Validation and calibration of the *activ*PAL^{TM} for estimating METs and physical activity in 4-6 year olds.

Abstract

Objectives. Examine the predictive validity of the *activ*PAL™ metabolic equivalents (MET) equation, develop *activ*PAL™ threshold values to define moderate-to vigorous-intensity physical activities (MVPA), and examine the classification accuracy and concurrent validity of the developed MVPA threshold values in 4- to 6-year-old children.

Design. A sample of forty 4- to 6-year-old children from the Illawarra region in New South Wales, Australia were included in data analysis.

Methods. Participants completed a ~150-min room calorimeter protocol involving age-appropriate sedentary behaviors (SB), light-intensity physical activities (LPA) and MVPA. *activ*PAL™ accelerometer counts were collected over 15 s epochs. Energy expenditure measured by room calorimetry and direct observation were used as the criterion measure. Predicted METs were calculated using the *activ*PAL™ MET equation. Predictive validity was evaluated using dependent-samples *t*-tests. Participants were randomly allocated into two groups to develop and cross-validate an intensity threshold for MVPA. Receiver operating characteristic (ROC) curve analysis was used to determine MVPA thresholds. Developed thresholds classification accuracy was cross-validated using sensitivity, specificity, and area under the ROC-curve (ROC-AUC).

Results. The *activ*PAL™ METs equation significantly overestimated METs during SB and significantly underestimated METs for LPA, MVPA and total METs compared to measured METs (all $P<0.001$). The developed threshold of ≥1418 counts per 15 s resulted in good classification accuracy for MVPA.

Conclusion. The current *activ*PAL™ METs equation requires further development before it can be used to accurately estimate METs in preschoolers. The developed threshold exhibited acceptable classification accuracy for MVPA; however studies cross-validating this MVPA threshold in free-living preschool-aged children are recommended.

Keywords: accelerometry; room calorimetry; young children; MVPA; inclinometer; activity monitor

Background

Accelerometry has become the method of choice for measuring free-living physical activity (PA) behaviors in children[1, 2]. However, sedentary behavior (SB), defined as any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting or reclining posture[3], has been shown to be adversely associated to cardiometabolic outcomes in adulthood, independent of moderate-to-vigorous physical activity (MVPA)[4]. In addition, some evidence suggests that SB and MVPA might have independent associations with health outcomes in children and adolescents[5]. As such, there is an increasing need for an accurate objective measure of both SB and PA, ideally using a single device to minimize participant burden.

Currently, hip-mounted accelerometers are the most common objective monitoring tool used to measure PA and SB in children. However, the placement of accelerometers on the hip and the use of threshold values makes it difficult to distinguish sitting from standing still[6], which in turn may increase measurement error when assessing SB and light intensity physical activity (LPA). Newer accelerometer-based devices use sensors which are sensitive to both static and dynamic accelerations and therefore make it possible to differentiate between postures[6].

One of the devices using this new technology is the *activ*PAL™ (PAL Technologies Ltd., Glasgow, UK). The *activ*PAL™ is a uni-axial accelerometer which is positioned on the anterior upper thigh. The positioning on the thigh enhances the ability to classify periods of time in different postures, categorized as lying/sitting, standing or walking. In addition, the *activ*PAL™ output reports accelerometer counts and estimates of METs based on step rate using an equation embedded in the *activ*PAL™ software[7]. The *activ*PAL™ has shown promising results for measurement of SB among children aged 3-12 years[8-10]. However, only one study has examined the predictive validity of the METs equation provided in the *activ*PAL™ software against a criterion measure in 15-25 year old females[11]. Moreover, only one study has developed a MVPA threshold for the *activ*PAL™, and that study examined only adolescent girls[12]. No studies have examined the validity of the *activ*PAL™ for predicting METs among preschool-aged children, nor developed a threshold to classify MVPA from *activ*PAL™ count output in preschoolers. As compliance with objective monitoring is often lower than desirable among children, and might decrease further if participants are required to wear multiple monitors, it is preferable to use one monitor when assessing children's habitual SB and PA levels. Therefore, the aim of this study was to examine the predictive validity of the *activ*PAL™ METs equation in 4-6 year old children. If the *activ*PAL™ METs equation was found to provide biased estimates of energy expenditure, our secondary aims were to develop and validate an *activ*PAL™ intensity threshold for classifying MVPA in 4-6 year old children.

Methods

Forty healthy 4-6 year old children were recruited from childcare centers in the Illawarra region of New South Wales, Australia. The study was approved by the University of Wollongong Human Research Ethics Committee. Parents of participants provided informed written consent, and their children provided their verbal assent to participate in the study.

Children followed a 150-min activity protocol including age-appropriate SB, LPA and MVPA such as, watching a movie on TV, playing with toys and shooting hoops, within the room calorimeter. Children ate a light standardized breakfast 1.5 h before entering the room calorimeter, which had a minimal impact on their energy expenditure[13]. Children performed all activities in an identical order over a pre-determined duration under the guidance of a trained research assistant (Online supplement 1).

The *activ*PAL™ (PAL Technologies Ltd., Glasgow, UK) is a uni-axial accelerometer which classifies periods of time in different postures, categorized as lying/sitting, standing or walking. In addition, the *activ*PAL™ output reports accelerometer counts and estimates of METs based on step rate using an equation embedded in the *activ*PAL™ software[7]. Before each experiment the *activ*PAL™ was initialized and time synchronized with the video camera—used for direct observation purposes—and the room calorimeter. Children were fitted with an *activ*PAL™ which was worn on the front of the right thigh using a double sided hydrogel adhesive pad and an elastic bandage to provide additional security.

To assess the validity of the *activ*PAL™ for predicting METs, EE measured by the room calorimeter was used as the criterion measure. Oxygen consumption and carbon dioxide production were measured continuously (paramagnetic O_2 and infrared CO_2 analysers, Sable System Inc, Las Vegas USA) and corrected to standard temperature, pressure and humidity in the room calorimeter (3 m x 2.1 m x 2.1 m). Technical procedures related to the room calorimeter are described in more detail elsewhere[13]. Chamber air was sampled every two min and rates of oxygen consumption and carbon dioxide production were then averaged over 10-min blocks to produce stable measures of EE[14].

During their time in the room calorimeter participants were digitally recorded, and activity start and end times and breaks between activities were recorded. To define a MVPA intensity threshold for the *activ*PAL™ and examine the validity of the *activ*PAL™ METs equation, children's movement was coded using the Children's Activity Rating Scale (CARS)[15]. CARS is based on a 1 to 5 coding scheme, identifying five levels defining the following intensities: level 1 and 2 = SB, Level 3 = LPA and Level 4 and 5 = MVPA. It has been shown to be a reliable and valid tool to assess PA levels in young children[16] and has been used in accelerometer validation studies in these age groups[17, 18]. Video footage was coded with the help of Vitessa 0.1 (Version 0.1, University of Leuven, Belgium) which generated a time stamp every time a change in intensity was coded by the observer. Data were coded by one observer who undertook two days of specific CARS training. During training, data from pilot trials were used. After coding, weighted average CARS scores were calculated for each 15s epoch corresponding to the *activ*PAL™ output. In this study averaged 15-s epochs were classified into intensity as follows: SB ≤ level 2; LPA > level 2.0 and ≤ 3.0; MVPA > level 3.0[15].

EE for every 10-min block was calculated using the Weir equation [19]. MET values were calculated by dividing measured EE by estimated basal metabolic rate (BMR) using the Schofield equation for children aged 4-10 years[20]. The 10-min blocks of EE were classified based on their equivalent MET values, into PA intensities as follows; SB ≤ 1.5 METs, LPA > 1.5 and < 3.0 METs and MVPA ≥ 3.0 METs.

*Predictive validity of the activ*PAL™ *METs equation. Activ*PAL™ MET values were collected in 15-s epochs and then averaged over 10-min blocks that aligned with 10-min MET values defined using EE measured by the room calorimeter. Participants' MET values were averaged per intensity and over the duration of the protocol. Predicted MET values were then compared to measured MET values by the room calorimeter.

*Development of an activ*PAL™ *MVPA intensity threshold.* To ensure the development and validation group were relatively similar, participants were stratified by sex and randomly allocated into either the development or validation group. To define an MVPA intensity threshold, data from the development group was used. *activ*PAL™ 15-s epoch acceleration counts were used as provided by the *activ*PAL™ software and aligned with direct observation data.

*Classification accuracy of the activ*PAL™ *MVPA intensity threshold using direct observation.* Data from participants allocated to the validation group were used to cross-validate the developed intensity threshold. *Activ*PAL™ data were classified as MVPA using the developed intensity threshold. *Activ*PAL™ data were then compared to direct observation data.

*Classification accuracy of the activ*PAL™ *MVPA intensity threshold using direct observation and EE.* The required EE for a given activity varies between individual children[21]. Because direct observation systems such as CARS rely on subjective classification and use general category descriptions to assign levels to activities based on the apparent intensity of the activity, it is possible that misclassification may occur for some individuals. To overcome this potential limitation and confirm findings for PA intensity classification based on direct observation, we developed an additional criterion measure that included both direct observation and EE measured by the room calorimeter. Ten min average EE values were divided by predicted BMR to define intensity levels. All epochs within the 10-min period immediately prior to the measured average EE value (i.e. forty 15 s epochs) were classified as SB, LPA, or MVPA. To prevent potential false misclassification (e.g. when all criterion epochs in a 10-min block were classified as MVPA but two min during these 10 min were LPA, these two min would be falsely classified as MVPA) direct observation data and EE expenditure data were compared for every 15-s epoch. Thereafter, criterion epochs were excluded if PA intensity defined using EE measured by the room calorimeter did not agree with the intensity levels derived from direct observation. In addition, epochs within the last min of a 10-min EE data block were excluded ensuring that any small time lag in the calorimeter readings would not lead to mismatching criterion data with *activ*PAL™ data. Likewise, criterion epochs which occurred during breaks between activities were excluded.

Demographic differences between the development group (n = 18) and cross-validation group (n = 18) were examined using independent samples t-tests and Fisher exact tests for weight status. Dependent *t*-tests were used to compare the differences between measured MET values and predicted MET values. Systematic bias was examined using the Bland-Altman method[22]. ROC analyses were used to define an *activ*PAL™ MVPA intensity threshold. In addition, the developed intensity threshold was cross-validated using sensitivity, specificity, and area under the receiver operating curve (ROC-AUC). ROC-AUC values of ≥ 0.90 are considered excellent, ≥ 0.80 and < 0.90 good, ≥ 0.70 and < 0.80 fair, and < 0.7 poor[23]. All statistical analyses were performed using MedCalc Version 12.3.0 software (Medcalc Software, Mariakerke, Belgium).

Results

Forty children completed the calorimeter activity protocol. Two children had missing data due to *activ*PAL™ failure, and another two had missing data due to calorimeter failure. For the remaining 36 children, 31 (85.1%), 34 (94.4%) and 32 (88.9%) had at least one 10-min block of SB, LPA or MVPA, respectively, according to calorimeter measured EE values. Descriptive characteristics for the total sample and the development and cross-validation groups are presented in Table 1. Boys and girls were equally divided between the development (n=18) and cross-validation (n=18) groups and no significant differences were found for age, weight, height, BMI, or weight status ($p > 0.05$).

*Predictive validity of the activ*PAL™ *METs equation*. The *activ*PAL™ METs equation overestimated METs during SB (+6.0%) and underestimated METs for LPA (-15.3%), MVPA (-32.8%) and total METs (-13.6%) (all $p<0.001$) (Figure 1). Due to signs of heteroscedasticity, bias and 95% limits of agreement were calculated using log-transformed data and presented as ratios. The bias between measured and predicted EE was -5% (-22% to +11%), +19% (-4% to +42%), +46% (-20% to +112%) and +15% (-19% to +49%) for SB, LPA, MVPA and total METs, respectively. The highest over-estimation and under-estimation were found for the lowest and highest MET values, respectively (Online supplement 2).

*Development of activ*PAL™ *MVPA intensity thresholds.* Of the possible 10584 15-s epochs available from 18 participants in the development sample, 9844 epochs (93.0%) were included as valid data. Missing data was due to the child being off screen. For classifying MVPA, ROC analysis resulted in an optimal threshold value of ≥1418 counts per 15 s (ROC-AUC=0.92). Sensitivity and specificity for this cut point were 82.9% and 90.9%, respectively (Table 2).

*Classification accuracy and concurrent validity of developed activ*PAL™ *MVPA intensity thresholds using direct observation.* Of the possible 10584 15-s epochs available from 18 participants in the cross-validation sample, 9758 epochs (92.2%) were included as valid data. Missing data was due to the child being off screen (826 epochs) and one child's *activ*PAL™ came off the child's leg (171 epochs) during the protocol. Sensitivity, specificity and ROC-AUC were analyzed for MVPA using the developed intensity threshold of ≥1418 counts per 15 s. Using the *activ*PAL™ intensity threshold resulted in a sensitivity and specificity of 88.3% and 88.2%, respectively. Classification accuracy for MVPA was found to be good (ROC-AUC=0.88).

*Classification accuracy and concurrent validity of developed activ*PAL™ *MVPA intensity thresholds using direct observation and measured EE.* Of the 10584 available 15-s epochs from 18 participants in the cross-validation sample, 6175 epochs (58.3%) were included as valid data. Data exclusion was due to lack of agreement between calorimeter and direct observation data (3412 epochs), the child being off screen (826 epochs) and because one child's *activ*PAL™ became detached during the protocol (171 epochs). Sensitivity, specificity and ROC-AUC were analyzed for MVPA using the developed intensity thresholds of ≥1418 counts per 15 s. Using the *activ*PAL™ intensity threshold resulted in a sensitivity and specificity of 94.8% and 84.8%, respectively. Classification accuracy for MVPA was found to be excellent (ROC-AUC=0.90).

Discussion

Using the MET equation embedded in the *activ*PAL™ software resulted in a significant over-estimation of METs during SB, and a significant under-estimation of METs during LPA, MVPA and overall. To our knowledge, no study has previously examined the predictive validity of the *activ*PAL™ METs equation in preschool-aged children. However, the current findings are consistent with a previous study which reported an underestimation of total METs in 15-25 year old females when using the *activ*PAL™ METs equation[11]. Reasons for the poor predictive validity might be because only one independent variable, steps per min, is used in the *activ*PAL™ equation to predict METs[11]. Variables like age, height and weight might possibly influence the association between steps per min and EE. In addition, Harrington et al.[11] reported a stronger relationship between *activ*PAL™ counts and EE than between steps and EE in 15-25 year old females. However, several studies have reported significant differences between predicted and measured EE when using EE prediction equations based on accelerometer counts from other commercially available hip-mounted accelerometers[24, 25]. The association between hip-mounted accelerometer counts and predicted METs differs per activity (e.g. walking up a hill might not lead to higher accelerometer counts but will expend more energy than walking on a flat section), and therefore a single equation appears to have problems predicting METs accurately across a broad spectrum of activities[26]. More complete approaches that go beyond single regression equations, such as multiple regression equations or pattern recognition may be required to accurately predict METs from accelerometry data in children[26]. Considering the results of this study, and previous published research, further development of the *activ*PAL™ MET equation is required before it can be used to accurately estimate preschool-aged children's EE.

Using the developed *activ*PAL™ threshold of ≥1418 counts per 15 s was found to perform well when classifying MVPA. Cross-validation of this threshold, using direct observation only or direct observation combined with EE, resulted in good and excellent classification accuracy for MVPA, respectively. To our knowledge this is the first study to develop and cross-validate MVPA *activ*PAL™ thresholds in 4-6 year old children. Previous studies validating the *activ*PAL™ in this age group have focused on sedentary behavior and sitting time[8, 9]. Only one study has developed and cross-validated an *activ*PAL™ MVPA threshold in youth[12]. Findings indicated that the threshold of ≥2997 counts per 15 s resulted in excellent classification accuracy for MVPA among 15-18 year old adolescent girls. The optimal *activ*PAL™ MVPA threshold found in that study was higher than that found in the current study. In addition, a higher sensitivity and specificity was reported[12]. The lower threshold value in our study might be due to the younger age of our participants, as physiological and biomechanical differences, such as differences resting energy expenditure and gait patterns, exist between children and adolescents[27, 28]. These differences are expected to influence accelerometer output and consequently MVPA threshold values[2]. In addition, Dowd et al.[12] implemented a protocol that included structured posture-based activities, while the current study included a range of free-living and lifestyle activities. The use of a more structured protocol may be one reason for the increased sensitivity and specificity compared to the current study.

Limitations of this study should be noted. The intensity thresholds developed in validation studies are dependent on the included activities and the results will therefore vary between studies. In this study a standardized activity protocol in a controlled setting was used and while the protocol included developmentally appropriate free-living activities, studies cross-validating the developed MVPA intensity thresholds in free living circumstances are needed. In addition, the activities were performed in a pre-specified order which might have led to EE during certain activities being more affected by excitement (at the start) or fatigue (at the end) than others. Further, using room calorimetry limited the ability to measure EE in time blocks shorter than 10 min[14] due to the calorimeter sampling frequency and the time lag which exists when measuring EE in large volumes. Due to the age of the participants it was not feasible to create a protocol that included activities of moderate-to-vigorous intensity that last 10 min. As such, using portable calorimetry may have been better suited to capture the sporadic and intermittent nature of preschoolers MVPA. The proportion of data classified as valid and used in the analyses when combining measured EE and direct observation was low, especially for MVPA. This was due to the strict screening protocol we used in order to reduce potential misclassification error from including, for example, data points in the MVPA category that may have been LPA. However, analyses based on both direct observation and measured EE combined with direct observation were used to overcome the impact of this limitation. Finally, it is possible that threshold methodology might be replaced by pattern recognition techniques in the future[29]. However, pattern recognition approaches are still in development and until such methodologies are more widely available, the accurate classification of MVPA using threshold values will remain an important issue for researchers.

Despite these limitations, this study had several strengths. The inclusion of a cross-validation group and a protocol which included a variety of child specific and developmentally appropriate activities, ranging in intensity from SB to MVPA is in line with current best practice recommendations for activity monitor validation studies[26]. Additionally, calorimetry was used which is the gold standard when measuring EE and its use is rare in studies among preschoolers[21]. Specifically, room calorimetry was used as the criterion method instead of a portable calorimetry device. Using room calorimetry eliminates the need to use a facemask, which could impact how a given activity is performed as it may not be tolerated by all preschool children. Finally, as differences in EE per activity between children is not taken into account when using direct observation alone, cross-validation of the developed MVPA threshold was conducted using both direct observation as well as EE in conjunction with direct observation as criterion measures. These analyses provided consistent findings and assisted in overcoming the potential limitations related to each criterion measure.

Conclusion

Further development of the integrated *activ*PAL^{TM} MET equation is required before it can be used with acceptable accuracy in preschool children. The MVPA intensity threshold of ≥1418 counts per 15 s resulted in good classification accuracy. However, further studies are required to assess the classification accuracy of the *activ*PAL^{TM} MVPA thresholds in free-living conditions.

Practical Implications

- Further development of the activPALTM MET equation is required before it can be used with acceptable accuracy in preschool children.
- The developed moderate-to-vigorous physical activity intensity threshold, which demonstrated good classification accuracy, provides a method to estimate physical activity from activPALTM data in young children.
- Being able to accurately assess moderate-to-vigorous physical activity, in addition to sedentary behavior, enhances the practical utility of the activPALTM in preschool children.

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Table 1. Participant characteristics*

	Total Sample (n=36)	Development Group (n=18)	Cross-validation Group (n=18)	P value
% boys	52.8	56.6	50.0	
Age (years)	5.3 (1.0)	5.4 (1.0)	5.2 (1.0)	0.67
Height (cm)	112.7 (8.4)	114.8 (9.2)	110.7 (7.2)	0.15
Weight (kg)	20.5 (3.8)	21.1(3.7)	19.9 (3.9)	0.37
BMI (kg/m2)	16.0 (1.5)	15.9 (1.2)	16.1 (1.8)	0.64
% overweight# (n)	25 (9)	11.1 (2)	38.9 (7)	0.12

BMI, body mass index; * data presented as mean (SD) unless otherwise stated; # defined according to the International Obesity Task Force definitions[30].

Table 2. ROC analysis for development and cross-validation of *activ*PAL™ MVPA intensity thresholds.

	Criterion measure	Intensity thresholds	Se% (95% CI)	Sp% (95% CI)	ROC-AUC (95% CI)
Development	DO	≥1418 counts per 15 s	82.9 (81.3-84.4)	90.9 (90.3-91.5)	0.92 (0.91-0.92)
Cross-validation	DO	≥1418 counts per 15 s	88.3 (86.8-89.7)	88.2 (87.4-88.9)	0.88 (0.88-0.89)
	DO and EE	≥1418 counts per 15 s	94.8 (93.0-96.3)	84.8 (83.8-85.7)	0.90 (0.89-0.91)

Cconfidence Interval (CI), Direct Observation (DO), Energy expenditure (EE), Area under the receiver operating characteristic curve (ROC-AUC), Sensitivity (Se%), Specificity (Sp%).

Figure Captions

Figure 1. Metabolic equivalent values (METs) measuredby the calorimeter versus predicted METs using the *activ*PAL™ equation for sedentary behavior (SB), light-intensity physical activity (LPA) and moderate- to vigorous-intensity physical activity (MVPA). * Significant difference between measured and predicted METs ($p<0.001$).