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Validity, Practical Utility and Reliability of the *Activ*pal in Pre-School Children

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ABSTRACT

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 pre-school children, single unit monitors such as the *activ*PAL™ are promising. However, validation is required as activity patterns differ from adults. **Methods:** Thirty pre-school children participated in a validation study. Children were videoed for one hour undertaking usual nursery activity while wearing an *activ*PAL™. Video (criterion method) was analyzed on a second-by-second basis to categorise posture and activity. This was compared with the corresponding *activ*PAL™ output. In a subsequent sub-study investigating practical utility and reliability, 20 children wore an *activ*PAL™ for seven consecutive 24-hour periods. **Results:** A total of 97,750 seconds of direct observation from 30 children were categorized as sit/lie (46%), stand (35%), 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 97.1%, and positive predictive value (PPV) 96.3%. For individual children, the median (interquartile range) sensitivity for *activ*PAL™ sit/lie was 92.8% (76.1-97.4), specificity 97.3% (94.9-99.2), PPV 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 % time categorised as 'walk' ($p=0.2$). The monitors were well tolerated by children during a seven day period of free-living activity. In the reliability study, at least five days of monitoring were required to obtain an intraclass correlation coefficient of ≥0.8 for time spent sit/lie according to *activ*PAL™ output. **Conclusion:** The *activ*PAL™ had acceptable

validity, practical utility, and reliability for the measurement of posture and activity during free-living activities in pre-school children.

Keywords: Activity monitoring, posture, child, validation

Introduction

Paragraph number 1 In children under five, the worldwide prevalence of overweight and obesity increased from 4.2% in 1990 to 6.7% in 2010 and is forecast to increase further over the next decade (10). Childhood obesity is now recognised 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 has 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 behaviours in early childhood in order that we can appropriately evaluate their importance in the life-course accumulation of positive energy balance.

Paragraph number 2 To date, no objective and practical posture detection methods have been validated in the pre-school child. Previous accelerometer-based posture detection systems reported in the literature were often bulky, involved several different sensors and their weight may have prohibited utility in a pre-school population (7,23).

Paragraph number 3 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 over a seven day 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 due to their highly transient movement patterns. Although little is known about the detailed pattern of activity undertaken by pre-schoolers, in children aged 6-10 years activity has been found to be characterised by short intermittent bouts of varying intensity, with an average duration of low/medium and high intensity activity of six seconds and three seconds 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.

Paragraph number 4 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 pre-school 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 pre-school children during a seven day free-living period (practical utility and reliability studies).

Methods

Paragraph number 5 For the validation study, 32 children were recruited from three local nursery schools with an n of 17, 8, and 7 in each. As 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 pre-school 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).

Paragraph number 6 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 standard deviation scores according to UK 1990 reference values (9,14).

Validation study: design and methods

Paragraph number 7 Each child wore an *activ*PAL™ monitor (35 x 53 x 7mm, weight 20g), 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) and one hour of time-synchronized video recording was filmed for either a single child or two children undertaking their usual nursery activity whilst 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.

Paragraph number 8 The *activ*PAL™ contains a uni-axial piezoresistive accelerometer and determines posture output on the basis of thigh inclination. Both the minimum sitting and minimum upright time as detected by *activ*PAL™ was changed from the default of 10 seconds to one second in the present study (adjustable within the *activ*PAL™ Professional Research Edition software (Version 5.8.2.3) between 1 to 100 seconds). This reduction was undertaken because of our interest in capturing postures and posture transitions irrespective of their duration.

Paragraph number 9 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 analysed 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 summarised 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 referred to as 'other'. Any seconds during which the child was either off screen or obscured (e.g. by another child or furniture) were coded separately.

Paragraph number 10 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.

Paragraph number 11 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.

Paragraph number 12 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.

Paragraph number 13 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 to monitor output (as there is no *activ*PAL™ output 'other'), specificity and PPVs were calculated using two approaches; both including and excluding all seconds in direct observation 'other' category.

Practical Utility and Reliability studies: design and methods

Paragraph number 14 Children wore an *activ*PAL™ monitor for seven consecutive days, 24 hours a day. The monitor was sited and attached with a PAL*stickie* as described above. Parents were also provided with a Tegaderm™ dressing which could be placed over the monitor for additional security if they felt this was required. Parents were asked to remove the monitor prior to their child's bathtime, and re-attach afterwards. New PAL*stickies* and Tegaderms were provided for use on re-attachment; it was recommended to parents to use a new PAL*stickie* daily. Removal prior to bathing or swimming was necessary as the *activ*PAL™ monitors used were not waterproof.

Practical Utility

Paragraph number 15 The percentage of missing or invalid data points over the seven day period was calculated according to expected total time in conjunction with parental diary record of times of non-wear e.g. bath time. Families were asked that children wear the monitors for 24-hour periods, i.e. throughout both day and night.

Paragraph number 16 To investigate perceived acceptability to families, a questionnaire was administered to parents at completion of the seven day period. A five-point Likert scale was used to assess response to ten 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

Paragraph number 17 Inter- and intra-subject variability was assessed over the seven day period to calculate the duration of monitoring required in order to represent usual activity and posture allocation (31). Pair-wise 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. Intra-class 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

Paragraph number 18 Minitab (Version 15.1 English) statistical software was used to generate tally counts of individual variables, and descriptive statistics for categorical variables. Minitab was also used for pair-wise comparisons with General Linear Model (GLM) ANOVA (using Tukey's 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. ICCs were calculated according to conventional methodology using GLM ANOVA, with an ICC $\geq$0.80 indicating acceptable reliability (36).

Bland Altman analyses were performed using GraphPad Prism (Version 4.03) (4). For all statistical tests a p value of <0.05 was considered significant.

Ethics

Paragraph number 19 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 prior to child recruitment to the study. Verbal assent from the children prior to their data collection session was obtained following an explanation in age appropriate language. Only children with no known impairment to mobility were included in the study.

Results

Characteristics of study participants

Paragraph number 20 Thirty children in the validation study provided adequate data for both direct observation and *activ*PAL™ accelerometry, with a mean age of 4.1 years (range 3.1 to 4.9 years), 66% female. The mean standard deviation scores (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.

Paragraph number 21 In the separate sample (n=20) recruited to the practical utility and reliability studies the mean age was 4.4 years (range 3.2 – 4.9 years), 70% female. One child had a BMI SDS >2 while none had a height, weight or BMI SDS < -2.

Validation study

Paragraph number 22 Cumulative *activ*PAL™ data for the 97,750 on-screen seconds on which comparisons with direct observation data were based categorised 40,755 (42%) seconds as sit/lie, 41,268 (42%) as stand, and 15,727 (16%) as walking. The corresponding direct observation data was sit/lie 45,282 seconds (46%), stand 34,092 seconds (35%), walk 15,356 seconds (16%), and 3,020 seconds (3%) spent in non-sit/lie/upright postures ('other'). The median proportion of duplicate seconds (as a result of >1 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%).

Paragraph number 23 Analysed 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 is 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 % time categorised 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'

Paragraph number 24 For individual children, the median sensitivity for *activ*PAL™ sit/lie was 92.8% (IQR 76.1-97.4%, minimum 44.7%), specificity 97.3% (IQR 94.9-99.2%, minimum 88.3%), and positive predictive value 97.0% (IQR 91.5-99.1%, minimum 83.8%). Results for all children combined are summarised in table 1, both including and excluding observation seconds categorised as 'other'. Excluding these 'other' seconds the median specificity increased to 99.5% (IQR 98.9-99.9%, minimum 96%) and median positive predictive value 99.4% (IQR 98.4-99.8, minimum 91%).

Validation of *activ*PAL™ 'Stand'

Paragraph number 25 For individual children, the median sensitivity for *activ*PAL™ stand was 91.8% (IQR 82.6-96.6%, minimum 70.0%), specificity 86.5% (IQR 75.6-91.7%, minimum 55.9%), and positive predictive value 70.4% (IQR 61.2-83.5%, minimum 40.2%). In the same format as described above, results for all children combined are summarised 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 positive predictive value 72.4% (IQR 63.7-86.9, minimum 42.7%).

Validation of *activ*PAL™ 'Walk'

Paragraph number 26 For individual children, the median sensitivity for *activ*PAL™ walk was 77.9% (IQR 69.1-86.9%, minimum 46.9%), specificity 96.5% (IQR 93.7-97.9%, minimum 83.5%), and positive predictive value 73.4% (IQR 68.0-85.1%, minimum 47.9%). As for sit/lie and stand results for all children combined are summarised 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 positive predictive value 77.6% (IQR 69.2-87.0, minimum 52.1%).

Direct observation 'other'

Paragraph number 27 As stated previously, the *activ*PAL™ has no unknown category for output, and therefore all data were categorised as either 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 positive predictive values was relatively small (table 1). The *activ*PAL™ output for all children (n=6) with >5% of the direct observation period in postures categorised as 'other' (e.g. crawl, crouch, kneel up etc) demonstrated that 'kneel up' was most often classified by the *activ*PAL™ as stand, and 'crouch' as sit/lie. Crawl was categorised 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 categorised as a combination of all three outputs, reflecting the heterogeneity of posture and activity comprising this group.

Practical utility

Paragraph number 28 In total, with 20 children asked to wear the monitor for seven consecutive periods of 24 hours, 86 hours of monitoring were identified as missing according to parental log sheets (mean 4.3 hours per child over entire seven day 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 hours of missing data (mean six hours per child), giving a total of 206 hours of data loss. This represented 6.1% of the potential maximum monitored time (3360 hours); equivalent to 10.3 hours of missing data per participant per week.

Paragraph number 29 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 pre-school children. Additionally, one parent reported that they had stopped using the overlying Tegaderm dressing because it was uncomfortable for their child.

Reliability

Paragraph number 30 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%; $p < 0.0001$). Variability between the subjects was far greater than within-subject variability. The mean (SD) proportion of time (for each 24 hour period) detected by *activ*PAL™

as sit/lie was 75.8 (6.9)%. The mean within-subject standard deviation for day-to-day variability in % time spent 'sit/lie' was 3.8% (range 1.7 -6.5%).

Paragraph number 31 ICCs for sit/lie time (%) were calculated for monitoring periods of 2 – 7 day duration (Table 3). 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 days, 0.80-0.99).

Discussion

Paragraph number 32 The present studies show that the *activ*PAL™ can objectively capture posture and activity in pre-school children successfully. We found the practical utility of the device in free-living young children encouraging and our data supports its use in this population.

Paragraph number 33 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 was 99.4% (predictive value 99.5%), standing 84.9% (predictive value 88%) and for walking 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, e.g. when time spent sitting was misclassified as standing. Thus it is important to not only calculate the overall sensitivity, specificity and positive predictive value for each monitor output category but also the range between children to provide an impression of variation between individuals.

Paragraph number 34 The most appropriate monitoring system for objectively measuring postural information in a free-living situation in young children will depend on a number of 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 multi-unit monitors in free-living young children (22,25). Simple, lightweight, non-cumbersome measuring systems that do not interrupt usual activity and can be worn continuously are likely to be preferable.

Paragraph number 35 In the present study we used direct observation as the criterion method with all postures and activity categorised on a second by second basis. Although laborious, this enabled a detailed account of activity over 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 e.g. sitting. Body position is often summarised into limited categories that can generally be classed 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 analysed 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 positive predictive values.

Paragraph number 36 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 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.

Paragraph number 37 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 degrees, 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.

Paragraph number 38 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. Multi-unit devices are more common with several multi unit 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.

Paragraph number 39 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 night time 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 recognised that periods of data loss in the practical utility study often reflected the parent/guardian forgetting to reattach monitor after removal for bath-time.

Paragraph number 40 There are several limitations to this study. Children do not spend all their time at 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 over a single seven day 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 over 24 hour periods and an assessment of awake time (e.g. according to parental diary) would have been a useful addition to determine awake-time sedentary behaviour and activity patterns.

Paragraph number 41 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 pre-school 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 paper. While variation in posture allocation appears to be important to risk of obesity and cardio-metabolic 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 future will only be possible with the advent of valid, practical, and reliable single unit measurement systems.

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Conflict of interest: One of the authors, Professor Malcolm Granat, is a co-inventor 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.

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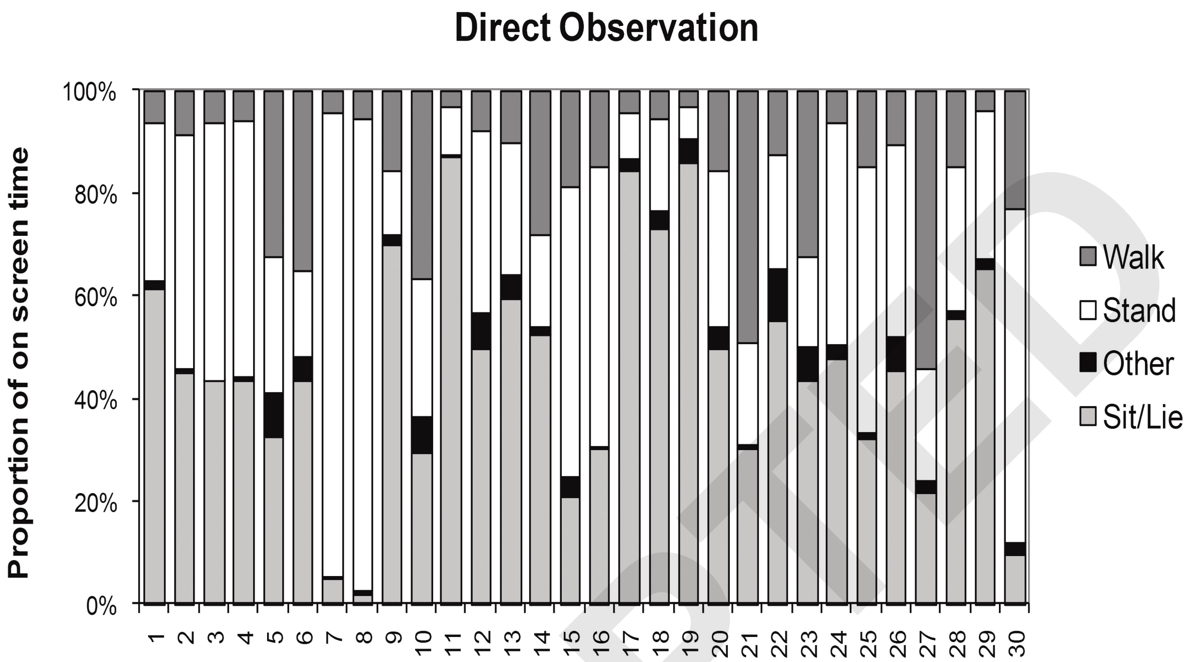
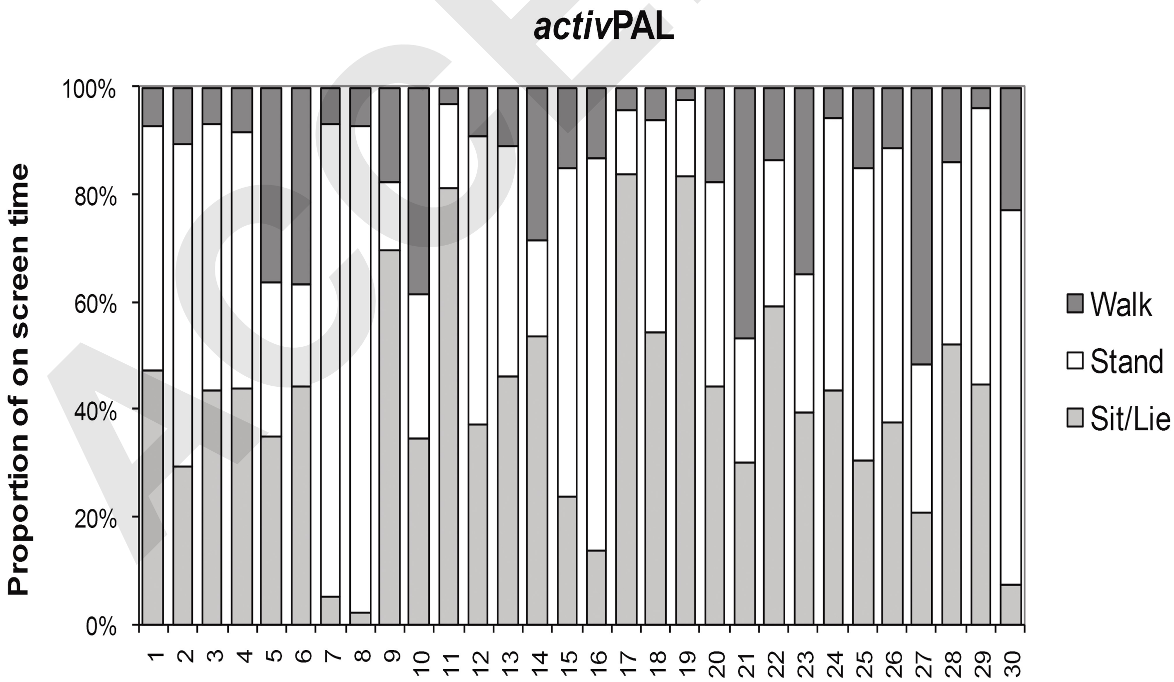
Figure captions

Figure 1. Proportion of on screen time according to direct observation (above) and *activ*PAL™ output category (below). Each individual child is represented by a vertical bar at the same corresponding number (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 by dashed lines.



Direct Observation
Proportion of on screen time
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Walk
Stand
Other
Sit/Lie



activPAL
Proportion of on screen time
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Walk
Stand
Sit/Lie

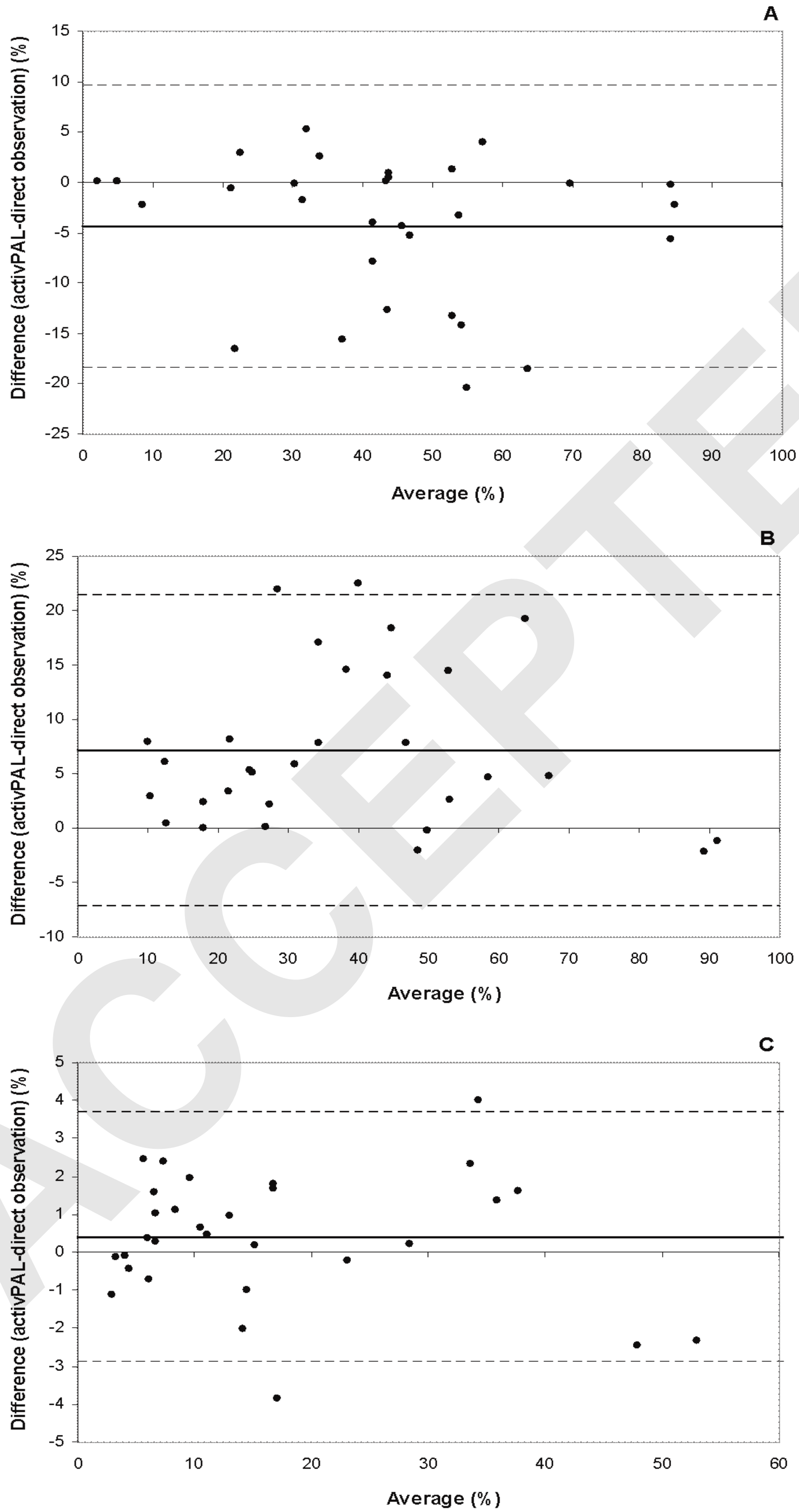

A
Difference (activPAL-direct observation) (%)
Average (%)
B
Difference (activPAL-direct observation) (%)
Average (%)
C
Difference (activPAL-direct observation) (%)
Average (%)

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

	True positives (seconds)	True negatives (seconds)	False positives (seconds)	False negatives (seconds)	Sensitivity (%)	Specificity (%)	Positive predictive value (%)
*activ*PAL output (Including all observation 'other' seconds)							
Sit/lie	39257	50970	1498	6025	86.7	97.1	96.3
Stand	31297	53687	9971	2795	91.8	84.3	75.8
Walk	12329	78998	3398	3025	80.3	95.9	78.4
*activ*PAL output (Excluding all observation 'other' seconds)							
Sit/lie	39257	49062	386	6025	86.7	99.2	99.0
Stand	31297	52110	8528	2795	91.8	85.9	78.6
Walk	12329	76443	2933	3025	80.3	96.3	80.8

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

Table 2. Practical utility questionnaire parental responses

Statement	Likert scale response (n (%))				
	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 days – was too long and caused problems	5 (25)	6 (30)	7 (35)	2 (10)	0 (0)
The monitor being worn for the 24 hour time 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	4 (20)	10 (50)	6 (30)	0 (0)	0 (0)

on correctly					
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 (0)	0 (0)	0 (0)
My child would not agree to wear the monitor again based on this experience	6 (30)	10 (50)	3 (0)	0 (0)	1 (5)

Table 3. Intraclass Correlation Coefficients (ICC) for *activ*PAL™ 'sit/lie' output according to duration of monitoring

Length of Monitoring (No. 24 hour 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)*
6	0.92	(0.84-0.96)*
7	0.93	(0.87-0.97)*

(* ICC of ≥0.8, usually interpreted as acceptable reliability in accelerometry studies)