8 has been identified as an acceptable level of reliability (2), an ICC of ≥0.7 has been suggested as being appropriate as it reduces the amount of data excluded and maximizes power (14). In this study, the number of required days were computed separately for $ICC_T=0.8$ and $ICC_T=0.7$. Statistical analyses were conducted using IBM SPSS Statistics version 21.0 (Cary, NC).

Results:

Of those randomly selected, a total of 216 students (76%) agreed to take part in the study. Due to malfunctioning devices, 21 datasets were excluded from analysis. A total of 195 valid datasets were included. No differences existed between excluded and included participants for age, height, weight or BMI. Participants mean age was 15.7 (±0.9) years, with a median BMI of 21.7 (IQR = 5.2) kg/m^2. Nine participants (4.6%) were classified as underweight, 132 participants (67.7%) had normal weight, 41 participants (21.0%) were overweight, and 13 participants (6.7%) were obese. A total of 29 participants provided 4 days of accelerometer data (14.9%), 140 provided 5 valid days (71.8%) and 26 providing 6 valid days (13.3%). A total of 180 participants provided data on both weekend days (92.3%), with 15 participants providing data on one weekend day only (7.7%).

Descriptive information on the amount of waking time spent (hrs.) in SLT, StT, LIPA and MVPA across days of the week is provided in Table 1. The percentage of the waking day spent in these behaviours, along with the number of steps accumulated across each day of the week, are also presented in Table 1. Daily waking hours across the measured week ranged from 12.8 (IQR=1.2) on Sundays to 16.2 (IQR=1.8) on Fridays.

The Spearman-Brown Prophecy Formulae based on ICCs for all collected data with a reliability of 0.7 and 0.8 were used to predict the number of days of complete data needed to reliably predict SLT, StT, LIPA, MVPA and steps. The results of the Spearman Brown Prophecy Formulae are presented in Table 2. For a reliability of 0.7, a minimum of 9 days of activPAL monitoring are required to reliably estimate SLT, StT, LIPA and MVPA. A minimum of 15 days of activPAL monitoring are required to achieve a reliability of 0.8 for all activity intensity variables. For steps, a minimum of 12 days of recording is required to give a reliability of 0.7, while 21 days of measurement are required to provide a reliability of 0.8.

Table 1: Descriptive characteristics of i) the total number of waking hours, ii) the number of waking hours spent sitting/lying, standing, in light intensity physical activity and in moderate to vigorous intensity physical activity, iii) the percentage of waking time spent sitting/lying, standing, in light intensity physical activity and in moderate to vigorous intensity physical activity and iv) the number of steps per day across days of the week.

	Monday (n = 171)	**Tuesday (n = 140)**	**Wednesday (n = 139)**	**Thursday (n = 63)**	**Friday (n = 84)**	**Saturday (n = 188)**	**Sunday (n = 184)**
Waking Hours	15.4	15.0	15.2	15.2	16.2	14.5	12.8
	(14.8, 16.0)	(14.3, 15.6)	(14.5, 15.8)	(14.7, 15.8)	(15.2, 17.0)	(13.2, 15.5)	(11.8, 14.0)
Sitting/Lying (hrs.)	10.3	9.8	10.0	9.2	10.4	9.2	8.6
	(9.1, 11.2)	(8.8, 11.0)	(8.7, 11.1)	(8.2, 11.0)	(9.4, 11.8)	(7.8, 10.7)	(7.2, 9.8)
Standing (hrs.)	3.3	3.3	3.3	3.8	3.4	3.3	2.8
	(2.7, 3.9)	(2.5, 3.9)	(2.6, 4.1)	(2.8, 4.4)	(2.6, 4.4)	(2.4, 4.4)	(2.0, 3.5)
LIPA (hrs.)	0.76	0.77	0.78	0.78	0.84	0.80	0.65
	(0.63, .97)	(0.64, .96)	(0.65, 1.00)	(0.63, 1.08)	(0.65, 1.09)	(0.55, 1.03)	(0.49, 0.85)
MVPA (hrs.)	0.80	0.91	0.83	1.06	0.85	0.72	0.44

	(0.58, 1.25)	(0.61, 1.29)	(0.55, 1.27)	(0.83, 1.34)	(0.50, 1.38)	(0.37, 1.11)	(0.23, 0.91)
% Waking hrs							
Sitting/Lying (%)	67.1	66.1	66.8	61.9	65.6	64.4	68.4
	(60.8, 72.8)	(60.0, 72.5)	(59.7, 73.4)	(55.3, 72.1)	(58.8, 73.7)	(54.9, 74.4)	(58.6, 75.9)
Standing (%)	21.7	21.6	21.6	24.0	21.9	23.0	21.9
	(17.7, 25.9)	(17.2, 26.9)	(18.1, 26.8)	(18.7, 30.1)	(16.8, 26.9)	(17.4, 30.3)	(16.1, 27.7)
LIPA (%)	5.0	5.1	5.2	5.1	5.5	5.6	5.2
	(4.1, 6.4)	(4.3, 6.4)	(4.3, 6.4)	(4.0, 7.3)	(4.3, 6.8)	(4.0, 7.1)	(3.9, 6.7)
MVPA (%)	5.3	6.3	5.5	6.6	5.5	4.9	3.4
	(3.9, 8.0)	(4.1, 8.5)	(3.7, 8.5)	(5.3, 8.9)	(3.2, 8.1)	(2.6, 7.7)	(1.8, 7.2)
Steps	8364	8539	8824	9994	9122	8010	5261
	(6428, 11263)	(6408, 11625)	(6312, 10922)	(7898, 11888)	(6512, 13113)	(4724, 10978)	(3540, 8644)

All data presented as median (25^{th} percentile, 75^{th} percentile) due to non-normality of data.

Table 2: Number of days of complete data required to estimate components of waking sitting/lying, standing, light and moderate-to-vigorous intensity physical activity and steps per day from the activPAL activity monitor in adolescent females.

Behaviours	**Target Reliability Value (ICC)**	
	0.7	**0.8**
Sitting/Lying Time (% Waking)	6.9 days	11.8 days
Standing Time (% Waking)	5.7 days	9.8 days
Light Intensity Physical Activity (% Waking)	5.2 days	9.0 days
Moderate-to-Vigorous Physical Activity (% Waking)	8.8 days	15.1 days
Steps	12.1 days	20.8 days

Discussion:

This study aimed to determine the number of days of activPAL monitoring required to reliably examine SLT, StT, LIPA, MVPA and steps in a sample of adolescent females. As far as the authors are aware, this is the first study to examine the reliability of objective measurement of free-living SB, based on posture rather than sedentary thresholds (i.e. less than ActiGraph 100 counts-per-minute), in an adolescent cohort. The findings of the present study suggest that a minimum of seven days of activPAL measurement is required to achieve a reliability coefficient of $\geq$0.7 for measurement of SLT, StT and LIPA, while at least 12 days of data are required for a coefficient of $\geq$0.8. Where the activPAL acceleration data are also used to quantify MVPA, 9 days of activPAL measurement are required to achieve a reliability coefficient of $\geq$0.7, while at least 15 days of measurement were required to achieve a reliability coefficient of $\geq$0.8 in this sample.

When examining physical behaviours in free-living environments, it is essential that sufficient data are gathered to ensure a reliable estimate of these variables is obtained (3, 27). Researchers have examined the minimum number of days of accelerometer measurement required to achieve acceptable reliability of free-living accelerometer output, focusing on the examination of daily accelerometer counts (7, 9), MVPA (1, 8, 13, 28) or step count (7, 29). However, limited information is available for the minimum number of days required to provide reliable estimates of SLT, StT and LIPA. It is becoming apparent that these behaviours at the lower end of the activity intensity continuum may play a significant role in energy balance and the prevention of risk factors for major non-communicable disease (21, 23). In order to strengthen the evidence of the associations between such health variables and SLT, StT and LIPA, it is necessary to ensure that sufficient data to provide reliable estimates is obtained. In adolescent females, a minimum of 9 days of SLT, StT, LIPA and MVPA are required to achieve an acceptable level of reliability. Interestingly, larger day to day variability in MVPA compared to the other behaviours of interest was evident, with it requiring 8.8 days of measurement to achieve a reliability of $\geq$0.7 (compared to 5.2, 5.7 and 6.9 for LIPA, StT and SLT respectively). Future research should aim to increase the number of measured days to a minimum of 9 consecutive days of accelerometer measurement, moving away from the commonly employed 4 days including 1 weekend day (4, 10).

As this is the first study to assess the minimum number of days required to reliably predict SLT, StT, LIPA using the activPAL in adolescent females, it is difficult to directly compare these findings with existing literature. However, the findings for the minimum number of days required to reliably predict MVPA are comparable to other studies utilising objective measures. In a study of 30 children aged 7-15 years, Janz et al. identified that a minimum of 6 days of accelerometer recording was necessary to achieve a reliability coefficient of ≥0.8 when estimating the amount of time spent sedentary and in MVPA (10). Similarly, in an analysis of 436 female adolescents (mean age = 14.1 years (SD = 0.45)), the minimum recommended wear duration to reliably predict minutes spent in MVPA was 6 days (16). Trost et al. identified that a 7 day monitoring protocol was recommended when examining the reliability of MVPA in a combined cohort of children and adolescents (28). However, notable differences in the variability of activity behaviours were observed between children and adolescents when examined separately, with a minimum of 4-5 days of recording recommended for children and 8-9 days recommended for adolescents (28). Discrepancies in the minimum number of days recommended in the current paper compared to existing literature is likely due to differences in activity monitor used (i.e. CSA/ActiGraph vs activPAL), activity monitor wear location (thigh versus hip/wrist), activity monitor protocol differences (i.e. 24 hour wear protocol compared to waking wear protocol for other devices), potential sample differences (i.e. age, sex, environmental and cultural differences) and data reduction methodologies (i.e. treadmill versus non-treadmill-based MVPA count-to-activity thresholds).

A significant strength of this study is the examination of objectively determined SLT and StT using the "gold standard" objective measurement device, the activPAL (11). The use of this device enables the differentiation of StT from LIPA, while an estimate of time spent in MVPA is also possible. As far as the authors are aware, this is the first study to examine the minimum number of days of measurement required to achieve acceptable reliability for each of these behaviours, rather than relying on estimates of sedentary time from count-to-activity thresholds that do not distinguish between sitting and standing. This study provides some of the first evidence on the minimum number of days of activPAL measurement for a reliable estimate of SLT in this population. Additionally, the relatively large sample size of adolescent females (n=195) was a strength of the study.

The limitations of this study must be acknowledged. Although accelerometers are the preferred objective measure of habitual physical behaviours (26, 31), lower limb worn devices like the activPAL have their own limitations, including the inability to measure arm movements (i.e. window cleaning, ironing etc.) and some specific activities (i.e. stair climbing, cycling, swimming etc.) (30). Due to the age and sex specific sample, it is not possible to generalise the findings of this study to other populations, as the calculated ICC values are constrained to the sample from which they are calculated (2). Additionally, newer generation activPAL monitors (i.e. the triaxial activPAL3™) have been developed, and output from different generation devices may not be comparable due to software and hardware upgrades. However, generally good agreement for postural position between generations of activPAL devices have previously been reported, suggesting that the minimum number of days of monitoring reported here for postural position may be applicable to newer generation devices (20).

Conclusion:

The findings of this study suggest that a minimum of 7 valid days of recording is required to achieve a reliability of ≥0.7 for activPAL derived SLT, StT and LIPA in individuals, while a minimum of 9 days is required for a reliable estimate of MVPA for individuals in an adolescent female population. This measurement period ensures that all days of the week are recorded, reducing the risk of bias due to any potential differences in waking hours or waking behaviours on this day. Future research should examine the minimum number of days required to achieve acceptable levels of reliability for activity intensities at the lower end of the activity intensity continuum in children, adults and older adults to help strengthen associations made between such activity behaviours and health.

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