ORIGINAL RESEARCH

Pediatric Exercise Science, 2011, 23, 468-476

Objective Measurement of Habitual Sedentary Behavior in Pre-School Children: Comparison of activPAL With Actigraph Monitors

Anne Martin, Mhairi McNeill, and Victoria Penpraze
University of Glasgow

Philippa Dall and Malcolm Granat
Glasgow Caledonian University

James Y. Paton
University of Glasgow

John J. Reilly
University of Strathclyde

The Actigraph is well established for measurement of both physical activity and sedentary behavior in children. The activPAL is being used increasingly in children, though with no published evidence on its use in free-living children to date. The present study compared the two monitors in preschool children. Children (n 23) wore both monitors simultaneously during waking hours for 5.6d and 10h/d. Daily mean percentage of time sedentary (nontranslocation of the trunk) was 74.6 (*SD* 6.8) for the Actigraph and 78.9 (*SD* 4.3) for activPAL. Daily mean percentage of time physically active (light intensity physical activity plus MVPA) was 25.4 (*SD* 6.8) for the Actigraph and 21.1 (*SD* 4.3) for the activPAL. Bland-Altman tests and paired *t* tests suggested small but statistically significant differences between the two monitors. Actigraph and activPAL estimates of sedentary behavior and physical activity in young children are similar at a group level.

Accelerometers can provide important insights into both physical activity and sedentary behavior of children (1,8). The Actigraph (MTI, Florida) for example provides objective measurement of both physical activity (with particular emphasis

Martin, McNeill, Penpraze, and Paton are with the College of Medical, Veterinary, and Life Sciences, University of Glasgow, Glasgow, Scotland, UK. Dall and Granat are with the School of Health, Glasgow Caledonian University, Glasgow, Scotland, UK. Reilly is with the Physical Activity for Health Research Group, School of Psychological Sciences and Health, University of Strathclyde, Glasgow, Scotland, UK.

in previous literature on total volume of physical activity and moderate-vigorous intensity physical activity, MVPA) and sedentary behavior (defined in previous Actigraph validation and calibration studies as no translocation of the trunk or as energy expenditure <1.5 times resting energy expenditure). Several pediatric calibration and validation studies in children are available for both sedentary behavior (as defined above) and physical activity (10,14,18,21,22).

The first evidence-based physical activity recommendations for preschool children have just been published, and these use the construct of total daily time spent in physical activity (light intensity physical activity combined with MVPA), arguing that a recommendation for MVPA is inappropriate for this age group (4), with the recommendation that preschool children spend at least three hours per day in physical activity (light intensity and above). Previous accelerometer studies have tended not to express physical activity in terms of total time spent active (18), and so it may be important that when accelerometers are compared in future the comparison is based on total physical activity.

A debate has also taken place on the issue of the definition of 'sedentary behavior', (12). Specifically, researchers have considered whether the definition should continue to focus on behaviors of low energy expenditure (sitting, lying, and standing with no translocation of the trunk; energy expenditure < 1.5 times resting), or whether posture (e.g., sitting and lying versus upright posture) should become the construct which is measured more commonly (7).

In recent years the activPAL (PAL Technologies Glasgow, Scotland) has been used widely for measurement of sedentary behavior, specifically posture, of adults (5,6). Moreover, the validity of the activPAL for measurement of posture is now established for both young children and adults (3,5,6). The activPAL is now being used widely in children, but no published studies have reported on activPAL measures of physical activity or sedentary behavior. It is unclear whether the activPAL will produce similar estimates of physical activity or sedentary behavior to that provided by established monitors such as the Actigraph. The primary aim of the current study was therefore to compare the two monitors for the measurement of sedentary behavior in free-living preschool children. A secondary aim was to compare the two monitors for measurement of total volume of physical activity in the same sample.

Methods

Study Participants

A convenience sample of preschool children was recruited to the current study. Parents of the children gave informed written consent to their participation, and the study was approved by the University of Glasgow Medical Faculty Ethics Committee. Data for the study were collected between June and September 2010. For descriptive purposes, height was measured to 0.1cm using a Leicester Portable Stadiometer and weight to 0.1kg in light underclothing on a SECA scale.

Comparison of activPAL vs. Actigraph

Study participants were asked to wear both the activPAL and Actigraph during waking hours for a period of 7 consecutive days. Parents were asked to remove

both accelerometers for bathing, showering and swimming (the devices used in the current study were not waterproof), and to record in a simple activity log the times when the devices were removed and/or reattached, and the reasons for this. Simultaneously obtained data between the hours of 07.00 and 21.00 were considered eligible for inclusion in the method comparison.

The activPAL is a small (5.3 × 3.5 × 0.7cm) lightweight (15g) single unit uniaxial accelerometer. The activPAL was attached on the midline of the anterior thigh on the right side as recommended (11) using an adhesive pad, the "PALstickie". To maintain the attachment the activPAL was covered with Tegaderm. Parents were shown how to attach and detach the activPAL, and were given instruction sheets to follow. Before use, the activPALs were synchronized with a PC using activPAL professional software. In the current study activPAL estimated sedentary behavior was defined as the time spent sitting/lying plus 'quiet standing' (standing with no stepping). The time spent physically active from the activPAL was considered to be all time spent not sitting, lying, or 'quiet standing' (standing with no stepping).

The Actigraph (MTI, Florida, USA) has been validated for sedentary behavior (no translocation of the trunk, as defined by direct observation) in preschool children on at least two occasions (15,21) and repeatedly validated and calibrated for measurement of physical activity (10,14,21,22). In the current study the Actigraph GT1M and GT3× (programmed to measure movements in the vertical plane only) were used as described previously (18), by attachment to the right hip on a waist belt. Actigraph usage was demonstrated to parents. Actigraph data were collected using 15 s epochs, though expressed as 60 s epochs for application of accelerometer cut-points. Sedentary behavior (calibrated against direct observation and equivalent to "no translocation of the trunk") was defined as all epochs spent below 1100 counts per minute (cpm; 15). This cut-point is not affected greatly by the epoch chosen or the age or size of the child (18).

Actigraph cut-points for sedentary behavior in young children were derived from calibration studies which used the previous version of the Actigraph, the 7164 model. It is not yet clear whether accelerometer output from the older (7164) and newer (GT1M and GT3×) models is equivalent. Corder et al. (2) suggested a small bias (of around 9%), such that Actigraph models after the 7164 should be corrected by increasing their "raw counts" by about 9%. On the other hand some studies suggest less need for such a correction with less evidence of bias between old and newer models, and close agreement between newer models based on the same technology (9,20). The comparison between Actigraph and activPAL for the current study, therefore, used both corrected Actigraph data (increased by 9%) and the uncorrected data. The Actigraph measures used were: time spent in sedentary behavior (cpm less than 1100); time spent in physical activity (cpm 1100 or more).

Statistical Analysis and Study Power

The present study aimed to compare Actigraph and activPAL for measurement of habitual sedentary behavior during waking hours. To obtain reasonably stable estimates of sedentary behavior using the Actigraph, the minimum period of monitoring should be 6h/day over three days (13). Our recent study of the stability of the activPAL in preschool children (n = 20; 3) also suggested that a period of at least 3 days and 6h/day was necessary for reasonable stability. The present study

therefore included data collection periods of at least 3d and 6h/d between the two devices, though monitoring periods were much longer than this in practice.

Study power was difficult to assess at the onset of the study, though was expected to be high as a result of the paired design. It was therefore decided to appraise power after obtaining data from 15 participants. In fact, the difference in daily time spent sedentary between the two monitors was statistically significant with paired comparisons from 15 children and so study data collection was continued only until all potential recruits (who had consented during an initial project recruitment phase) had been included.

Formal comparisons were made between the activPAL and Actigraph in three ways. First, rank order correlations between the two devices were made for the percentage of daily time spent sedentary. Rank correlation provides an assessment of relative validity, the ability of the two techniques to agree in rank assessment, likely to be particularly suitable information for epidemiological applications of the devices where rank order and classification may be paramount. The second approach taken was a formal comparison of output between the two devices using a paired *t* test to determine the significance of differences between the two devices for measurement of the absolute amount of sedentary behavior. Finally, to determine the degree of agreement between the two devices in their assessment of sedentary behavior, a Bland-Altman analysis was carried out with calculation of 'limits of agreement' as the mean difference between monitors plus or minus 1.96 times the standard deviation of the differences.

Results

Characteristics of Study Sample

From a total of 32 children recruited, 23 provided adequate data (at least 3d, with 6h/d) from both monitors to permit an estimate of habitual sedentary behavior. Data from 8 children were not included in the analysis due to lost/missing or malfunctioning accelerometers ($n = 2$) or forms of noncompliance with the study protocol ($n = 6$). One child did not complete the study because of illness. From 23 eligible datasets mean (*SD*) simultaneous monitoring time from both monitors was 5.6d (1.5) and 10.0 hr/d (1.2).

Characteristics of the study sample, including anthropometry and sedentary behavior and physical activity during the day, are given in Table 1. Mean (*SD*) of time spent sedentary was 78.9% (4.3) for activPAL, 76.8% (6.5) for Actigraph when data were uncorrected, and 74.6% (6.8) for Actigraph after correction of Actigraph raw data for the possible small bias in newer models relative to the older 7164 model. Mean (*SD*) for time spent in total volume of physical activity was 21.1% (4.3), 25.4% (6.8), and 23.2% (6.5) for activPAL, corrected Actigraph data, and uncorrected Actigraph data, respectively.

Comparisons Between Sedentary Behavior and Physical Activity Measured Using activPAL vs Actigraph

The percentage daily time spent sedentary was high from both devices, and was similar between the two devices on a group basis (Table 1). Rank order correlations

Table 1 Characteristics of the Study Participants (n = 23, 14 girls), Mean Monitoring Time 10.0h/d

	Mean / Median*	*SD* / Range*
Age (years)	4.5	0.7
Anthropometric data		
Weight (kg)	18.8	3.5
Height (cm)	106.7	5.5
BMI (kg/m^2)	16.4	2.0
BMI z-score	0.16*	-1.5–2.9*
% time spent sedentary		
activPAL	78.9	4.3
Actigraph, corrected data[a]	74.6	6.8
Actigraph, uncorrected data	76.8	6.5
% time spent physically active		
activPAL	21.1	4.3
Actigraph, corrected data[a]	25.4	6.8
Actigraph, uncorrected data	23.2	6.5

[a] denotes Actigraph data when corrected as described in the text

between the two devices were statistically significant ($r = .676$, $p < .001$ and $r = .663$, $p = .001$), both when Actigraph data were corrected and when uncorrected, respectively. Differences in percentage of time spent sedentary between the monitors were significant both when the Actigraph data were corrected (paired t test, $p < .001$) and when not corrected (paired t test, $p = .04$).

The Bland-Altman analysis (Figure 1) shows a difference for percentage of time spent sedentary of -4.3% ± 4.8 of daily time (and limits of agreement -14.0–5.4%) when Actigraph data were corrected, and -2.1% ± 4.6 (limits of agreement -11.4–7.2%) when Actigraph data were uncorrected. Correlations between the differences and the means for sedentary behavior of the two activity monitors were significant, r = +0.56 ($p < .01$) for Actigraph when corrected and r = +0.52 ($p < .05$) for Actigraph when uncorrected.

Discussion

Main Findings, Comparisons With Other Evidence, and Study Implications

The activPAL is now being used widely in studies of physical activity and sedentary behavior of children, and it is important to establish the comparability of the activPAL with the Actigraph, which has dominated the preschool physical activity and sedentary behavior literature. The present study found that, at a group level, estimates of percentage of daily time spent sedentary were broadly similar between the activPAL and Actigraph monitors. The present study also suggests that the two monitors should not be considered to be interchangeable, with more marked differences between them at the individual level.

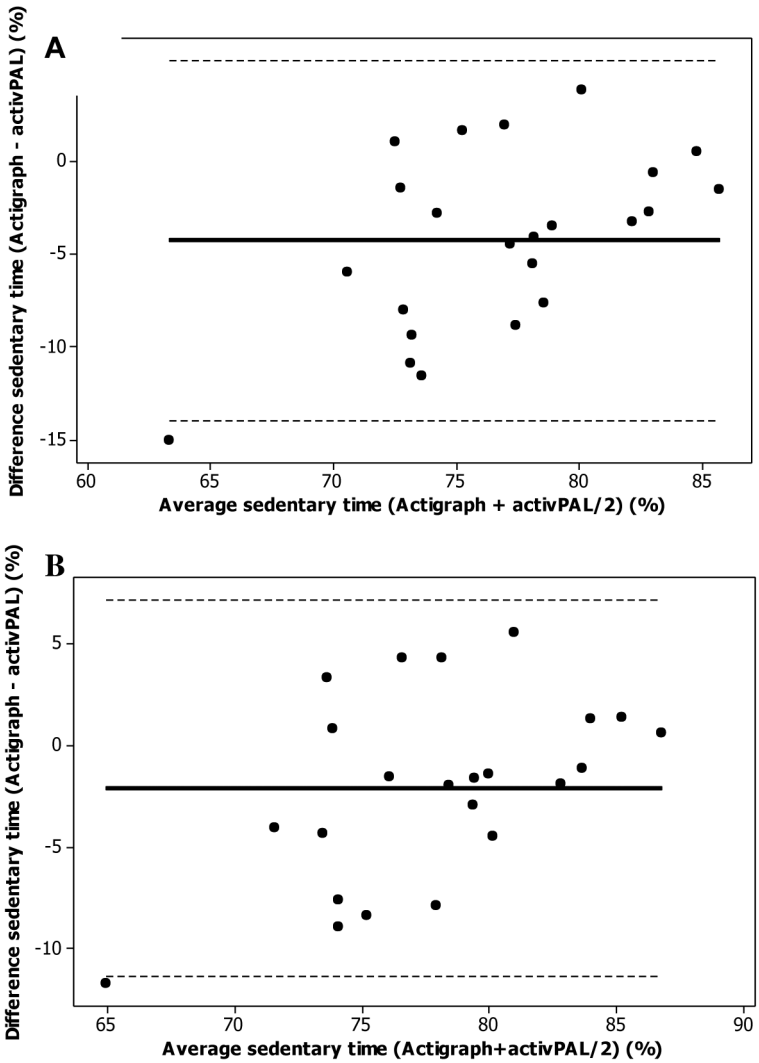

Figure 1 — 'Bland-Altman' Plots for percentage time spent in sedentary behavior measured by activPAL and Actigraph—corrected data (A) and Actigraph—uncorrected data (B).

Previous studies of preschool Scottish children (using doubly-labeled water, direct observation, and Actigraph accelerometry; 16–19) have established that most of their time is spent in sedentary behavior, and relatively little time spent in physical activity, though this has not been expressed previously as hours of physical activity per day as in the current study. Mean total time spent physically active per day (waking hours) in the current study was 2.5h/d (0.7) using the Actigraph (and 2.0 hr/d *SD* 0.4 using the activPAL) which is less than the three hours every day of physical activity (light intensity physical activity and above) recommended

in the recent evidence-based guidance for physical activity in preschoolers (4). The recommendation was met by 26% (n = 6) of the preschoolers in the current study using the Actigraph, and only 1 child when the activPAL was used. Thus, an apparently small difference between the activPAL and Actigraph in group level estimates of sedentary behavior and physical activity could have important effects when used for some applications, such as population surveillance and assessment of compliance with guidelines.

If alternative cut-points were applied to the Actigraph data, quite different estimates of amount of time spent sedentary and physically active would have been obtained in the current study. To illustrate this we used the Trost-Freedson cut-points (18) which produced group mean estimates of 39% of daytime in MVPA (approximately 4 hr per day), much higher than the total volume of physical activity estimated in the current study, and which would have produced a dramatically lower estimate of time spent in sedentary behavior. Several previous pediatric calibration and validation studies of the Actigraph have produced evidence that the optimal cut-point for the Actigraph with 1-min epochs is around 1100–1200 cpm for sedentary behavior (15,21) and 3000–3600 cpm for MVPA (10,14,21).

The activPAL may have two potential advantages over the Actigraph: the data are user friendly and could conceivably be used for self monitoring of sedentary behavior and/or physical activity by parents and children in intervention studies, self monitoring being an important element of behavior change (8); the activPAL allows 'sedentary behavior' to be deconstructed by providing a specific measurement of sitting behavior, and does so accurately (3). Sitting behavior is an increasingly important construct in adult exercise science (7,12) and it may become more important in pediatric exercise science in future. While the activPAL, as used in this study, provided only measures of sedentary behavior and physical activity, it is able to provide more detailed information, for example evidence on breaks in sitting and bouts of sitting, and the number of sit-stand transitions. The relatively simple constructs of sedentary and active used with the activPAL in the current study would be sufficient for many purposes though, including surveillance of the adequacy of physical activity and sedentary behavior in preschool children .

Study Strengths and Limitations

The present study was the first application of the activPAL in free-living preschool children, and the first monitor comparison for the measurement of sedentary behavior in preschool children.

One limitation of the current study was that it is not clear whether Actigraph cut-points which were derived from the older 7164 model can be applied to the newer Actigraph models. At least one study has suggested that a correction for bias is desirable before cut-points based on the older model are applied but the evidence is not entirely consistent (2,9,22). As a result of these doubts the Actigraph output in the current study was treated both with and without the small correction for bias: this correction made little difference to group mean estimates of physical activity and sedentary behavior and did not alter the statistical significance of differences between the activPAL and Actigraph.

The present study used a construct of sedentary behavior with the Actigraph which was equivalent to time spent with no translocation of the trunk (and so included standing), based on prevous pediatric validation and calibration studies

which used direct observation (15,21). Sedentary behavior is a complex construct, and one which is still evolving (7,12). In the current study if 'sedentary' was defined from activPAL output as sitting and lying time only (i.e., not including 'quiet standing', standing with no stepping) mean percentage of time was much lower at 51.9% (*SD* 7.0). Some degree of difference in quantification of sedentary time between the two devices tested in the current study was inevitable, given the differences in location of the devices (activPAL placed on the thigh, Actigraph on the hip), and in the different definitions of sedentary behavior upon which the two devices were based (activpAL being designed to measure sitting, lying, and quiet standing; Actigraph being calibrated to measure no translocation of the trunk; 15). Choice of the most suitable monitor to measure sedentary behavior in young children should be informed by both the monitor characteristics and the construct of sedentary behavior or physical activity which is under consideration. At present no single monitor has been established for measurement of all aspects of sedentary behavior in children.

Conclusions

The present study suggests that the Actigraph and activPAL should provide estimates of daily time spent sedentary, and daily time spent in physical activity, which are broadly similar in young children on a group basis so long as sedentary behavior is defined on the basis of energy expenditure considerations (sitting and/or standing with no stepping) and not posture. However, the current study also suggests that activPAL and Actigraph differ when considered at the level of the individual child, and that even an apparently small difference might be important for some applications, such as population surveillance of physical activity and/or sedentary behavior.

References

1. Baggett, C.D., J. Stevens, D.J. Catellier, et al. Compensation or displacement of physical activity in middle school girls. *Int. J. Obes.* 34:1193–1199, 2010.
2. Corder, K., S. Brage, A. Ramachandran, C. Snehalatha, N. Wareham, and U. Ekelund. Comparison of two Actigraph models for assessing free-living physical activity in Indian adolescents. *J Sports Sci.* 25:1607–1611, 2007.
3. Davies, G, Reilly, J.J., McGowan, A.J., Dall, P.M., Granat, M.H., Paton, J.Y. Validity, practical utility, and reliability of the activPAL in pre-school children. *Med Sci Sports Exerc,* In Press.
4. Get up and Grow: Healthy eating and physical activity for early childhood. Australian Government Department of Health and Ageing 2010. www.health.gov.au/internet/main/publishing.nsf/Content (accessed 21 September 2010).
5. Grant, P.M., C.G. Ryan, W.W. Tigbe, and M.H. Granat. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br. J. Sports Med.* 40:992–997, 2006.
6. Godfrey, A., K.M. Culhane, and G.M. Lyons. Comparison of the performance of the activPAL professional physical activity logger to a discrete accelerometer based activity monitor. *Med. Eng. Phys.* 29:930–934, 2007.
7. Hamilton, M.T., D.G. Hamilton, D.W. Dunstan, T.W. Zderic, and N. Owen. Too little exercise and too much sitting: inactivity physiology and the need for new recommendations on sedentary behavior. *Curr Cardiovasc Risk Rep.* 2:292–298, 2008.

8. Hughes A.R., L. Stewart, J. Chapple, M. Donaldson, M. Zabihollah, S.F. Ahmed, C.H Kelnar et al. Randomized controlled trial of a best-practice, individualized, behavioral program or treatment of childhood overweight: Scottish Childhood Overweight Treatment Trial (SCOTT). *Pediatrics.* 21:e539–e546, 2008.
9. Kozey, S.L., H.J.W. Staudenmayer, R.P. Troiano, and P.S. Freedson. Comparison of Actigraph 7164 and Actigraph GTIM during self-paced locomotion. *Med. Sci. Sports Exerc.* 42:971–976, 2010.
10. Mattocks C., A. Ness, S.D. Leary, and C. Riddoch. Calibration of an accelerometer during free-living activities in children. *Int. J. Pediatr. Obes.* 2:218–227, 2007.
11. PAL Technologies Ltd. ActivPAL – Product Portfolio. http://www.paltech.plus.com/products.htm (accessed 29 September 2010).
12. Pate, R.R., J.R. O'Neill, and F. Lobelo. The evolving definition of "sedentary". *Exerc. Sport Sci. Rev.* 36:173–178, 2008.
13. Penpraze, V., J.J. Reilly, C.M. Maclean, et al. Monitoring of physical activity in young children: how much is enough? *Pediatr. Exerc. Sci.* 18:483–491, 2006.
14. Puyau, M.R., A.L. Adolph, F.A. Vohbra, and N.F. Butte. Validation and calibration of physical activity monitors in children. *Obes. Res.* 10:150–157, 2002.
15. Reilly, J.J., J. Coyle, L.A. Kelly, G.B. Burke, S. Grant, and J.Y. Paton. An objective method for measurement of sedentary behavior in 3-4 year olds. *Obes. Res.* 11:1155–1158, 2003.
16. Reilly, J.J., D.M. Jackson, C. Montgomery, et al. Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. *Lancet.* 363:211–212, 2004.
17. Reilly, J.J., L.A. Kelly, C. Montgomery, et al. Physical activity to prevent obesity in young children: cluster randomised controlled trial. *BMJ.* 333:1041–1044, 2006.
18. Reilly, J.J., V. Penpraze, J.K. Hislop, G. Davies, S. Grant, and J.Y. Paton. Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch. Dis. Child.* 93:614–619, 2008.
19. Reilly, J.J. Low levels of objectively measured physical activity level in pre-schoolers in child-care. *Med. Sci. Sports Exerc.* 42:502–507, 2010.
20. Rothney, M.P., G.A. Apher, Y. Song, and K.Y. Chen. Comparing the performance of three generations of Actigraph accelerometers. *J. Appl. Physiol.* 105:1091–1097, 2008.
21. Sirard, J.R., S.G. Trost, K.A. Pfeiffer, M. Dowda, and R.R. Pate. Calibration and evaluation of an objective measure of physical activity in pre-school childen. *J Phys Act Health.* 2:345–357, 2005.
22. Treuth, M.S., K. Schmitz, and D.J. Catellier. Defining accelerometer thresholds for activity intensities in adolescent girls. *Med. Sci. Sports Exerc.* 36:1259–1266, 2004.