1   **Title:** Minimum Wear Duration for the activPAL^{TM} Professional Activity Monitor in Adolescent

2   Females.

3   **Running Head:** Minimum activPAL Wear Time

4   **Competing Interests:** The authors declare no conflict of interest.

5   **Abstract:**

6   **Objectives:** This study aims to determine the minimum number of days of monitoring required to reliably predict

7   sitting/lying time, standing time, light intensity physical activity (LIPA), moderate-to-vigorous intensity physical

8   activity (MVPA) and steps in adolescent females.

9   **Methods:** 195 adolescent females (mean age=15.7 years; SD=0.9) participated in the study. Participants wore the

10   activPAL activity monitor for a seven day protocol. The amount of time spent sitting/lying, standing, in LIPA and

11   in MVPA and the number of steps per day were quantified. Spearman-Brown Prophecy formulae were used to

12   predict the number of days of data required to achieve an intraclass correlation coefficient of both 0.7 and 0.8.

13   **Results:** For the percentage of the waking day spent sitting/lying, standing, in LIPA and in MVPA, a minimum of 9

14   days of accelerometer recording is required to achieve a reliability of ≥ 0.7, while a minimum of 15 days is required

15   to achieve a reliability of ≥ 0.8. For steps, a minimum of 12 days of recording is required to achieve a reliability of

16   ≥ 0.7, with 21 days to achieve a reliability of ≥ 0.8.

17   **Conclusion:** Future research in adolescent females should collect a minimum of 9 days of accelerometer data to

18   reliably estimate sitting/lying time, standing time, LIPA and MVPA, while 12 days is required to reliably estimate

19   steps.

20   **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

48 and SB (1, 9). There is also debate in relation to the necessity of the inclusion of weekend data for the

49 reliable estimation of typical activity in young children (8, 18). In adults, it has been recommended

50 that a minimum of seven consecutive days of accelerometry wear time is required for a reliable

51 estimate of time spent inactive and in MVPA (13), while any 3 days of measurement is appropriate

52 for examining steps per day (29).

53 When establishing the minimum number of days required to reliably estimate sedentary time,

54 researchers have historically relied on devices that require count-to-activity thresholds to estimate

55 sedentariness. A count-to-activity threshold is a threshold that relates arbitrary accelerometer count

56 values to an estimate of energy expenditure. The most typical sedentary threshold utilised is that for

57 the ActiGraph, whereby <100 accelerometers counts per minute signifies sedentary time. The use of

58 sedentary thresholds relies on the lack of ambulation to estimate SB rather than examining the

59 postural allocation of the individual (11, 17). Such estimates may under/over-estimate sedentary time

60 due to the inclusion of standing or low ambulatory activities (11, 17). Device developments have

61 enabled the examination of postural allocation to accurately distinguish between SLT and StT, and

62 have been encouraged over count-to-activity thresholds (17). One such device, the activPAL™ (PAL

63 Technologies Ltd, Glasgow, UK), has previously been identified as a valid measure of SLT in

64 children (19) and adults (11) and as a measure of MVPA in adolescent females (6).

65 To the author's knowledge, the minimum number of days of monitoring required when examining

66 free-living SLT, StT, LIPA, MVPA and steps when using the activPAL in an adolescent population

67 has not been defined. The purpose of this study was to determine the number of days of activPAL

68 monitoring required to reliably estimate SLT, StT, LIPA, MVPA and steps in an adolescent female

69 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

97 periods of non-wear time and to identify the earliest and latest time the monitor registered movement

98 over a typical 24 hour measurement period. To determine the number of valid days of accelerometry

99 required to reliably estimate SLT, StT, LIPA and MVPA, a criteria for a valid measurement day was

100 defined. A valid measurement day was classified as a day with <4 hours of non-wear time during

101 waking hours (defined below) (5). Non-wear time was defined as a period with ≥60 minutes of

102 consecutive zero activity counts (25). The non-wear periods for each day were summed, and all

103 measurement days with ≥4 hours of non-wear time during waking hours were removed from this

104 analysis. For all remaining participants, the daily non-wear time was summed, and the non-wear time

105 was subtracted from both the waking day time and the sitting/lying time to ensure that only wear

106 periods were included for analysis.

107 All components of PA and SB were presented as a percentage of waking hours (5). The amount of

108 waking time was calculated as waking hours = bed time - rise time. To estimate the number of bed

109 hours, the first registered non-sedentary epoch after 7:00 a.m. was identified as rise time. This time

110 was chosen as no participant was identified to have risen from bed prior to 7:00 a.m. during visual

111 inspection of the data. The last registered non-sedentary epoch, which was followed by an

112 uninterrupted sedentary period (>2 hours), was identified as the time the participants went to bed (5).

113 The activPAL was used to estimate daily SLT, StT, LIPA, MVPA and steps. A detailed description of

114 the methodologies applied to examine the activPAL output for these physical behaviours has

115 previously been provided (5, 6). Briefly, SLT was defined as all time spent in a sitting/lying posture

116 during a waking day. Standing time was defined as time spent in a standing position with no stepping

117 (i.e. standing still), and was calculated by summing the total number of seconds spent standing. LIPA

118 was defined as all time spent in stepping at an intensity of <3 metabolic equivalents (METs) (e.g. slow

119 walking, household chores, etc.), while MVPA was defined as all time spent stepping at an intensity

120 of >3 METs. For MVPA, a threshold of 2997 counts per epoch (15 s) was used to estimate METs for

121 each 15s period, where MVPA was defined as >3 METs (6). Steps were determined from the

122 activPAL output, and were summed over the measured day to provide steps per day. Sitting/lying time

123 was adjusted by subtracting non-wear time from SLT. This method of examining non-wear time data

124 was completed as 1) non-wear time would otherwise be categorised as SLT and 2) no records for the

125 types of activity completed during non-wear time were collected. Total wear time during the waking

126 day was calculated by subtracting non-wear time from the identified waking measurement period.

127 Finally, SLT, StT, LIPA and MVPA were then presented as a percentage of the total wear time during

128 the waking day.

129 Descriptive statistics are presented as mean (SD), median (25th percentile, 75th percentile) or number

130 (percentage) as appropriate. All numeric data were assessed for skewness by visual inspection of

131 histograms and formal tests of normality. The distributions of the sedentary and PA variables were

132 found to be skewed so Box-Cox transformations were used to transform the data to normality prior to

133 analyses. Linear mixed models (LMM) were used to model the transformed daily data, accounting for

134 the different number of days of recorded data across the sample. Single day intraclass correlations

135 (ICC) values were computed from the LMM models, where the ICC is defined as the ratio of

136 between-individual variance to the sum of the between- and within- individual variance. The

137 reliability of the activPAL daily measurements of physical behaviours and steps was assessed using

138 the Spearman-Brown prophecy formula (22). The number of required days to reach the target average

139 ICC was computed using the Spearman-Brown prophecy formula: $N=ICC_T(1-ICC_S)/(ICC_S(1-ICC_T))$,

140 where ICC_S=single day ICC, N=number of required days and ICC_T=target average measures ICC.

141 Although an average measures ICC (computed as the ICC of an average measure across N days) of

142 ≥0.8 has been identified as an acceptable level of reliability (2), an ICC of ≥0.7 has been suggested as

143 being appropriate as it reduces the amount of data excluded and maximizes power (14). In this study,

144 the number of required days were computed separately for ICC_T=0.8 and ICC_T=0.7. Statistical

145 analyses were conducted using IBM SPSS Statistics version 21.0 (Cary, NC).

146 **Results:**

147 Of those randomly selected, a total of 216 students (76%) agreed to take part in the study. Due to

148 malfunctioning devices, 21 datasets were excluded from analysis. A total of 195 valid datasets were

149 included. No differences existed between excluded and included participants for age, height, weight

150 or BMI. Participants mean age was 15.7 ($\pm$0.9) years, with a median BMI of 21.7 (IQR = 5.2) kg/m^2.

151 Nine participants (4.6%) were classified as underweight, 132 participants (67.7%) had normal weight,

152 41 participants (21.0%) were overweight, and 13 participants (6.7%) were obese. A total of 29

153 participants provided 4 days of accelerometer data (14.9%), 140 provided 5 valid days (71.8%) and 26

154 providing 6 valid days (13.3%). A total of 180 participants provided data on both weekend days

155 (92.3%), with 15 participants providing data on one weekend day only (7.7%).

156 Descriptive information on the amount of waking time spent (hrs.) in SLT, StT, LIPA and MVPA

157 across days of the week is provided in Table 1. The percentage of the waking day spent in these

158 behaviours, along with the number of steps accumulated across each day of the week, are also

159 presented in Table 1. Daily waking hours across the measured week ranged from 12.8 (IQR=1.2) on

160 Sundays to 16.2 (IQR=1.8) on Fridays.

161 The Spearman-Brown Prophecy Formulae based on ICCs for all collected data with a reliability of 0.7

162 and 0.8 were used to predict the number of days of complete data needed to reliably predict SLT, StT,

163 LIPA, MVPA and steps. The results of the Spearman Brown Prophecy Formulae are presented in

164 Table 2. For a reliability of 0.7, a minimum of 9 days of activPAL monitoring are required to reliably

165 estimate SLT, StT, LIPA and MVPA. A minimum of 15 days of activPAL monitoring are required to

166 achieve a reliability of 0.8 for all activity intensity variables. For steps, a minimum of 12 days of

167 recording is required to give a reliability of 0.7, while 21 days of measurement are required to provide

168 a reliability of 0.8.

169 **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

170 physical activity and in moderate to vigorous intensity physical activity, iii) the percentage of waking time spent sitting/lying, standing, in light intensity

171 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)

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

173   **Table 2**: Number of days of complete data required to estimate components of waking sitting/lying,

174   standing, light and moderate-to-vigorous intensity physical activity and steps per day from the

175   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

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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 ≥ 0.7 for measurement of SLT, StT and LIPA, while at least 12 days of data are required for a coefficient of ≥ 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 ≥ 0.7, while at least 15 days of measurement were required to achieve a reliability coefficient of ≥ 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 ≥ 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

203 days of accelerometer measurement, moving away from the commonly employed 4 days including 1
204 weekend day (4, 10).

205 As this is the first study to assess the minimum number of days required to reliably predict SLT, StT,
206 LIPA using the activPAL in adolescent females, it is difficult to directly compare these findings with
207 existing literature. However, the findings for the minimum number of days required to reliably predict
208 MVPA are comparable to other studies utilising objective measures. In a study of 30 children aged 7-
209 15 years, Janz et al. identified that a minimum of 6 days of accelerometer recording was necessary to
210 achieve a reliability coefficient of ≥0.8 when estimating the amount of time spent sedentary and in
211 MVPA (10). Similarly, in an analysis of 436 female adolescents (mean age = 14.1 years (SD = 0.45)),
212 the minimum recommended wear duration to reliably predict minutes spent in MVPA was 6 days
213 (16). Trost et al. identified that a 7 day monitoring protocol was recommended when examining the
214 reliability of MVPA in a combined cohort of children and adolescents (28). However, notable
215 differences in the variability of activity behaviours were observed between children and adolescents
216 when examined separately, with a minimum of 4-5 days of recording recommended for children and
217 8-9 days recommended for adolescents (28). Discrepancies in the minimum number of days
218 recommended in the current paper compared to existing literature is likely due to differences in
219 activity monitor used (i.e. CSA/ActiGraph vs activPAL), activity monitor wear location (thigh versus
220 hip/wrist), activity monitor protocol differences (i.e. 24 hour wear protocol compared to waking wear
221 protocol for other devices), potential sample differences (i.e. age, sex, environmental and cultural
222 differences) and data reduction methodologies (i.e. treadmill versus non-treadmill-based MVPA
223 count-to-activity thresholds).

224 A significant strength of this study is the examination of objectively determined SLT and StT using
225 the "gold standard" objective measurement device, the activPAL (11). The use of this device enables
226 the differentiation of StT from LIPA, while an estimate of time spent in MVPA is also possible. As
227 far as the authors are aware, this is the first study to examine the minimum number of days of
228 measurement required to achieve acceptable reliability for each of these behaviours, rather than
229 relying on estimates of sedentary time from count-to-activity thresholds that do not distinguish

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230   between sitting and standing. This study provides some of the first evidence on the minimum number

231   of days of activPAL measurement for a reliable estimate of SLT in this population. Additionally, the

232   relatively large sample size of adolescent females (n=195) was a strength of the study.

233   The limitations of this study must be acknowledged. Although accelerometers are the preferred

234   objective measure of habitual physical behaviours (26, 31), lower limb worn devices like the

235   activPAL have their own limitations, including the inability to measure arm movements (i.e. window

236   cleaning, ironing etc.) and some specific activities (i.e. stair climbing, cycling, swimming etc.) (30).

237   Due to the age and sex specific sample, it is not possible to generalise the findings of this study to

238   other populations, as the calculated ICC values are constrained to the sample from which they are

239   calculated (2). Additionally, newer generation activPAL monitors (i.e. the triaxial activPAL3™) have

240   been developed, and output from different generation devices may not be comparable due to software

241   and hardware upgrades. However, generally good agreement for postural position between

242   generations of activPAL devices have previously been reported, suggesting that the minimum number

243   of days of monitoring reported here for postural position may be applicable to newer generation

244   devices (20).

245 **Conclusion:**

246 The findings of this study suggest that a minimum of 7 valid days of recording is required to achieve a

247 reliability of ≥0.7 for activPAL derived SLT, StT and LIPA in individuals, while a minimum of 9

248 days is required for a reliable estimate of MVPA for individuals in an adolescent female population.

249 This measurement period ensures that all days of the week are recorded, reducing the risk of bias due

250 to any potential differences in waking hours or waking behaviours on this day. Future research should

251 examine the minimum number of days required to achieve acceptable levels of reliability for activity

252 intensities at the lower end of the activity intensity continuum in children, adults and older adults to

253 help strengthen associations made between such activity behaviours and health.

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