Validity, Practical Utility, and Reliability of the *activ*PAL™ in Preschool Children

GWYNETH DAVIES[1], JOHN J. REILLY[2], AMY J. MCGOWAN[1], PHILIPPA M. DALL[3], MALCOLM H. GRANAT[3], and JAMES Y. PATON[1]

[1]School of Medicine, University of Glasgow, Glasgow, UNITED KINGDOM; [2]Physical Activity for Health Research Group, University of Strathclyde, Glasgow, UNITED KINGDOM; and [3]School of Health, Glasgow Caledonian University, Glasgow, UNITED KINGDOM

ABSTRACT

DAVIES, G., J. J. REILLY, A. J. MCGOWAN, P. M. DALL, M. H. GRANAT, and J. Y. PATON. Validity, Practical Utility, and Reliability of the *activ*PAL™ in Preschool Children. *Med. Sci. Sports Exerc.*, Vol. 44, No. 4, pp. 761–768, 2012. **Purpose**: With the increasing global prevalence of childhood obesity, it is important to have appropriate measurement tools for investigating factors (e.g., sedentary time) contributing to positive energy balance in early childhood. For preschool children, single-unit monitors such as the *activ*PAL™ are promising. However, validation is required because activity patterns differ from adults. **Methods**: Thirty preschool children participated in a validation study. Children undertaking usual nursery activity while wearing an *activ*PAL™ 1 h were recorded using a video camera. Video (criterion method) was analyzed on a second-by-second basis to categorize posture and activity. This was compared with the corresponding *activ*PAL™ output. In a subsequent substudy investigating practical utility and reliability, 20 children wore an *activ*PAL™ for seven consecutive 24-h periods. **Results**: A total of 97,750 s of direct observation from 30 children were categorized as sit/lie (46%), stand (35%), and walk (16%); with 3% of time in non–sit/lie/upright postures (e.g., crawl/crouch/kneel-up). Sensitivity for the overall total time-matched seconds detected as *activ*PAL™ "sit/lie" was 86.7%, specificity was 97.1%, and positive predictive value was 96.3%. For individual children, the median (interquartile range) sensitivity for *activ*PAL™ sit/lie was 92.8% (76.1%–97.4%), specificity was 97.3% (94.9%–99.2%), and positive predictive value was 97.0% (91.5%–99.1%). The *activ*PAL™ underestimated total time spent sitting (mean difference = −4.4%, $P < 0.01$) and overestimated time standing (mean difference = 7.1%, $P < 0.01$). There was no difference in overall percent time categorized as "walk" ($P = 0.2$). The monitors were well tolerated by children during a 7-d period of free-living activity. In the reliability study, at least 5 d of monitoring was required to obtain an intraclass correlation coefficient of ≥0.8 for time spent "sit/lie" according to *activ*PAL™ output. **Conclusions**: The *activ*PAL™ had acceptable validity, practical utility, and reliability for the measurement of posture and activity during free-living activities in preschool children.
Key Words: ACTIVITY MONITORING, POSTURE, CHILD, VALIDATION

In children younger than 5 yr, the worldwide prevalence of overweight and obesity increased from 4.2% in 1990 to 6.7% in 2010 and is forecast to increase further during the next decade (10). Childhood obesity is now recognized to be associated with significant morbidities (including cardiovascular disease and diabetes) and premature mortality in adulthood (13,29,35). Furthermore, children who are obese in early childhood are more likely to become obese adults (17). There is an increasing body of evidence that inactivity and sedentary behaviors are associated with obesity risk (12,19,20,23). Studies have often used surrogate measures such as self-report or subsets of sedentary behaviors such as time spent watching television to define this risk, although more recently, objective methods such as accelerometry have been used (12,18,19). The evidence from the adult literature suggests that, in addition to sedentary behavior, posture allocation is important to the energy balance equation and hence to risk of obesity and diabetes (23). It is therefore important that we have appropriate tools for measurement of physical activity and sedentary behaviors in early childhood so that we can appropriately evaluate their importance in the life-course accumulation of positive energy balance.

To date, no objective and practical posture detection methods have been validated in the preschool child. Previous accelerometer-based posture detection systems reported in the literature were often bulky and involved several different sensors, and their weight may have prohibited utility in a preschool population (7,23).

Address for correspondence: Gwyneth Davies, M.B.Ch.B., National Heart and Lung Institute, Emmanuel Kaye Building, 1b Manresa Rd., London SW3 6LR, United Kingdom; E-mail: gwyneth.davies1@imperial.ac.uk.
Submitted for publication June 2011.
Accepted for publication October 2011.

0195-9131/12/4404-0761/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e31823b1dc7

Single-unit sensors are potentially more useful for research involving young children. The *activ*PAL™ physical activity logger is a small, single-unit, lightweight physical activity monitor produced by PAL Technologies Ltd. (Glasgow, UK), which can record posture and activity during a 7-d period. The *activ*PAL™ has been validated for its ability to detect walking (15,34) and for posture detection in adults (15,16). No prior validation for posture determination has previously been undertaken in children. We considered a validation in young children important because of their highly transient movement patterns. Although little is known about the detailed pattern of activity undertaken by preschoolers, in children aged 6–10 yr, activity has been found to be characterized by short intermittent bouts of varying intensity, with an average duration of low/medium- and high-intensity activity of 6 and 3 s, respectively (3). Therefore, we did not expect that the validation results from adult subjects would necessarily be applicable to young children. We also considered it important that validation should be assessed in an environment usually encountered by the child.

The main aim of the present study was to validate the *activ*PAL™ for measurement of posture allocation against the gold standard of direct observation in preschool children in their usual nursery environment (the validation study). Secondary aims were to investigate the practical utility and reliability of the monitor for measurement of posture allocation in preschool children during a 7-d free-living period (practical utility and reliability studies).

METHODS

For the validation study, 32 children were recruited from three local nursery schools with $n = 17$, $n = 8$, and $n = 7$ in each. Because this was a methodological study, it was felt that a convenience sample of this sort, using local nursery schools, would be acceptable with recruitment from children in their preschool year. All data comparisons were made on 30 children in whom complete *activ*PAL™, and direct observation data were available. This convenience sample was estimated to be sufficient for validation based on similar validation studies involving children of comparable age (32).

In a separate sample of 20 children (none of whom had been involved in the validation study), we also conducted a practical utility and reliability study. For both studies, basic descriptive characteristics for each child including age, sex, height, and weight were recorded. Height and weight data were converted into SD scores (SDS) according to UK 1990 reference values (9,14).

Validation Study: Design and Methods

Each child wore an *activ*PAL™ monitor (35 × 53 × 7 mm, weight 20 g), with a PAL*stickies*™ gel pad used to attach the monitor to the right anterior thigh, midway between the hip and the knee in the midline. Video data were recorded using a Sony High Definition 4.0 Megapixel Handycam digital video camera (HDR-HC5, Tokyo, Japan), and 1 h of time-synchronized video recording was filmed for either a single child or two children undertaking their usual nursery activity while wearing the *activ*PAL™. During filming, the children's activity was not restricted in any way. No more than two children wore the monitors simultaneously because of monitor availability and, more importantly, for practical reasons regarding the feasibility of capturing observation data from multiple children at any one time. Data collection took place for different children throughout the normal nursery day and on different days to suit each of the three individual nurseries.

The *activ*PAL™ contains a uniaxial piezoresistive accelerometer and determines posture output from thigh inclination. Both the minimum sitting and the minimum upright times as detected by *activ*PAL™ were changed from the default of 10 s to 1 s in the present study (adjustable within the *activ*PAL™ Professional Research Edition software (Version 5.8.2.3) between 1 and 100 s). This reduction was undertaken because of our interest in capturing postures and posture transitions irrespective of their duration.

Posture and activity were recorded according to the time in seconds on the video clock at which they occurred, on a second-by-second basis. Videos were analyzed by a single observer. There was no minimum duration of any single posture. Where more than one posture occurred within an individual second, all were documented. Each second of direct observation data was summarized as sit, lie, stand, walk, "other," or off screen. Many postures did not easily fit within definitions of walk, stand, sit, or lie. These included a heterogeneous assortment of postures such as crouching down (squatting), kneeling up, crawling and other postures, which were difficult to describe and for which a diagram was used to record. All such postures were grouped and called "other." Any seconds during which the child was either off screen or obscured (e.g., by another child or furniture) were coded separately.

The *activ*PAL™ Professional Research Edition software classifies all data into one of the following categories: sit/lie, stand, and walk (this software also detects the number of steps taken and activity intensity, outcomes that were not included in this study). There is no "unknown" category for output. The .pal files generated by the *activ*PAL™ Professional Research Edition software were imported into HSC PAL analysis software (version 2.14) developed by Dr. Philippa Dall and Professor Malcolm Granat at Glasgow Caledonian University. This software allows detailed analysis of the *activ*PAL™ output as classified by the original *activ*PAL™ Professional Research Edition software by listing the time (in seconds) at which a change in output category (i.e., a transition) occurred. It does not alter the output category assigned by original analysis of the raw data by the *activ*PAL™ Professional software. Use of this software allowed comparison with time-matched video data for validation purposes.

Where two postures occurred within the same second, either for direct observation or *activ*PAL™ output, an artificial comparison "duplicate" second was generated at exactly the same time point in the corresponding *activ*PAL™ or video output summary. This ensured that all subsequent seconds continued to be appropriately time-matched.

To compare only time "on screen," the time-matched data from direct observation and *activ*PAL™ monitors were filtered to exclude any seconds when the direct observation data had been coded as obscured or off screen. For each category of interest (e.g., sit/lie, stand, walk), each second of monitor data was classified as either a true positive, false positive, or a false negative when compared to the time-matched data from direct observation. True positives were defined as all time-matched seconds when the monitor output category and the video observation category were identical. False positives were defined as those time-matched seconds in which the monitor output detected the category of interest, but this did not agree with direct observation. True negatives were all time-matched seconds correctly identified as not being the category of interest. False negatives were defined as all time-matched seconds not detected by the monitor as the category of interest despite being in this category according to direct observation.

Sensitivity, specificity, and positive predictive value (PPV) for each monitor output category were calculated for each child. In addition, the sums of time-matched seconds across all children according to each monitor output category were used to calculate the overall sensitivity, specificity, and PPV. Because direct observation categories were not identical with monitor output (because there is no *activ*PAL™ output "other"), specificity and PPV were calculated using two approaches; both including and excluding all seconds in direct observation "other" category.

Practical Utility and Reliability Studies: Design and Methods

Children wore an *activ*PAL™ monitor for seven consecutive days, 24 $h \cdot d^{-1}$. The monitor was sited and attached with a PAL*stickie* as described above. Parents were also provided with a Tegaderm™ dressing that could be placed over the monitor for additional security if they felt this was required. Parents were asked to remove the monitor before their child's bath time and reattach afterward. New PAL*stickies* and Tegaderms were provided for use on reattachment; it was recommended to parents to use a new PAL*stickie* daily. Removal before bathing or swimming was necessary as the *activ*PAL™ monitors used were not waterproof.

Practical utility. The percentage of missing or invalid data points during the 7-d period was calculated according to expected total time in conjunction with parental diary record of times of nonwear (e.g., bath time). Families were asked that children wear the monitors for 24-h periods (i.e., throughout both day and night).

To investigate perceived acceptability to families, a questionnaire was administered to parents at completion of the 7-d period. A five-point Likert scale was used to assess response to 10 statements relevant to practical utility: ranging from "strongly disagree" to "strongly agree," respectively. Potential problems with practical utility were identified by the responses "agree" or "strongly agree" with each statement.

Reliability. Intersubject and intrasubject variability was assessed during the 7-d period to calculate the duration of monitoring required to represent usual activity and posture allocation (31). Pairwise comparisons according to the proportion of time spent in *activ*PAL™ output sit/lie were made both within subjects across multiple days and between subjects. Intraclass correlation coefficients (ICC) for time spent in *activ*PAL™ output category sit/lie were used to determine the number of days required for reliability in terms of representing usual activity.

Statistics

Minitab (Version 15.1 English, State College, PA) statistical software was used to generate tally counts of individual variables and descriptive statistics for categorical variables. Minitab was also used for pairwise comparisons with general linear model (GLM) ANOVA (using the Tukey correction for multiple comparison), which adjusted for repeated-measures within subjects so the sums of squares in the GLM were correctly adjusted for the calculations in terms of the within- and between-subject variability. ICC were calculated according to conventional methodology using GLM ANOVA, with an ICC ≥ 0.80 indicating acceptable reliability (36). Bland–Altman analyses were performed using GraphPad Prism (Version 4.03) (4). For all statistical tests, $P < 0.05$ was considered significant.

Ethics

Ethical approval for the study was granted by the Faculty of Medicine Research Ethics Committee for the University of Glasgow. Written parental informed consent was obtained before child recruitment to the study. Verbal assent from the children before their data collection session was obtained after an explanation in age-appropriate language. Only children with no known impairment to mobility were included in the study.

RESULTS

Characteristics of study participants. Thirty children in the validation study provided adequate data for both direct observation and *activ*PAL™ accelerometry, with a mean age of 4.1 yr (range = 3.1–4.9 yr), or whom 66% were female. The mean SDS were 0.6 for height, 0.8 for weight, and 0.6 for body mass index (BMI). Three children had a BMI SDS >2; no child had a height, weight, or BMI SDS < −2.

In the separate sample ($n = 20$) recruited to the practical utility and reliability studies, the mean age was 4.4 yr (range = 3.2–4.9 yr), of whom 70% were female. One child had a BMI SDS >2, whereas none had a height, weight, or BMI SDS < −2.

Validation study. Cumulative *activ*PAL™ data for the 97,750 onscreen seconds on which comparisons with direct observation data were based categorized 40,755 s (42%) as sit/lie, 41,268 s (42%) as stand, and 15,727 s (16%) as walking. The corresponding direct observation data were sit/lie = 45,282 s (46%), stand = 34,092 s (35%), walk = 15,356 s (16%), and non–sit/lie/upright postures ("other") = 3020 s (3%). The median proportion of duplicate seconds (as a result of more than one posture within a single second) in comparison to real-time total seconds for the direct observation and *activ*PAL™ analyses was 0.15% per child (interquartile range (IQR) = 0.08%–0.32%).

Analyzed on an individual child basis, the median on-screen time spent in each *activ*PAL™ output category was 43.5% (IQR = 30.2%–50.9%) for sit/lie, 41.2% (IQR = 26.0%–53.2%) for stand, and 12.2% (IQR = 7%–21.6%) for walk. The direct observation data and *activ*PAL™ output for each child are represented graphically in Figure 1. The *activ*PAL™ underestimated total time spent sitting (mean difference = −4.4%; paired *t*-test, $P < 0.01$) and overestimated time standing (mean difference = 7.1%; paired *t*-test, $P < 0.01$). There was no difference in overall percent time categorized as "walk" ($P = 0.2$). Bland–Altman plots comparing the direct observation data with *activ*PAL™ output for each child are shown in Figure 2. The bias was not associated with the amount of time detected in each category ($r = -0.17$, $P = 0.4$ and $r = -0.03$, $P = 0.9$ for "sit/lie" and "stand," respectively).

Validation of *activ*PAL™ "sit/lie". For individual children, the median sensitivity for *activ*PAL™ sit/lie was 92.8% (IQR = 76.1%–97.4%, minimum = 44.7%), specificity was 97.3% (IQR = 94.9%–99.2%, minimum = 88.3%), and PPV was 97.0% (IQR = 91.5%–99.1%, minimum = 83.8%). Results for all children combined are summarized in Table 1, both including and excluding observation seconds categorized as "other." Excluding these "other" seconds, the median specificity increased to 99.5% (IQR = 98.9%–99.9%, minimum = 96%) and median PPV increased to 99.4% (IQR = 98.4%–99.8%, minimum = 91%).

Validation of *activ*PAL™ "stand". For individual children, the median sensitivity for *activ*PAL™ stand was 91.8% (IQR = 82.6%–96.6%, minimum = 70.0%), specificity was 86.5% (IQR = 75.6%–91.7%, minimum = 55.9%), and PPV was 70.4% (IQR = 61.2%–83.5%, minimum = 40.2%). In the same format as described above, results for all children combined are summarized in Table 1. When "other" seconds were not included, the median specificity was 87.9% (IQR = 78.1%–94.0%, minimum = 56.4%) and median PPV was 72.4% (IQR = 63.7%–86.9%, minimum = 42.7%).

Validation of *activ*PAL™ "walk". For individual children, the median sensitivity for *activ*PAL™ walk was 77.9% (IQR = 69.1%–86.9%, minimum = 46.9%), specificity was 96.5% (IQR = 93.7%–97.9%, minimum = 83.5%), and PPV was 73.4% (IQR = 68.0%–85.1%, minimum = 47.9%). As for sit/lie and stand, results for all children combined are

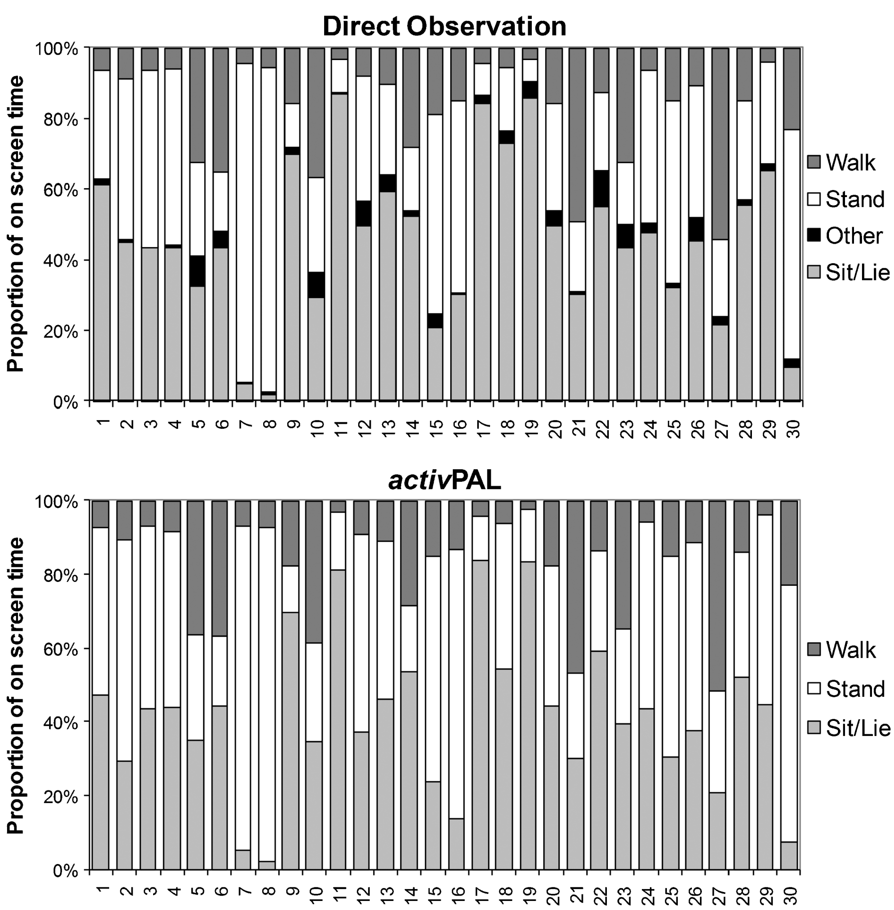

FIGURE 1—Proportion of on screen time according to direct observation (*top*) and *activ*PAL™ output category (*bottom*). Each individual child is represented by a *vertical bar* at the same corresponding number (nos. 1–30) on the *x*-axis.

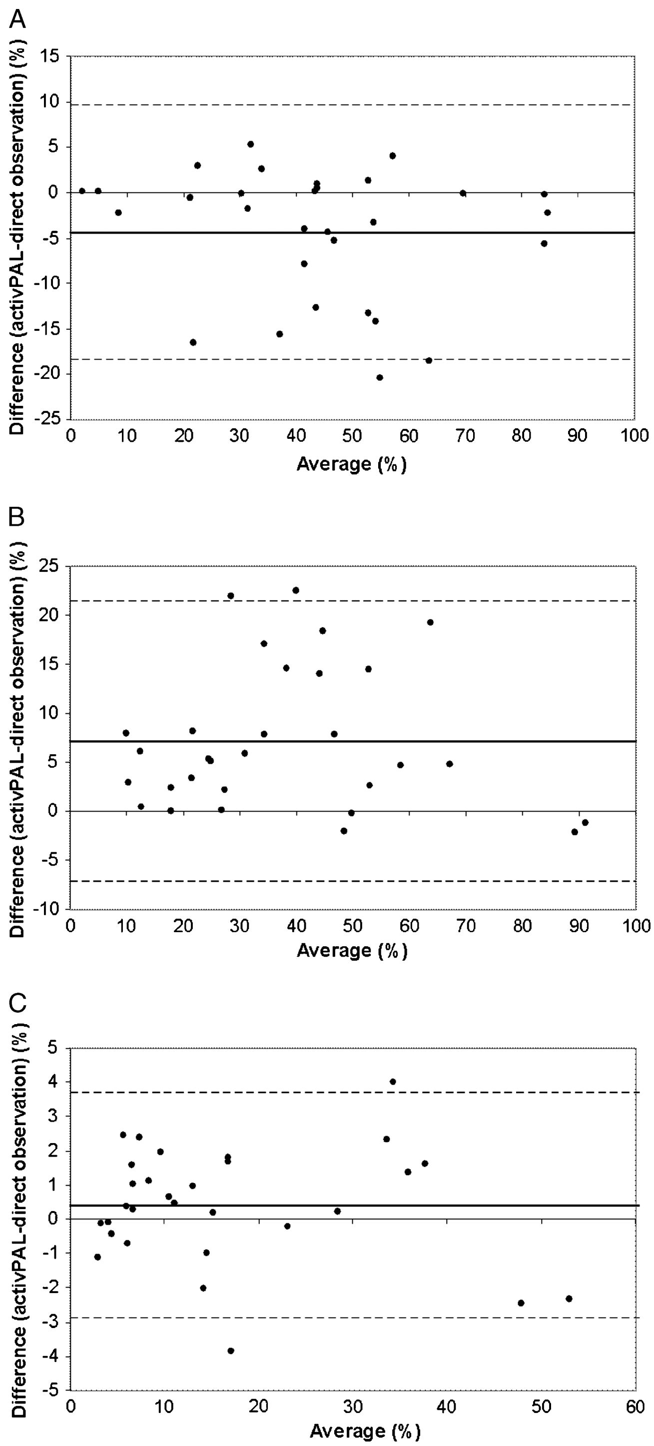

FIGURE 2—Agreement between proportion of time in *activ*PAL™ category and direct observation category. Bland–Altman plots are shown for *activ*PAL™ and direct observation sit/lie (A), stand (B), and walk (C). Each child is represented by a single data point on each graph. Mean bias is represented by a *solid line*; 95% limits of agreement, *dashed lines*.

summarized in Table 1. When "other" seconds were not included in calculations, the median specificity was 96.7% (IQR = 94.4%–98.1%, minimum = 84.8%) and median PPV was 77.6% (IQR = 69.2%–87.0%, minimum = 52.1%).

Direct observation "other". As stated previously, the *activ*PAL™ has no unknown category for output, and therefore, all data were categorized as sit/lie, stand, or walk. Because overall only a low total proportion of time was spent in "other" postures, their impact on sensitivity, specificity, and PPV was relatively small (Table 1). The *activ*PAL™ output for all children (n = 6) with >5% of the direct observation period in postures categorized as "other" (e.g., crawl, crouch, kneel up) demonstrated that "kneel up" was most often classified by the *activ*PAL™ as stand; and "crouch," as sit/lie. Crawl was categorized by a combination of stand and walk output and rarely by the output of sit/lie. The observed seconds that required a diagram to define were categorized as a combination of all three outputs, reflecting the heterogeneity of posture and activity comprising this group.

Practical utility. In total, with 20 children asked to wear the monitor for seven consecutive periods of 24 h, 86 h of monitoring was identified as missing according to parental log sheets (mean of 4.3 h per child during entire 7-d measurement period). These periods were accounted for by the total weekly times attributed by parental report to bath time or swimming, with the additional exception of one subject in whom the monitor was documented as having detached from the leg at night on three separate occasions. Monitor output identified a further 120 h of missing data (mean of 6 h per child), giving a total of 206 h of data loss. This represented 6.1% of the potential maximum monitored time (3360 h)—equivalent to 10.3 h of missing data per participant per week.

Responses to the five-point Likert scale statements are shown in Table 2. Overall, the responses supported the practicality of using the *activ*PAL™ in these preschool children. In addition, one parent reported that they had stopped using the overlying Tegaderm dressing because it was uncomfortable for their child.

Reliability. Using GLM ANOVA with correction for multiple comparisons, no significant differences in sit/lie time between different days of the week were detected (P = 0.707). GLM ANOVA also assessed the differences in proportion of sit/lie time between subjects (r^2 (adj) = 69.39%, P < 0.0001). Between-subject variability was far greater than within-subject variability. The mean ± SD proportion of time (for each 24-h period) detected by activPAL™ as sit/lie was 75.8% ± 6.9%. The mean within-subject SD for day-to-day variability in percent time spent "sit/lie" was 3.8% (range = 1.7%–6.5%).

ICC for sit/lie time (%) were calculated for monitoring periods of 2–7 d in duration (Table 3). The 95% confidence intervals of ICC ≥0.8 for sit/lie time (%) were achieved with five or more days of monitoring (95% CI (ICC for 5 d) = 0.80–0.99).

DISCUSSION

The present studies show that the *activ*PAL™ can objectively capture posture and activity in preschool children

SPECIAL COMMUNICATIONS

TABLE 1. Results of *activ*PAL™ validation against direct observation.

	True Positives (s)	True Negatives (s)	False Positives (s)	False Negatives (s)	Sensitivity (%)	Specificity (%)	PPV (%)
*activ*PAL output (including all observation "other" seconds)							
Sit/lie	39,257	50,970	1498	6025	86.7	97.1	96.3
Stand	31,297	53,687	9971	2795	91.8	84.3	75.8
Walk	12,329	78,998	3398	3025	80.3	95.9	78.4
*activ*PAL output (excluding all observation "other" seconds)							
Sit/lie	39,257	49,062	386	6025	86.7	99.2	99.0
Stand	31,297	52,110	8528	2795	91.8	85.9	78.6
Walk	12,329	76,443	2933	3025	80.3	96.3	80.8

Shown are total combined seconds in each *activ*PAL output category and comparison with observation data, for all children in the validation study.

successfully. We found the practical utility of the device in free-living young children encouraging, and our data support its use in this population.

Our results compare well with the adult activPAL™ validation study, which used direct observation (16), particularly considering children were filmed in their free-living nursery environment. The sensitivity for *activ*PAL™ sit/lie reported by Grant et al. (16) was 99.4% (predictive value = 99.5%), that for standing was 84.9% (predictive value = 88%), and that for walking was 67.4% (predictive value = 63.7%) during the "activities of daily living" validation component of the study, in which adult subjects were asked to perform a set range of common activities and tasks (16). We found a wide range in degree of agreement between *activ*PAL™ and direct observation between individual children. Whereas for some children the *activ*PAL™ monitor was excellent at detecting time spent in different postures, for a limited number of children, there was sometimes substantial mismatch; for example, when time spent sitting was misclassified as standing. Thus, it is important to calculate not only the overall sensitivity, specificity, and PPV for each monitor output category but also the range between children to provide an impression of variation between individuals.

The most appropriate monitoring system for objectively measuring postural information in a free-living situation in young children will depend on several factors: the specific population, the intended setting for use, and the practical utility of the monitoring system itself. We wanted to investigate the *activ*PAL™ because of the likely potential limitations of multiunit monitors in free-living young children (22,25). Simple, lightweight, noncumbersome measuring systems that do not interrupt usual activity and can be worn continuously are likely to be preferable.

In the present study, we used direct observation as the criterion method with all postures and activity categorized on a second-by-second basis. Although laborious, this enabled a detailed account of activity during the observation period. Validation of activity monitors capable of detecting posture has largely been undertaken by documentation of posture and activity in real time by an observer or on video recordings, without the use of particular reference scales beyond simple definitions of; for example, sitting. Body position is often summarized into limited categories that can generally be classified as "up" (walk or stand) and "down" (sit and lie), in order that outcomes such as the number of sit-to-stand transitions or time spent sitting can be quantified. However, as our results show, it may be important to be able to quantify a wider group of postures by direct observation during validation studies involving young children. The non–sit/lie, stand, or walk postures created the greatest challenge during our validation. We grouped these postures under the global term "other," representing those seconds identified as crouch (squat), kneel up, crawl, and other (those that required a diagram to define) in one heterogeneous category. This category was considered necessary because certain postures, for example, kneel up, could not, in our opinion, be placed comfortably within a definition of either sit or stand. However, by keeping this category separate, it meant a comparison of a different total number of categories between the *activ*PAL™ and direct observation. We therefore analyzed the data both including and excluding any direct observation data coded as "other." Both were undertaken to reflect the influence this has on sensitivity, specificity, and PPV.

There is currently little recognition of all these "in-between" postures (e.g., kneel up) and no consensus regarding their acceptable summary classification or the acceptability of error created by misclassification. However, by using detailed direct observation data, it will be possible to determine whether a single-unit monitor for posture detection can ever be capable of collecting the complete array of activities performed by

TABLE 2. Practical utility questionnaire parental responses.

	Likert Scale Response (*n* (%))				
Statement	Strongly Disagree	Disagree	Some	Agree	Strongly Agree
The *activ*PAL™ monitor interfered with normal day-to-day activities	6 (30)	9 (45)	5 (25)	0 (0)	0 (0)
The *activ*PAL™ monitor interfered with my child's day to day activity	6 (30)	8 (40)	6 (30)	0 (0)	0 (0)
The length of study—7 d—was too long and caused problems	5 (25)	6 (30)	7 (35)	2 (10)	0 (0)
The monitor being worn for the 24-h period caused problems	5 (25)	5 (25)	9 (45)	1 (5)	0 (0)
The *activ*PAL™ was uncomfortable to wear (including attaching and removing monitor)	4 (20)	7 (35)	7 (35)	1 (5)	1 (5)
The *activ*PAL™ was painful to wear (including attaching and removing monitor)	8 (40)	7 (35)	5 (25)	0 (0)	0 (0)
A lot of input was required to ensure the monitor was kept on correctly	4 (20)	10 (50)	6 (30)	0 (0)	0 (0)
Attaching the monitor correctly was difficult	7 (35)	10 (50)	3 (15)	0 (0)	0 (0)
I would not agree to have my child wear the monitor again based on this experience	7 (35)	10 (50)	3 (15)	0 (0)	0 (0)
My child would not agree to wear the monitor again based on this experience	6 (30)	10 (50)	3 (15)	0 (0)	1 (5)

TABLE 3. ICC for *activ*PAL™ "sit/lie" output according to duration of monitoring.

Length of Monitoring (No. 24-h periods)	ICC	95% CI for ICC
2	0.37	0.11–0.67
3	0.53	0.30–0.75
4	0.87	0.73–0.94
5	0.89	0.80–0.99[a]
6	0.92	0.84–0.96[a]
7	0.93	0.87–0.97[a]

[a] ICC of ≥0.8, usually interpreted as an acceptable reliability in accelerometry studies.

young children or indeed whether it is necessary or meaningful to do so. Thus, we suggest that for validation studies, particularly in children, it is important to include direct observation strategies that have the potential to capture unusual body positions irrespective of the duration that this posture may be sustained for.

Where postural misclassifications between monitor output categories (e.g., sit and stand) occurred during validation in the current study, they were often as a result of sitting being identified by the *activ*PAL™ as standing. This occurred in particular when children sat at the front of their chair with thighs hanging down and knees toward the floor, or over the side of a chair with one leg in a "normal" sitting position with thigh horizontal, knee bent at 90°, and foot on floor and the other leg over the side of the chair with thigh hanging down. This resulted in an overestimation of *activ*PAL™ defined standing time and underestimation of sitting. Occasionally, standing was misidentified by the *activ*PAL™ as sitting, for example, if a child stood with one leg straight and one bent at the knee with the foot resting on top of the other foot, thereby altering thigh inclination.

Apart from the *activ*PAL™, few other single-unit posture detecting activity monitors have been described in the literature to date (5,21,27), and there are no published validation studies involving young children for single-unit systems. Multiunit devices are more common with several multiunit accelerometer-based systems reported in the literature (1,2, 6–8,11,22–24,28,30,37–40), often published with impressive validity statistics undertaken in controlled laboratory settings. Such monitors have largely been validated in adult subjects, although several have been validated in school age children (6,22). Robust field validation studies in free-living subjects are commonly lacking, particularly in childhood. A balance exists between the acceptability and utility of activity monitors capable of capturing posture against the ability to discriminate postures accurately. Increasing the number and site of body sensors generally increases the ability to detect postural allocation accurately and increases the number of categories that can be identified.

The choice of the child's usual nursery environment and undertaking usual nursery activity in the present validation study was an attempt to simulate usual activity. This approach has been considered useful in previous accelerometry validations in nursery (32). Interestingly, the overall average proportion of time spent sedentary in the sample of children in the validation component of the present study was similar to larger studies, which have measured total time spent sedentary using accelerometers and activity monitors in the free-living environment (26,33), and to the practical utility component of this study (although notably, we also included nighttime data). We were encouraged by the parental responses to the questions about the practical utility and of the relatively low degree of data loss. It was recognized that periods of data loss in the practical utility study often reflected the parent/guardian forgetting to reattach monitor after removal for bath time.

There are several limitations to this study. Children do not spend all their time at the nursery, and therefore, it is possible that the range and characteristics of movement undertaken beyond the nursery environment differ to those observed within the validation study. In the reliability study, children wore the monitors during a single 7-d period, and therefore although this allowed day-to-day variability in *activ*PAL™ output to be determined, it could not give any information about week-to-week variability that would be important when comparing interventions longitudinally over time. Furthermore, the proportion of time detected as "sit/lie" was calculated during 24-h periods and an assessment of awake time (e.g., according to parental diary) would have been a useful addition to determine awake time sedentary behavior and activity patterns.

In summary, the results of the present studies suggest that the *activ*PAL™ has acceptable validity, practical utility, and reliability for the measurement of posture allocation in preschool children. The *activ*PAL™ can also measure related concepts such as breaks in sedentary time and posture transitions, but these were beyond the scope of this article. Although variation in posture allocation seems to be important to the risk of obesity and cardiometabolic disease in adults, it is not yet clear to what extent investigating posture allocation objectively in early childhood will be helpful in understanding the development of adverse health outcomes in later life. However, such investigations in the future will only be possible with the advent of valid, practical, and reliable single-unit measurement systems.

One of the authors (Malcolm Granat) is a coinventor of the *activ*PAL™ physical activity monitor and a director of PAL Technologies Ltd. However, he was not involved in data collection or the statistical analysis of the results.

The remaining authors declare no competing interests.

The authors did not receive funding for this study.

The authors thank Dr. David Young, Department of Statistics and Modelling Science, University of Strathclyde, for his statistical advice.

The results of this study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Aminian K, Robert P, Buchser EE, Rutschmann B, Hayoz D, Depairon M. Physical activity monitoring based on accelerometry: validation and comparison with video observation. *Med Biol Eng Comput*. 1999;37(3):304–8.

2. Arvidsson D, Slinde F, Nordenson A, Larsson S, Hulthen L. Validity of the ActiReg system in assessing energy requirement in chronic obstructive pulmonary disease patients. *Clin Nutr*. 2006;25(1):68–74.
3. Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc*. 1995;27(7):1033–41.
4. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1(8476):307–10.
5. Bliley KE, Schwab DJ, Zahn SK, et al. Design of posture and activity detector (PAD). *Conf Proc IEEE Eng Med Biol Soc*. 2007;2659–63.
6. Busser HJ, Ott J, van Lummel RC, Uiterwaal M, Blank R. Ambulatory monitoring of children's activity. *Med Eng Phys*. 1997;19(5):440–5.
7. Bussmann JB, Martens WL, Tulen JH, Schasfoort FC, van den Berg-Emons HJ, Stam HJ. Measuring daily behavior using ambulatory accelerometry: the Activity Monitor. *Behav Res Methods Instrum Comput*. 2001;33(3):349–56.
8. Bussmann JB, Tulen JH, van Herel EC, Stam HJ. Quantification of physical activities by means of ambulatory accelerometry: a validation study. *Psychophysiology*. 1998;35(5):488–96.
9. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. *Arch Dis Child*. 1995;73(1):25–9.
10. de Onis M, Blossner M, Borghi E. Global prevalence and trends of overweight and obesity among preschool children. *Am J Clin Nutr*. 2010;92(5):1257–64.
11. Foerster F, Fahrenberg J. Motion pattern and posture: correctly assessed by calibrated accelerometers. *Behav Res Methods Instrum Comput*. 2000;32(3):450–7.
12. Ford ES, Kohl HW III, Mokdad AH, Ajani UA. Sedentary behavior, physical activity, and the metabolic syndrome among U.S. adults. *Obes Res*. 2005;13(3):608–14.
13. Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. *N Engl J Med*. 2010;362(6):485–93.
14. Freeman JV, Cole TJ, Chinn S, Jones PR, White EM, Preece MA. Cross sectional stature and weight reference curves for the UK, 1990. *Arch Dis Child*. 1995;73(1):17–24.
15. Godfrey A, Culhane KM, Lyons GM. Comparison of the performance of the *activ*PAL professional physical activity logger to a discrete accelerometer-based activity monitor. *Med Eng Phys*. 2007;29(8):930–4.
16. Grant PM, Ryan CG, Tigbe WW, Granat MH. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br J Sports Med*. 2006;40(12):992–7.
17. Guo SS, Wu W, Chumlea WC, Roche AF. Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *Am J Clin Nutr*. 2002;76(3):653–8.
18. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003–06. *Eur Heart J*. 2011;32(5):590–7.
19. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *JAMA*. 2003;289(14):1785–91.
20. Jackson DM, Djafarian K, Stewart J, Speakman JR. Increased television viewing is associated with elevated body fatness but not with lower total energy expenditure in children. *Am J Clin Nutr*. 2009;89(4):1031–6.
21. Langer D, Gosselink R, Sena R, Burtin C, Decramer M, Troosters T. Validation of two activity monitors in patients with COPD. *Thorax*. 2009;64(7):641–2.
22. Lanningham-Foster LM, Jensen TB, McCrady SK, Nysse LJ, Foster RC, Levine JA. Laboratory measurement of posture allocation and physical activity in children. *Med Sci Sports Exerc*. 2005;37(10):1800–5.
23. Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. *Science*. 2005;307(5709):584–6.
24. Lyons GM, Culhane KM, Hilton D, Grace PA, Lyons D. A description of an accelerometer-based mobility monitoring technique. *Med Eng Phys*. 2005;27(6):497–504.
25. Mackey AH, Hewart P, Walt SE, Stott NS. The sensitivity and specificity of an activity monitor in detecting functional activities in young people with cerebral palsy. *Arch Phys Med Rehabil*. 2009;90(8):1396–401.
26. Martin A, McNeill M, Penpraze V, et al. Objective measurement of habitual sedentary behavior in pre-school children: comparison of *activ*PAL with ActiGraph monitor. *Pediatr Exerc Sci*. 2011;23(4):468–76.
27. Mathie MJ, Celler BG, Lovell NH, Coster AC. Classification of basic daily movements using a triaxial accelerometer. *Med Biol Eng Comput*. 2004;42(5):679–87.
28. Najafi B, Aminian K, Paraschiv-Ionescu A, Loew F, Bula CJ, Robert P. Ambulatory system for human motion analysis using a kinematic sensor: monitoring of daily physical activity in the elderly. *IEEE Trans Biomed Eng*. 2003;50(6):711–23.
29. Owen CG, Whincup PH, Orfei L, et al. Is body mass index before middle age related to coronary heart disease risk in later life? Evidence from observational studies. *Int J Obes (Lond)*. 2009;33(8):866–77.
30. Paraschiv-Ionescu A, Buchser EE, Rutschmann B, Najafi B, Aminian K. Ambulatory system for the quantitative and qualitative analysis of gait and posture in chronic pain patients treated with spinal cord stimulation. *Gait Posture*. 2004;20(2):113–25.
31. Penpraze V, Reilly JJ, Maclean C, et al. Monitoring of physical activity in young children: how much is enough? *Pediatr Exerc Sci*. 2006;18:483–91.
32. Reilly JJ, Coyle J, Kelly L, Burke G, Grant S, Paton JY. An objective method for measurement of sedentary behavior in 3- to 4-year olds. *Obes Res*. 2003;11(10):1155–8.
33. Reilly JJ, Jackson DM, Montgomery C, et al. Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. *Lancet*. 2004;363(9404):211–2.
34. Ryan CG, Grant PM, Tigbe WW, Granat MH. The validity and reliability of a novel activity monitor as a measure of walking. *Br J Sports Med*. 2006;40(9):779–84.
35. Steinberger J, Moran A, Hong CP, Jacobs DR Jr, Sinaiko AR. Adiposity in childhood predicts obesity and insulin resistance in young adulthood. *J Pediatr*. 2001;138(4):469–73.
36. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc*. 2005;37(suppl 11):S531–43.
37. Uiterwaal M, Glerum EB, Busser HJ, van Lummel RC. Ambulatory monitoring of physical activity in working situations, a validation study. *J Med Eng Technol*. 1998;22(4):168–72.
38. van den Berg-Emons HJ, Bussmann JB, Balk AH, Stam HJ. Validity of ambulatory accelerometry to quantify physical activity in heart failure. *Scand J Rehabil Med*. 2000;32(4):187–92.
39. White DK, Wagenaar RC, Ellis T. Monitoring activity in individuals with Parkinson disease: a validity study. *J Neurol Phys Ther*. 2006;30(1):12–21.
40. Zhang K, Werner P, Sun M, Pi-Sunyer FX, Boozer CN. Measurement of human daily physical activity. *Obes Res*. 2003;11(1):33–40.