Validation and Calibration of an Accelerometer in Preschool Children

Russell R. Pate, Maria J. Almeida, Kerry L. McIver, Karin A. Pfeiffer, and Marsha Dowda

Abstract

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Objective: Obesity rates in young children are increasing, and decreased physical activity is likely to be a major contributor to this trend. Studies of physical activity in young children are limited by the lack of valid and acceptable measures. The purpose of this study was to calibrate and validate the ActiGraph accelerometer for use with 3- to 5-year-old children.

Research Methods and Procedures: Thirty preschool children wore an ActiGraph accelerometer (ActiGraph, Fort Walton Beach, FL) and a Cosmed portable metabolic system (Cosmed, Rome, Italy) during a period of rest and while performing three structured physical activities in a laboratory setting. Expired respiratory gases were collected, and oxygen consumption was measured on a breath-by-breath basis. Accelerometer data were collected at 15-second intervals. For cross-validation, the same children wore the same instruments while participating in unstructured indoor and outdoor activities for 20 minutes each at their preschool.

Results: In calibrating the accelerometer, the correlation between $\dot{V}O_2$ (ml/kg per min) and counts was $r = 0.82$ across all activities. The only significant variable in the prediction equation was accelerometer counts ($R^2 = 0.90$, standard error of the estimate = 4.70). In the cross-validation, the intraclass correlation coefficient between measured and predicted $\dot{V}O_2$ was $R = 0.57$ and the Spearman correlation coefficient was $R = 0.66$ ($p < 0.001$). Cut-off points for moderate- and vigorous-intensity physical activity were identified at 420 counts/15 s ($\dot{V}O_2$ = 20 mL/kg per min) and 842 counts/15 s ($\dot{V}O_2$ = 30 mL/kg per min), respectively. When these cutpoints were applied to the cross-validation data, percentage agreement, kappa, and modified kappa for moderate activity were 0.69, 0.36, and 0.38, respectively. For vigorous activity, the same measures were 0.81, 0.13, and 0.62.

Discussion: Accelerometer counts were highly correlated with $\dot{V}O_2$ in young children. Accelerometers can be appropriately used as a measure of physical activity in this population.

Key words: physical activity, measurement, count cutpoints, indirect calorimetry, ActiGraph

Introduction

Obesity rates in the United States have increased markedly in recent decades, in children and adolescents as well as adults (1–3). Among children 4 and 5 years of age, the prevalence of overweight increased from 5.8% in 1971–1974 to more than 10% in 1988–1994 (4). By 1999–2002, the prevalence of overweight in children ages 2 to 5 years was 10.3% (3). Although the causes of this change have not been determined with certainty, reduced physical activity is likely to be a major contributor in children and adolescents (5–7) as well as adults (8–12). Accordingly, there is a great need to understand the factors that influence physical activity in children and to learn how to help them be more active. Previous studies of physical activity in young children have been limited by the lack of acceptable measures of physical activity. It is well known that young children are unable to self-report their physical activity accurately (13,14), and surrogate reports by parents and other adults have limited validity (15).

Accelerometry has recently come into wide use as a measure of physical activity. Advantages to accelerometry include its objectivity and low subject reactivity, characteristics which overcome major problems of self-report measures. However, accelerometry has the disadvantage of under-detecting certain non-weight-bearing activities, and

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Arnold School of Public Health, University of South Carolina, Columbia, South Carolina.
Address correspondence to Russell R. Pate, Department of Exercise Science, Arnold School of Public Health, University of South Carolina, 730 Devine Street, Columbia, SC 29208.
E-mail: rpate@gwm.sc.edu

most accelerometers cannot be worn in water. Also, it is known that, if accelerometry data are to be reduced to metrics that express physical activity in terms of intensity and/or energy expenditure, the instrument must be calibrated against suitable criterion measures. Furthermore, because young children tend to perform physical activity in short bursts rather than in prolonged bouts, it has been recommended that accelerometry data be collected in short increments (e.g., 15 seconds) (16).

It is important that accelerometers be calibrated for application in specific population subgroups because previous studies have demonstrated population specificity in the relationship between accelerometry counts and energy expenditure (17–19). In particular, it is known that age and factors associated with age influence this relationship (17,19,20). The ActiGraph accelerometer (MTI Model 7164; ActiGraph, Fort Walton Beach, FL) has been used in a number of physical activity studies in children, adolescents, and adults (17,18,21–23). Although the ActiGraph has been used with young children, it has not been calibrated, using 15-second data collection increments, vs. a metabolic criterion measure ($\dot{V}O_2$). Such a criterion reflects both intensity of physical activity and rate of energy expenditure. Accordingly, the primary purpose of this study was to calibrate the ActiGraph accelerometer for use with 3- to 5-year-old children using concurrently measured $\dot{V}O_2$ (indirect calorimetry) as the criterion measure of physical activity. In addition, proposed cutpoints for moderate- and vigorous-intensity physical activity were developed. The calibration equation and cutpoints were cross-validated using a metabolic criterion that was measured while children performed unstructured physical activity in outdoor and indoor settings.

Research Methods and Procedures

Subjects

Thirty preschool children, ages 3 to 5 years, were recruited from two commercial preschools and one religious preschool in Columbia, SC. The sample included both African-American and white children. A wide range of heights and weights was represented. None of the participants had any physical limitations that restricted their participation in physical activity. The protocol for this study was approved by the University of South Carolina Institutional Review Board and by each preschool's director. Before participation, the parent or guardian of each child provided written informed consent.

Age and ethnicity were provided by each participant's parent or guardian on the consent form. Height was measured to the nearest 0.1 cm using a portable stadiometer (Shorr Productions, Olney, MD). Weight was measured to the nearest 0.1 kg using an electronic scale (Model 770; Seca, Hamburg, Germany). The average of two measurements was used for both height and weight.

Study Design

A cross-sectional study design was used, and data were collected during three sessions. At the first session, the parent/guardian brought the child to our laboratory setting so that the child could participate in a session of rest and three structured activities (two walking speeds and one jogging speed). During the second and third sessions, the data collection staff went to the participant's preschool so that the child could perform indoor and outdoor unstructured activities. Data from the first session (rest and structured activities) were used for the calibration analysis, while data from the second and third sessions (unstructured activities) were used for cross-validation purposes.

Accelerometry

The ActiGraph is a uniaxial accelerometer that measures acceleration in the vertical plane; it is small ($5.08 \times 4.06 \times 1.52$ cm), light (42.52 g), and unobtrusive. Its acceleration signal is filtered by an analog band-pass filter (0.1 to 3.6 Hz) and digitized by an 8-bit A/D converter at a sampling rate of 10 samples per second, storing data in user-defined intervals (24). For the present study, the monitors were initialized to save data in 15-second intervals (epochs) to detect the spontaneous activities of 3- to 5-year-old children. Children wore the accelerometers on the right hip (anterior to the iliac crest), secured with an elastic belt. Data from our research group have shown an acceptable inter-instrument reliability coefficient ($r = 0.91$ for structured activities) (R.R. Pate, M.J. Almeida, K.L. McIver, K.A. Pfeiffer, and M. Dowda, unpublished observations).

Metabolic Measures

Expired respiratory gases were collected, and oxygen consumption ($\dot{V}O_2$) was measured on a breath-by-breath basis using the Cosmed portable metabolic system (Model K4b2; Cosmed, Rome, Italy). The unit is a lightweight system (925 g) that is worn on the back by means of a harness system. The appropriate pediatric face mask was chosen and fitted for each child to ensure that air did not leak from the mask. Figure 1 shows a child wearing the Cosmed system. Before each measurement session, the unit was calibrated with standard gases. The system has been validated previously (25).

Structured activities were performed in laboratory and gymnasium settings. Parents were asked not to give their child food within the 2-hour period before the testing session. At the start of the resting session, each child was asked to sit comfortably in a reclining chair while watching a popular children's movie or cartoon. During the resting measurements, only the mask was worn, with the Cosmed unit placed on a surface next to the child. The test did not begin until the child was quiet and the metabolic readings were stabilized. Children were monitored for 10 minutes in the resting state.

Figure 1: Four-year-old child wearing the Cosmed K4b2 system for measurement of $\dot{V}O_2$ during physical activity.

Structured Activities

A researcher paced each child for 5 minutes at each of three different speeds as he or she walked or jogged on level ground. The researcher used a stop watch and split times to keep the pace. The child was instructed to stay by the researcher's side throughout each test. If a child could not keep up with the pace, he or she was asked to keep moving at his or her own speed. Split times were recorded, if necessary, to determine the real speed at which children completed the test. Two walks were completed, one at 2 mph and the other at 3 mph. The jogging session was performed at 4 mph. Each child completed the activities in order of increasing intensity.

Between structured activities, the child was given time to rest and recover from the exercise. Throughout the testing process, each child was verbally encouraged to maintain the prescribed pace and complete the entire 5 minutes at each speed. At the completion of each test (speed), the child received a small incentive. If any event requiring the child to stop for a length of time occurred during the testing session, the test was terminated and a second trial was attempted.

Unstructured Activities

To cross-validate the calibration equation and cutpoints developed from data collection during the children's performance of structured activities, each child wore both an ActiGraph and the Cosmed while participating in self-selected activities for 20 minutes in both indoor and outdoor settings at his or her preschool. Activities were not prescribed or directed by the researchers, and children participated in normal activities with their classmates; however, in situations where other children were not present, the researchers participated in the choice of activity with the child. Typical indoor activities included playing with blocks, reading, computer time, sociodramatic play, and music and movement play. Outdoor sessions typically included climbing, swinging, digging, playing with balls or other objects, and running or chasing. Each child participated in an activity for 4 to 6 minutes and was then instructed to select something else. Research staff encouraged the children to participate in a range of physical activity levels while inside and outside.

Data Reduction

For both the calibration and cross-validation analyses, data were summarized in terms of activity counts per 15 seconds. Specific to the calibration analysis, Minutes 8 and 9 from the rest period and Minutes 3 and 4 from each of the three speeds were used. Accelerometer counts and $\dot{V}O_2$ were averaged over those 2-minute periods for each of the four activities. Specific to the cross-validation analysis, 8 minutes of the 40 minutes of observation were randomly chosen for inclusion in the analyses; 4 minutes were from indoor activities, and 4 minutes were from outdoor activities. The 8 minutes chosen represented a range of activity intensities and provided a sufficient amount of data to assess the agreement between measured and predicted $\dot{V}O_2$.

Statistical Analysis

For the calibration analysis, means and standard deviations were calculated for $\dot{V}O_2$ and accelerometer counts observed during rest and each structured activity. These were determined for the total group and for sex and race subgroups. Random-coefficient models using PROC MIXED in SAS software (version 8.2; SAS Institute, Cary, NC) were used to explore the relationship between $\dot{V}O_2$ and accelerometer counts. Intercepts and slopes were fitted for each subject, and then an overall regression line was calculated. In addition to accelerometer counts for prediction of $\dot{V}O_2$, other variables were considered both one at a time and in a multivariate model. The variables included sex, race, age, height, quadratic terms for age and height, and interactions of the variables with accelerometer counts. The models were compared and assessed using goodness-of-fit statistics (26,27).

Count cutpoints for moderate- and vigorous-intensity physical activity were identified through visual inspection of the distribution of the $\dot{V}O_2$ values for slow walking, brisk walking, and jogging. This method was used because met-

Table 1. Characteristics of subjects

Variable	Mean (standard deviation) or percent
Male	44.8%
African-American	55.2%
Age (years)	4.4 (0.8)
Height (cm)	105.4 (6.7)
Weight (kg)	18.6 (4.6)
BMI (kg/m^2)	16.5 (2.2)

$n = 29$.

Table 2. $\dot{V}O_2$ and accelerometer counts by activity of preschool children

Activity	$\dot{V}O_2$ (ml/kg per min)	Counts
Resting	9.1 (2.7)	0.2 (0.5)
Slow walk	18.2 (4.0)	377.5 (101.1)
Brisk walk	25.5 (6.1)	726.0 (203.7)
Jog	36.8 (5.9)	1009.4 (325.0)

$n = 29$. Values are means (standard deviation).

abolic equivalent-based cutpoints, as typically applied with older youth and adults, are not appropriate for young children. The count value corresponding to the $\dot{V}O_2$ level that appeared to best discriminate between slow walking and brisk walking was selected as the cutpoint for moderate-intensity physical activity. The same procedure using the data for brisk walking and jogging was used to select a cutpoint for vigorous-intensity physical activity.

For the cross-validation analysis, several methods were used to assess agreement between $\dot{V}O_2$ as measured by the Cosmed during the children's performance of unstructured activities and $\dot{V}O_2$ estimated from the regression equation. Intraclass, Spearman, and Pearson correlations for the associations between measured and predicted $\dot{V}O_2$ were calculated. Also, after dichotomizing the data using the moderate-to-vigorous physical activity (MVPA)[1] and vigorous physical activity (VPA) cutpoints, agreement between categories based on measured $\dot{V}O_2$ and estimated intensity was assessed using percentage agreement, kappa, and modified kappa statistics (26).

Results

Calibration Study

No ActiGraph data were available for one child because of instrument failure. Therefore, data from 29 children were available for analysis. Resting accelerometry data were not available for one child due to instrument problems; for that child, the mean count for resting for all children was used. Forty-five percent of the children were males, and 55% were African-American; the mean age was 4.4 years [standard deviation (SD) = 0.8 year; range, 3.30 to 5.95 years)] (Table 1). BMI values ranged from 13.7 to 24.5. African-American and white children did not differ significantly by age (African-American: age = 4.5 ± 0.7 years; white: age = 4.3 ± 0.8 years; $p = 0.63$), height (African-American: height = 105 ± 7.5 cm; white: height = 104.8 ± 6.2 cm; $p = 0.66$), weight (African-American: weight = 19.5 ± 5.8 kg; white: weight = 17.4 ± 2.3 kg; $p = 0.22$), or BMI (African-American: BMI = 17.0 ± 2.7; white: BMI = 15.8 ± 0.8; $p = 0.11$).

$\dot{V}O_2$ values as measured by the Cosmed during rest and during the three structured activities are shown in Table 2. No gender differences were observed for any of the variables. No race differences were observed for accelerometer counts, but $\dot{V}O_2$ did vary by race, with values for white children higher than those for African-American children. Figure 2 shows $\dot{V}O_2$ data and ActiGraph counts for each subject for rest and the three structured activities. The Pearson correlation coefficient between $\dot{V}O_2$ and counts across all activities was 0.82. ActiGraph counts for each of the activities are also shown. Goodness-of-fit indices from the model with only ActiGraph counts were $R^2 = 0.904$ (standard error of the estimate = 4.70), and the Akaike information criterion was 735.8. With the addition of other variables, there was no meaningful change. The model with counts as the only independent variable was $\dot{V}O_2$ (ml/kg per min) = 10.0714 + 0.02366(counts/15 s). This equation was used to determine cutpoints for MVPA and VPA. First, we visually inspected the data points for slow walk, brisk walk, and jog and concluded that 20 mL/kg per min consistently differentiated between slow walk and brisk walk and that 30 mL/kg per min consistently differentiated between brisk walk and jog. Then the equation was solved for the count values corresponding to 20 and 30 mL/kg per min. This yielded count cutpoints of 420 for moderate-intensity activity and 842 for VPA.

Cross-Validation

The mean $\dot{V}O_2$ during free play was 20.7 mL/kg per min (SD = 9.02 mL/kg per min) and 339.4 counts (per 15 seconds) (SD = 483.88 counts). Both the accelerometer counts and $\dot{V}O_2$ as estimated from accelerometer counts

[1] Nonstandard abbreviations: MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity; SD, standard deviation.

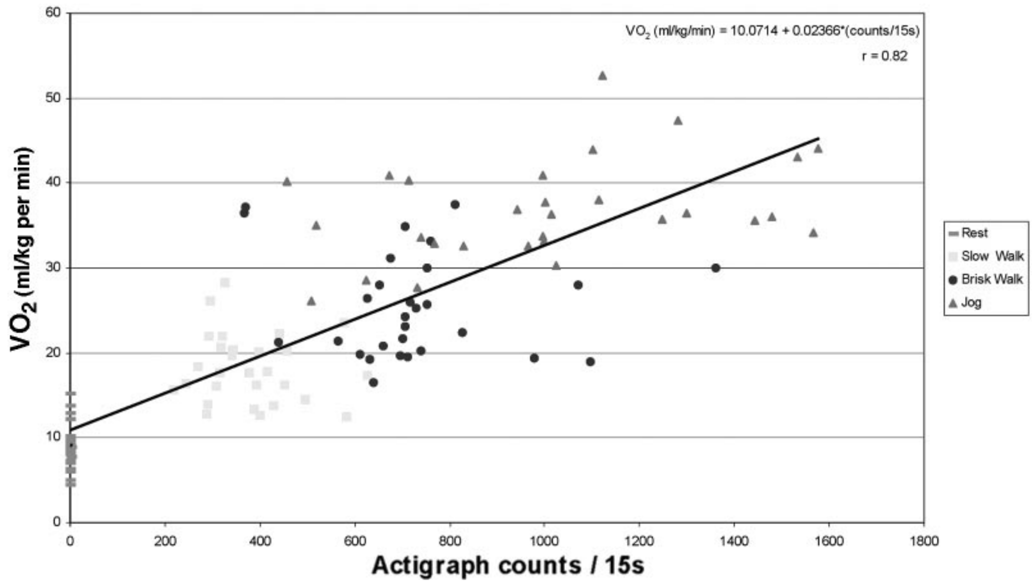

Figure 2: Relationship between accelerometer counts and $\dot{V}O_2$.

were highly skewed. The intraclass correlation coefficient from $\dot{V}O_2$ estimated from accelerometer counts and $\dot{V}O_2$ as measured by the Cosmed was 0.57 using log-transformed data. The Spearman correlation coefficient between the two measures was 0.66 ($p < 0.001$).

Sensitivity and specificity for the MVPA cutpoint were 96.6% and 86.2%, respectively. For the VPA cutpoint, the sensitivity was 65.5% and the specificity was 95.4%. Percentage agreement, kappa, and modified kappa for MVPA were 0.69, 0.36, and 0.38, respectively. For VPA, the same measures of agreement were 0.81, 0.13, and 0.62.

Discussion

This study is the first to provide calibration and cross-validation data for accelerometry as a measure of physical activity using a metabolic criterion measure in young children. The findings indicate that ActiGraph counts are very highly correlated with $\dot{V}O_2$ in 3- to 5-year-old children who perform structured, weight-bearing physical activities for several minutes. When the calibration and count cutpoint established with structured activities were cross-validated while children performed unstructured activities, accelerometer counts and $\dot{V}O_2$ were still well-correlated. Also, there was good agreement between intensity categories as estimated from accelerometer counts and $\dot{V}O_2$ while children performed unstructured activities. Count cutpoints for moderate-intensity ($\dot{V}O_2$ = 20 mL/kg per min) and vigorous-intensity ($\dot{V}O_2$ = 30 mL/kg per min) physical activity were quite sensitive and specific. These findings demonstrate that accelerometry can be appropriately used as a measure of physical activity in young children.

Few studies have focused on the calibration of accelerometers, especially in young children. Three previous studies were conducted with preschool children, but they used a different criterion measure (directly observed structured physical activity) than the current investigation (20,28,29). Only one of those studies provided correlation coefficients for the relationship between activity counts and direct observation scores for various physical activity intensities, and the coefficients ranged from $r = 0.46$ to $r = 0.70$ (20). These values are similar to those observed in the current study, in which we found correlations of $r = 0.82$ and $r = 0.66$ for rest/structured activities and free play activities, respectively. However, any comparisons between this study and the others must be interpreted with caution, because our study used a different criterion measure.

An important purpose of conducting a calibration study is to establish physical activity count cutpoints to be used in a given population. It is difficult to compare the cutpoints generated in this study to others in the literature because of differences in both criterion measure and participant characteristics. Two of the previous studies conducted in preschool children established a cutpoint only for the transition from sedentary to light activity (28,29). The third study of preschool children established cutpoints of approximately ≥934 for moderate activity and ≥1242 for vigorous activity (20). These values were collected in 15-second epochs and are considerably higher than those found in the current study; however, a different criterion measure was used. Other studies that have used the same criterion measure as the current study (indirect calorimetry) have involved older children and adolescents, used a different epoch length, and established significantly different cutpoints (17,30). These cutpoints cannot be compared with those established in the current study because physical activity count cutpoints are age-specific. We are confident that the cutpoints established in this study can be used for preschool-age children when data are collected in 15-second intervals.

A unique component of this investigation was cross-validation of the calibration equation and count cutpoints using a metabolic criterion measure while children performed free play activities indoors and outdoors. It seemed important and appropriate to undertake such a cross-validation in this study because young children typically engage in physical activity in short, discontinuous bursts. Hence, it seemed possible that a calibration equation and count cutpoints developed from data collected while children performed steady, continuous activity might not accurately reflect activity performed in the children's normal sporadic manner. However, we found that $\dot{V}O_2$ and activity intensity levels estimated using the calibration equation and cutpoints correlated well with $\dot{V}O_2$ and activity intensities measured while the children performed free play activities. This is reassuring, because it is likely that $\dot{V}O_2$ measured with indirect calorimetry during free play in young children is limited by the kinetics of oxygen consumption. Therefore, it is possible that accelerometer counts reflect activity level in free-living young children even more accurately than suggested by our cross-validation analyses.

This study had certain limitations. The sample was relatively small and included a high percentage of African-American children, and this may limit generalization of the findings. Also, as noted above, the procedures for calibrating and cross-validating the accelerometer were limited by the application of indirect calorimetry for measurement of $\dot{V}O_2$ as a criterion measure. Indirect calorimetry, although a recognized criterion measure of physical activity, is limited by the delayed rate of change in measured $\dot{V}O_2$ with a change in activity level. In addition, the method used in this study for specification of physical activity cutpoints involved visual examination of data, and it is acknowledged that this approach is non-traditional. However, the more traditional metabolic equivalent-based method for designation of intensity cutpoints is ill-suited to application with young children, in whom resting metabolic rate is high and economy of movement is low. The results of the cross-validation component of this study suggest that the selected cutpoints for moderate- and vigorous-intensity physical activity are acceptably sensitive and specific.

In summary, the ActiGraph accelerometer was calibrated and cross-validated as a measure of physical activity in young children using a metabolic criterion measure of activity. The findings indicate that ActiGraph counts are well-correlated with $\dot{V}O_2$ when observed during both structured, continuous physical activity and free play activity. We conclude that the ActiGraph accelerometer provides a valid measure of physical activity intensity and cumulative physical activity in preschool children.

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