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Calibration and cross-validation of a wrist worn Actigraph in young preschoolers

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Abstract

Objective: To calibrate the Actigraph GT3X+ accelerometer for wrist worn placement in young preschoolers by developing intensity thresholds for sedentary, low and high intensity physical activity. Furthermore, to cross-validate the developed thresholds in young preschoolers. *Methods:* Actigraph GT3X+ was used to measure physical activity during structured activities and free play in 38 children (15-36 months). Activity was video recorded and scored into sedentary, low and high intensity physical activity based on Children´s Activity Rating Scale (CARS) and combined with accelerometer data using a 5 second epoch. ROC analysis was used to develop intensity thresholds in 26 randomly selected children. The remaining 12 children were used for cross-validation. *Results:* Intensity thresholds for sedentary were ≤ 89 vertical counts (Y) and ≤ 221 vector magnitude (VM) counts/5 sec and ≥ 440 Y-counts and ≥ 730 VM-counts/5 sec for high intensity physical activity. Sensitivity and specificity were 60-100% for the developed intensity thresholds. Strong correlations (Spearman rank correlation 0.69-0.91) were found in the cross-validation sample between the developed thresholds for the accelerometer and CARS scoring time in all intensity categories. *Conclusion:* Data from a wrist mounted Actigraph activity monitor appears accurate to categorize young preschoolers into physical activity intensity categories.

Key words: Accelerometry, Children, Observation, Physical Activity, Toddler

Introduction

Physical activity and sedentary behavior have been identified as important lifestyle variables influencing health and development in children (1, 2). Physical activity has positive effects on adiposity, motor skills, cardio metabolic health, bone health, cognition and psychosocial well-being already in pre-school children (1). In order to obtain accurate estimates of sedentary time and physical activity in young children objective methods are needed (3). This is particularly important when associations with health outcomes are examined and when effects of interventions are evaluated (4). Accelerometers have been proven feasible and valid to assess physical activity and sedentary time in young children (1, 5, 6).

Accelerometers have most often been worn on the hip but alternative placement sites have been used, e.g. the wrist (7, 8). Wrist worn devices have shown good feasibility and acceptance among participants in previous studies (8) and may increase compliance (9). In contrast to hip mounted monitors wrist placed devices captures movements performed by the arms. This might particularly be important in order to capture the short bursts of high intensity activity in young children (10).

Calibration studies are needed to translate accelerometer output into intensity categories. The acceleration signal collected by many commercially available activity monitors is usually summarized in an arbitrary unit (counts). Several studies have been performed in order to calibrate these counts into applicable data such as time spent in sedentary behavior and various levels of physical activity (11). The placement of the activity monitor may affect the output (9, 12), thus affecting the validity of the measurement. Wrist worn accelerometers have shown good validity regarding accelerometer counts and physical activity energy expenditure in school aged children and adults (13, 14). However, poor correlation has been found when comparing wrist worn with hip worn accelerometers, which indicates that output from accelerometers worn on different sites are incomparable (9, 13). Age is another factor that might affect accelerometer output (3). Therefore, calibration and validation studies in specific age groups are needed (15).

The aim of this study was to calibrate the Actigraph GT3X+ accelerometer for wrist worn placement in ambulatory young preschoolers by developing intensity thresholds for sedentary, low and high intensity physical activity. Furthermore, we cross-validated the developed intensity thresholds in a sub-sample of our population and applied the developed thresholds in two year old children who wore the accelerometer during daily life.

Methods

Participants

Thirty-eight children (16 girls), 15-36 months old, were recruited from four preschools in Stockholm, Sweden. Parents received detailed information and signed written informed consent prior to inclusion. Only children that were ambulatory were included. Ethical permission was obtained from The Regional Ethical Review Board in Stockholm County, Dnr 2009/217-31/2.

The calibration, i.e. development of physical activity intensity thresholds, was conducted in a sub-group of the thirty-eight children (n=26). Every two out of three children from each of the four preschools were randomly selected, thus children from all preschools were included in the calibration part. To test the validity of the developed intensity thresholds, cross-validation was performed in the remaining 12 children.

The developed thresholds were thereafter applied to a sample of 20 two year old children (9 girls) who wore the monitor for seven days. Children were part of an ongoing intervention study aimed at preventing overweight and obesity in children with overweight or obese parents (16). The first 10 children from the intervention and the reference group, respectively, were included. Thus, the sample consisted of children with both normal weight and overweight/obese parents.

Procedures

Height and weight was measured using a portable stadiometer and an electronic scale (Tanita HD-316, Tanita Corp.; Tokyo, Japan). The Actigraph was attached around children's non-dominant wrist before the session started. In case the child had not developed any hand preference the left wrist was chosen.

Children were videotaped during 30 minutes of activity including indoor structured play followed by 15 minutes of outdoor free play at the preschool play yard. The structured indoor activities were divided into three phases of five minutes each; watching a cartoon, drawing and running an obstacle course. Activities were videotaped using a Canon Legria, FS306, camera (Canon Inc, Tokyo 146-8501, Japan). To identify the exact time the activities were performed each accelerometer were shaken before the session started while the computer clock was videotaped. Furthermore the clock in the same computer that was used for initializing the accelerometers was video recorded before each session started.

Actigraph GT3X+

The Actigraph GT3X+ (Actigraph, Pensacola, FL) measures acceleration in three orthogonal planes. It is light weight and has the size of 5 x 5 x 2 cm and water resistant. Data from the three axes can be extracted separately as well as a combined measure, the vector magnitude (VM). Data can be downloaded in raw format, gravity (g). The raw signal can also be digitized by an analog-to-digital converter and rectified and integrated over a defined epoch.

For this study a sampling rate of 30 Hertz was used and the counts were summed for a time interval of 5 seconds (3), for the Y-axis (vertical axis) and the VM, respectively.

Children´s Activity Rating Scale

Children's Activity Rating Scale (CARS) was used as the criterion measure to derive intensity thresholds for the accelerometer (17). CARS and modified versions have previously been used for calibration and has been proposed as the preferred criterion measure in young children (3, 11).

Physical activity intensity was coded in 5 second intervals according to CARS levels 1-5. Level 1 represent minor hand or arm movements; Level 2 standing, moving arms; Level 3 walking at a slow pace; Level 4 brisk walking; and Level 5 running (17). Coding of these intensities was performed by one researcher by video observations recording intensity every 5th second.

CARS score 1 was considered as sedentary, CARS 2-3 low intensity physical activity and CARS 4-5 high intensity physical activity. Similar scoring has been used in previous calibration studies (6, 11, 18). In order to develop thresholds for sedentary, data from watching a cartoon and drawing was used. In order to differentiate high intensity physical activity from low physical activity, data from running an obstacle course and free play were included.

Feasibility sample

For the application of the intensity thresholds 20 children wore the Actigraph GT3X+ for seven consecutive days and nights. The accelerometer data (Y-axis) was analyzed in the ActiLife program (Actigraph, Pensacola, FL), using the developed thresholds. No criteria for non-wear time were used, the accelerometers were assumed to have been worn 24 hours per day. In order to exclude sleep time 11 hours of sedentary time was removed as studies have shown that Swedish children two years of age sleep an average 11 hours per day, including naps (19). The data was not checked for waking and sleep- times, thus wake sedentary time might have been removed and sleep time might have been classified as sedentary time. Minutes spent in sedentary behavior, low and high intensity physical activity were calculated. Counts per minute (CPM) was also calculated as a measure of average intensity, based on total counts per day divided by total wear time (24h/day).

Statistical analysis

Descriptive data of the calibration-, the cross-validation- and the feasibility samples are presented as percent or means and standard deviations (SD). Each activity performed in the calibration and cross-validation part of the study for sedentary behavior, low and high intensity physical activity is presented as mean (SD) counts/5 seconds. Differences in mean counts/5 seconds between activities and intensity levels respectively, were tested using Student´s paired two-tailed T-test. In order to develop accelerometer thresholds for sedentary behavior, low and high intensity physical activity receiver operating characteristic (ROC) curves was used (18, 20). CARS score was paired with accelerometer data for the same each 5th second. Accelerometer data with corresponding CARS score 1 was averaged as well as accelerometer data with corresponding CARS score 2+3 and 4+5. Sensitivity and specificity in percent (%) as well as area under the curve (AUC) with confidence intervals (CI) are presented. An area under the curve of 1 represents perfect classification, whereas an area of 0.5 represents an absence of classification accuracy. ROC-AUC values of ≥ 0.90 are considered excellent, 0.80–0.89 good, 0.70–0.79 fair, and < 0.70 poor (21).

Cross-validation number of minutes spent in different intensity levels according to accelerometer data based on the thresholds developed in the calibration part was compared to number of minutes spent in corresponding CARS score. Data from all activities was used, i.e. watching a cartoon, drawing, running an obstacle course and free play. Mean minutes and SD of time spent in sedentary behavior, in low and in high intensity physical activity, respectively, was calculated. Spearmans rank correlations were used to assess agreement between minutes spent in different intensities according to accelerometer counts and CARS score for both the Y-axis and the VM. A correlation value of < 0,3 indicates poor association; 0.3-0,5 fair; 0.6-0.8 moderately strong and > 0.8 very strong association (22).

Data was analyzed using SPSS, version 20, for Windows (SPSS Inc., Chicago, IL). Level of significance was set at $p \leq 0.05$.

Results

Demographic characteristics of the children split by the calibration and the cross-validation samples are presented in table 1. Children were observed for an average of 29 minutes (range 15-36 min).

Table 2 displays mean (SD) Y-axis and VM accelerometer counts/5 seconds for each structured activity and free play, as well as for sedentary behavior, low and high intensity physical activity, based on CARS score. A statistically significant difference ($p< 0.05$) was seen between mean counts for sedentary and for low intensity physical activity as well as between low and high intensity physical activity and between sedentary and high intensity physical activity, for both the Y-axis and VM.

The developed intensity thresholds per 5 seconds for the Y-axis and VM are shown in table 3. Sensitivity, specificity and area under the curve (AUC) are also shown. AUC was at least 0.878 for all developed thresholds.

Table 4 displays cross-validation mean (SD) time classified as sedentary, low intensity physical activity and high intensity physical activity for CARS score and accelerometer data based on the developed thresholds. Spearman rank correlation between the two measures were above 0.69 for all intensities.

The 20 children (9 girls) which were measured during daily life were in average (SD) 2.0 (0.06) years old and provided valid data for a mean (SD) of 5.8 (0.6) days. Mean (SD) time spent in sedentary behavior, low and high intensity physical activity was 384 (70) minutes per day; 307 (SD 46) minutes per day and 89 (SD 34) minutes per day, respectively. Average intensity (SD) was 1116 (262) CPM.

Discussion

This is, to our knowledge, the first study to calibrate an accelerometer, worn on the wrist, in children as young as two years. We developed age specific intensity thresholds for sedentary behavior, low and high intensity physical activity, using a wrist mounted Actigraph accelerometer. The developed thresholds were also cross-validated and subsequently applied in 20 children, two years of age, in which physical activity was measured during daily life for seven days. Optimal Y-axis intensity thresholds to differentiate sedentary from low physical activity and low from high intensity physical activity were ≤ 89 counts and ≥ 440 counts per 5 seconds, respectively. The correlation between CARS score and mean time spent in each intensity levels according to the developed thresholds was at least moderately strong.

Previous calibration studies in preschool children, have used a hip placement of the monitor and collected data using a different epoch length (15-60 sec) (18, 23-25). One previous calibration study have provided intensity thresholds for children as young as 2 years of age (18) but most studies have been performed on children 3-5 years (23-25). The results from these previous studies have provided intensity thresholds for sedentary between 48 (18) and 301 (24) counts/15 seconds and between 417 (18) and 614 (24) counts/15 second for moderate to vigorous intensity physical activity. Due to differences in placement sites, types of accelerometers, epoch lengths and criterion measures, comparison between studies should be interpreted carefully. However, in general, we found higher intensity thresholds for sedentary behavior, low and high intensity physical activity, except for the sedentary threshold developed by Sirard et al (2005). This is likely explained by a different placement of the activity monitor (wrist) in the present study compared to previous studies.

Due to the intermittent activity pattern of young children we collected data using a 5 second epoch. A short epoch length might be necessary in order to capture the short bursts of high intensity physical activity that is characteristic for young children (3). Previous studies among older children have shown that activities in higher intensities rarely lasts for more than 10 seconds (26). When the use of different epoch lengths has been compared the estimates of time spent in higher intensities are higher when shorter epoch lengths are used (27, 28). To capture the short bursts of high intensity physical activity an even shorter epoch length, e.g. 1 second, might be preferred. However, it might be difficult to synchronize data on a 1 second level and the accuracy of each 1 second scoring to correspond with the same 1 second data from the accelerometer might be questionable.

Similar to some previous studies we used ROC analysis to develop intensity specific thresholds in order to maximize sensitivity and specificity (18, 24, 25). To differentiate sedentary from low physical activity specificity was 60% when sensitivity was 100%. Thus, all time spent sedentary will be correctly classified. However, part of the time spent in higher intensities will incorrectly be classified as sedentary. To differentiate high from low intensity physical activity specificity was higher than sensitivity. Thus no time spent in lower levels of physical activity will be classified as high intensity. However, part of the time that was spent in high intensity physical activity will be classified as low intensity. Therefore, there is a possibility that the thresholds developed in this study will overestimate time spent sedentary and underestimate time spent in higher intensities.

Strong correlations were found in the cross-validation between the developed thresholds for the accelerometer and CARS scoring for time spent in sedentary, low and high intensity physical activity. No difference between the two measures was found for sedentary time. However, a statistically significant difference between the two measures for minutes in low and high intensity physical activity was observed. More minutes were classified as low intensity and fewer minutes were classified as high intensity physical activity with CARS compared to that from the accelerometer, indicating that the developed intensity threshold for high intensity might be too low. However, as the correlations between the measures were high children with high intensity will still be identified.

Drawing and watching cartoons were used when deriving intensity thresholds for sedentary because children were likely to have more epochs sedentary during these activities compared to running an obstacle course and free play. Similarly, running an obstacle course and free play were used to derive thresholds for high intensity physical activity as these activities most likely included higher levels of activity. When choosing a short epoch length, such as 5 seconds, it is very important that the exact 5 second data from the accelerometer is synchronized with the exact 5 seconds the CARS score is based on. To ensure that the accelerometer data was correctly matched with the CARS score the clock in the computer used to initialize the accelerometers was video recorded before each session started. Furthermore, each accelerometer was shaken as a marker while the clock on the computer used to initialize the accelerometer was videotaped.

CARS have been interpreted differently across studies (11, 18). Like a previous study on feasibility and validity of accelerometers on 1-3 year olds, CARS score 1 and 2 was considered sedentary behavior (6). However, if the child was standing, performing minor hand movements, it was considered to be a CARS score 2. Thus, standing still was considered sedentary behavior, which might be questionable. Observational criterion methods, such as CARS, might not be optimal in order to capture the intermittent activity pattern of small children. However, we coded the activities every 5^{th} second which is likely the shortest epoch that can be used when data from accelerometry and an observational method should be synchronized. Previous calibration studies have used different criterion measures such as measures of energy expenditure (23) or other observational methods (25). In field-based research an observational method is convenient and inexpensive. CARS has been suggested as a good method for differentiating levels of physical activity in children (17).

Limited data is available on activity levels in children below the age of three years. One study on children 19 months old showed that children spent 184 minutes in low intensity physical activity and 47 minutes in moderate and vigorous intensity activity daily (29). A systematic review by Tucker (30) suggested that approximately 50% of 2-6 year old children were physically active for at least 60 minutes per day at a moderate or higher intensity levels. However, the majority of children included were 3-5 years old. Dolinsky et al (5) reported that 2 to 5 year old children spent 366 minutes per day sedentary and participated in moderate and vigorous intensity activity for 15 minutes per day, objectively measured by Actical accelerometers. In contrast, we observed substantially higher amounts of time spent in high intensity activity. These differences may be explained by differences in epoch length, intensity thresholds and the age of the children.

Differences in placement sites may explain differences between studies. Previous studies support the assertion that accelerometer output is higher when the device is worn on the wrist compared to the hip (9, 12, 14). Routen et al (9) observed that total counts was higher from the wrist placement compared with hip placement in 11 year old children (9). Site- and age specific intensity thresholds were applied to calculate time in different physical activity levels. Time spent sedentary was higher and time spent in low and high intensities was lower when data from the hip worn device was compared to the wrist worn (9).

Strengths of this study include that both structured activities and free play were included when deriving the intensity thresholds. As been mentioned earlier, preschool children have an intermittent activity pattern that might not be captured if activities are structured. Thus, it is important to include free play when calibrating accelerometers in this population. Further, we used a short epoch length to capture the momentary bursts of high intensity activity that characterizes young children. We also performed a cross-validation of the developed intensity thresholds which indicates that the developed intensity thresholds accurately estimates physical activity levels when compared to direct observation. This study provides results that are of importance for future research where objectively measured physical activity in young preschoolers is needed. These developed intensity thresholds enables categorization of young children’s physical activity and allows for the wrist as an alternative placement site, which might increase compliance.

The study is based on a relatively small sample. Further, children wore the accelerometer solely on the wrist. To enable comparison with previous calibration studies it would have been preferable if children simultaneously would have worn an accelerometer on the hip. We used an observational method as criterion measure, which include a subjective component when assessing the activity level. However the criterion measure used has been suggested the preferable method to assess different physical activity levels in preschool children. Future studies needs to confirm the derived thresholds in larger sample sizes, and compare the agreement between different placements of accelerometry in young preschoolers.

The developed intensity thresholds for a wrist mounted Actigraph activity monitor appear valid to categorize sedentary behavior and high intensity physical activity categories in children 2 years of age.

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Table 1. Characteristics of participant's percent or mean and standard deviation (SD), for calibration sample and cross-validation sample, respectively. Total sample N = 38.

Variable	Calibration sample N = 26	Cross-validation sample N = 12
Girls	38 %	50 %
Age (months)	26 (6.0)	25 (5.6)
Height (cm)	89.6 (5.1)	90.3 (6.2)
Weight (kg)	13.9 (1.6)	14.2 (1.8)
BMI (kg x m^2)†	17.2 (1.7)	17.5 (2.5)

†BMI= Body Mass Index

Table 2. Mean (SD) accelerometer Y-axis and Vector magnitude (VM) counts / 5 sec for the activities performed and for CARS classification sedentary, low and high intensity physical activity. Total sample N = 38.

	Y	VM
Activity		
Watching a cartoon	107 (89)	205 (156)
Drawing	142 (63) *	298 (111) *
Obstacle course	350 (122) *	626 (213) *
Free play	318 (117)	531 (197) *
CARS classification†		
Sedentary	128 (80)	246 (85)
Low intensity	296 (81) **	519 (127) **
High intensity	485 (160) **	836 (270) **

†Sedentary = CARS 1, Low intensity = CARS 2-3, High intensity = CARS 4-5

* Compared to the category below, $p < 0.05$

** Compared to the category below, $p < 0001$

Table 3. Sensitivity, specificity, area under the curve (AUC) and intensity thresholds (5 sec) for sedentary, low and high intensity physical activity, respectively. Calibration sample N = 26.

Axis	Activity level	Sensitivity (%)	Specificity (%)	AUC (95% CI)	Intensity threshold (5 s)
Y	Sedentary †	100	60.0	0.980 (0.950-1.000)	≤ 89
	Low intensity				90-439
	High intensity †	60,0	92.3	0.878 (0.784-0.973)	≥ 440
VM	Sedentary†	100	60.0	0.982 (0.954-1.0)	≤ 221
	Low intensity				222-729
	High intensity †	60,0	92.3	0.895 (0.811-0.980)	≥ 730

† Sedentary from watching cartoon and drawing and high intensity from obstacle course and free play