Validation of Accelerometer Cut Points in Toddlers with and without Cerebral Palsy

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ABSTRACT

OFTEDAL, S., K. L. BELL, P. S. W. DAVIES, R. S. WARE, AND R. N. BOYD. Validation of Accelerometer Cut Points in Toddlers with and without Cerebral Palsy. *Med. Sci. Sports Exerc.*, Vol. 46, No. 9, pp. 1808–1815, 2014. **Aim:** The purpose of this study was to validate uni- and triaxial ActiGraph cut points for sedentary time in toddlers with cerebral palsy (CP) and typically developing children (TDC). **Methods:** Children ($n = 103$, 61 boys, mean age = 2 yr, SD = 6 months, range = 1 yr 6 months–3 yr) were divided into calibration ($n = 65$) and validation ($n = 38$) samples with separate analyses for TDC ($n = 28$) and ambulant (Gross Motor Function Classification System I–III, $n = 51$) and nonambulant (Gross Motor Function Classification System IV–V, $n = 25$) children with CP. An ActiGraph was worn during a videotaped assessment. Behavior was coded as sedentary or nonsedentary. Receiver operating characteristic–area under the curve analysis determined the classification accuracy of accelerometer data. Predictive validity was determined using the Bland–Altman analysis. **Results:** Classification accuracy for uniaxial data was fair for the ambulatory CP and TDC group but poor for the nonambulatory CP group. Triaxial data showed good classification accuracy for all groups. The uniaxial ambulatory CP and TDC cut points significantly overestimated sedentary time (bias = -10.5% , 95% limits of agreement [LoA] = -30.2% to 9.1% ; bias = -17.3% , 95% LoA = -44.3% to 8.3%). The triaxial ambulatory and nonambulatory CP and TDC cut points provided accurate group-level measures of sedentary time (bias = -1.5% , 95% LoA = -20% to 16.8% ; bias = 2.1% , 95% LoA = -17.3% to 21.5% ; bias = -5.1% , 95% LoA = -27.5% to 16.1%). **Conclusion:** Triaxial accelerometers provide useful group-level measures of sedentary time in children with CP across the spectrum of functional abilities and TDC. Uniaxial cut points are not recommended. **Key Words:** SEDENTARY BEHAVIOR, PHYSICAL ACTIVITY, MOTOR IMPAIRMENT, YOUNG CHILDREN, DISABILITY

Cerebral palsy (CP) is the most common cause of physical disability in childhood with an incidence of around 2 per 1000 live births (21). It is an umbrella term for a group of permanent disorders of movement and posture, which cause activity limitation ranging from minimal to severe (25). The severity of gross motor impairment is classified using the Gross Motor Function Classification System (GMFCS I–V) (22).

The preschool years are a period of rapid gross motor development in children with CP, and most reach 90% of their functional capacity by the age of 4–5 yr (26). The underlying brain injury causing CP is nonprogressive, but the clinical manifestations change through the life span (25). Evidence of a peak in functional abilities around the age of 7 yr and a clinically significant decline during adolescence

has been found for some marginally and nonambulatory children with CP (GMFCS III–V) (13). This potential decline is of importance as it could be the difference between having the capacity to sit, crawl, stand, or walk with support and not being able to perform these activities (13). Not all children in this group experience this decline (13), and further research is required to determine which children will progress to a loss of functional ability.

Habitual physical activity (HPA) has been suggested as crucial to maintaining functional abilities as children with CP reach adolescence as it is thought (i) to prevent secondary musculoskeletal impairments and maximize functioning; (ii) to foster cognitive, social, and emotional development of children; and (iii) to develop and maintain neural structures and pathways (10,12,13). It is therefore of concern that school-age children and adolescents with CP participate in less HPA than children with typical development (6). The prevention of obesity is also of particular importance for children with CP, not only because of the long-term health risks associated with excess body fat but also because of the increased impairment to functional mobility related to being obese (14,23). An increased prevalence of obesity has been identified in children with CP classified as GMFCS I–II (24) while those classified as GMFCS IV–V have been found to have above average fat mass and below average muscle

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mass when compared with typically developing children (TDC) (32). The overall prevalence of overweight and obesity has been reported between 16% and 29% of children with CP across all GMFCS levels, depending on the population studied (9,17).

Sedentary behavior has been defined as “any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalent of task (MET) while in a sitting or reclining posture” (31). Emerging evidence suggests sedentary behavior has an independent influence on health, separate from that due to lack of sufficient moderate-to-vigorous physical activity (35). HPA includes all planned and unplanned physical activity a child undertakes throughout the day (3). Accelerometers have been used extensively in typically developing preschoolers in an attempt to quantify HPA by using intensity-related count thresholds (8,11). Only one study has attempted to calibrate and validate a uniaxial accelerometer in toddlers using 15-s sampling intervals and found poor validity for predicting sedentary time (39). It is possible that the immature movement patterns and short duration of activity bouts that are characteristic of toddlers may be better measured using shorter sampling intervals and three rather than one axis (2,7,20).

There is a methodological challenge in measuring physical activity intensity using activity monitors in toddlers with CP. The relationship between activity monitor output and activity intensity is unpredictable because of the disordered movement patterns and atypical postures, which are some of the core features of CP (25). The relationship is further complicated by diverse modes of ambulation: crawling, cruising, rolling, bottom shuffling, and atypical gait patterns. Each mode of ambulation might elicit a highly variable output from the activity monitor independent of intensity. The relationship between the level of intensity and activity monitor output may not be as easily inferred from data output as it would from a child who is primarily walking, jogging, or running using a typical gait pattern, and this makes deriving an intensity cut point difficult. A recent study of typically developing toddlers used lying/sitting, standing, walking slow or moderate, and running to classify activity intensity (39), but these activity descriptors may not apply to children with CP for several reasons. First, children with CP may not have the ability to perform these skills. Second, the metabolic equivalent of task (MET) values assigned to activities as a measure of activity intensity to separate light activity from moderate-to-vigorous physical activity might not truly represent the true exertion experienced by a child with CP. It has been shown that school-age children with CP have a greater energy cost of walking than TDC, and this could be an issue in a younger population as well, although it has not been confirmed (34). Measurement of oxygen consumption during specific physical tasks to determine MET values for children with CP using a portable indirect calorimeter would be difficult, if not impossible, in toddlers with CP. The influence of the apparatus on movement during activities such as rolling, crawling, and

bottom shuffling as well as compliance issues in the young age group would all affect the ability to obtain the required measurements. Focusing instead on the measurement of sedentary versus nonsedentary behavior eliminates much of this ambiguity while still allowing the assessment of a measure that can be linked to important health outcomes.

This study aimed (i) to develop uniaxial and triaxial ActiGraph cut points for determining time spent sedentary and (ii) to evaluate and compare the predictive validity of these cut points in children age 18 to 36 months with CP across the spectrum of functional severity (GMFCS I–V) and TDC.

METHODS

Participants

Children were assessed as part of two overlapping prospective longitudinal cohort studies: the Queensland CP Child Study of Motor Function and Brain Development (NHMRC 465128) (5) and the Queensland CP Child Study of Growth, Nutrition and Physical Activity (NHMRC 569605) (4). Detailed descriptions of study design and inclusion and exclusion criteria have been published elsewhere (4,5). Informed consent was obtained from the child's primary caretaker. For the present study, only assessments conducted between 18 and 36 months were included. Not all appointments in this age range were for the Growth Nutrition and Physical Activity Study; therefore, height and weight measures were not available for all children. Ethical approvals were received from the University of Queensland Medical Research Ethics Committee (2008002260), the Children's Health Services District's Ethics Committee (HREC/08/QRCH/122), and the Queensland CP League (CPLQ 2008/2010 1029).

Children with typical development age 18 to 36 months were recruited through the University of Queensland and Royal Children Hospital staff. Ethical approvals were received from the University of Queensland Medical Research Ethics Committee (2008002260 amendment 7/3/13) and the Children's Health Services District's Ethics Committee (HREC/08/QRCH/122/AM05). Healthy children were included if they were born at term (>37 wk gestation), had no admissions to the neonatal care unit, had no diagnosis receiving medical/allied health care, were not on regular medications, and had an informed consent from their primary caretaker.

Children with CP were divided into an ambulatory (GMFCS I–III) and nonambulatory (GMFCS IV–V) group. The GMFCS is a five-level ordinal grading system based on the assessment of self-initiated movement with emphasis on function with regard to sitting and walking (22). The type of CP and motor distribution (unilateral, bilateral, and number of limbs involved) was determined by two independent physiotherapists, and analysis was undertaken to assess differences between groups (29,33).

For the CP group, 96 assessments were performed on 75 children. Some children contributed data at several age points to allow more epochs for analysis over a wider age range. The number of individual children versus number of included assessments has been noted in Tables 1–4. Participants were randomly divided into calibration and validation groups at a 2:1 ratio to allow a larger sample for calibrating cut points. Separate analysis was performed for ambulatory and nonambulatory children with CP and TDC.

Data collection started in 2009 before the release of the triaxial ActiGraph. Consequently, some assessments of children with CP only have data from uniaxial monitors (GT1M) available ($n = 36$), whereas some assessments have data from monitors that provide both uniaxial and triaxial measurement (GT3X and GT3X+) ($n = 60$). Uniaxial data are therefore available for all 96 assessments, whereas triaxial data are only available for 60 assessments for children with CP. All TDC wore monitors, which provide both uniaxial and triaxial measurement ($n = 28$). The participant's weight was measured to the nearest 100 g using portable electronic scales (Homemaker, Australia) or chair scales (Seca Ltd., Germany). Height or recumbent length was measured to the last completed millimeter with a portable stadiometer (Shorr Productions, LLC, Olney, MD). Body mass index was determined as weight (kg) / height (m)².

Activity Monitoring

All children with CP had their functional abilities assessed by an experienced physiotherapist using the Gross Motor Function Measure 66 (GMFM-66) (28). The GMFM assessment was play based, with the therapist using toys and games to encourage the child to show the range of their gross motor skills in a natural, self-initiated manner. This

ensured the transition from sedentary to active in a range of situations (e.g., changing from sitting unsupported on a floor doing a puzzle to crawling to retrieve a piece of the puzzle placed out of reach) could be observed. The length of valid wear time was determined as the time taken to complete the assessment less any time the child was carried or was out of view from the camera. The children with typical development were also videotaped while wearing the ActiGraph during a 20- to 30-min play session and were encouraged to partake in activities including quiet floor play, walking, running, and jumping in a similar manner to the children with CP. Children wore an ActiGraph accelerometer during the assessment, which was videotaped to enable direct observation scoring of their activity level.

Two ActiGraph models (Shalimar, FL) were used, the GT1M and the GT3X (original GT3X and GT3X+). The GT1M is a biaxial accelerometer and measures magnitude of movement in the vertical (X) and anteroposterior (Y) planes. The GT3X is a triaxial accelerometer that measures movement in an additional third mediolateral plane (Z) and computes a composite vector magnitude ($VM: \sqrt{X^2 + Y^2 + Z^2}$) of the three axes. The GT3X+ is the same as the GT3X but also provides raw accelerometer data in addition to count per user-specified epoch output. The vertical axis of the GT1M and GT3X can be used interchangeably (30). For the uniaxial analysis, a cut point for the vertical axis was determined and applied, whereas for the triaxial analysis, a cut point for vector magnitude was determined and applied. Comparisons were made between the classification accuracy, sensitivity, specificity, and predictive validity of the uniaxial and triaxial cut points for each study group (TDC, GMFCS I–III, and GMFCS IV–V). The accelerometer was attached to a neoprene belt worn around the waist, centered at the child's back. The hip or the lower back has been

TABLE 1. Characteristics of the calibration and validation samples for children with CP and TDC.

Group	Calibration Sample			Validation Sample		
	TDC ^a	I–III ^b	IV–V ^b	TDC ^a	I–III ^b	IV–V ^b
Children (n)						
Uniaxial	18	33	14	10	18	11
Triaxial	18	21	6	10	16	7
Ax (n)						
Uniaxial	18	39	21	10	23	13
Triaxial	18	18	11	10	18	7
Age (year:months)	2:3 (0:6)	2:4 (0:6)	2:4 (0:7)	2:5 (0:6)	2:6 (0:7)	2:5 (0:7)
GMFM-66 score (%)	—	51 ± 9	26 ± 6	—	50 ± 8	28 ± 7
GMFM-66 range (%)	—	42–65	20–33	—	39–63	20–39
Sex						
Boys	8	13	9	5	8	8
Girls	10	26	12	5	15	5
Anthropometry						
Height (cm)	88.0 ± 1.1	86.2 ± 3.7	84.9 ± 7.9	88.6 ± 5.9	84.1 ± 6.3	86.5 ± 8.5
Height (z-score)	0.0 ± 1.1	−0.6 ± 1.0	−0.9 ± 1.8	−0.1 ± 1.1	−1.3 ± 1.5	−0.5 ± 0.8
Weight (kg)	13.4 ± 1.6	12.2 ± 1.4	11.4 ± 2.1	13.9 ± 1.7	11.3 ± 2.1	12.6 ± 1.9
Weight (z-score)	0.4 ± 0.9	−0.6 ± 1.0	−1.2 ± 1.4	0.4 ± 1.1	−1.5 ± 1.7	−0.2 ± 0.5
BMI (kg·m ^{−2})	17.3 ± 1.3	16.5 ± 1.2	15.8 ± 1.6	17.8 ± 1.9	16.9 ± 1.0	15.7 ± 1.3
BMI (z-score)	1.0 ± 0.9	0.1 ± 1.1	−0.3 ± 1.3	1.2 ± 1.2	−0.4 ± 1.1	0.8 ± 0.7

Values are presented as mean ± SD or n , unless otherwise noted.

^aTDC, typically developing children.

^bGMFCS, Gross Motor Function Classification System.

Children, number of individual children; Ax, number of assessments; GMFM, Gross Motor Function Measure; BMI: body mass index.

TABLE 2. Classification accuracy, sensitivity, and specificity of cut points for sedentary time.

Sample	Age	<i>n</i>	Ax	ROC-AUC	95% CI	Cut Point	SE %	SP %
Uniaxial								
I–III ^a	18–36	33	39	0.77	0.76–0.78	2	71	77
IV–V ^a	18–36	14	21	0.68	0.66–0.71	2	49	77
TDC	18–36	18	18	0.77	0.75–0.80	2	67	85
Triaxial								
I–III ^a	18–36	21	24	0.81	0.80–0.82	40	75	76
IV–V ^a	18–36	6	11	0.81	0.78–0.84	10	75	77
TDC	18–36	18	18	0.82	0.79–0.84	40	77	73

^aGMFCS, Gross Motor Function Classification System.

n, number of individual children; Ax, number of total assessments included; ROC-AUC, receiver operator characteristic–area under the curve; CI, confidence interval; SE, sensitivity; SP, specificity.

suggested as the best placement of an accelerometer in children (38). The lower back placement was chosen for this group of toddlers as it was deemed less obtrusive for the variety of ambulation methods used, and to minimize the effect of asymmetry due to their physical impairments. Acceleration data were reported as counts per 5-s epoch.

Observed behavior was classified as either sedentary or nonsedentary in real time using the computerized direct observation software Behavioral Evaluation Strategy and Taxonomy (Educational Consulting, Inc., FL) (40). For coding purposes, sedentary behavior was identified as lying or sitting with or without limb movement, or standing completely still due to the inability of the accelerometer to distinguish between lying, sitting, and standing still (all recording zero counts per epoch). If a child was out of view or moved by the physiotherapist or parent, this was scored as a zero and excluded from analysis. A single observer conducted all video coding. Intrarater reliability was established by duplicate scoring of 20 videos (four children from each GMFCS level). Percent agreement for 2163 5-s

epochs of duplicate scores was 87% with a kappa score of 0.82 ($P < 0.001$). Four videos of TDC were also scored twice, and the percent agreement of 453 5-s epochs was 91% with a kappa score of 0.84 ($P < 0.001$). Both of these kappa scores were classified as “almost perfect agreement” (18).

Second-by-second direct observation activity scores were averaged over each 5-s epoch to allow matching with the accelerometer data output. The ActiGraph was initialized to a digital watch shown at the start of the videotape to allow synchronization. If a 5-s epoch was exclusively sedentary (activity score = 1.0), it was classified as sedentary; if it contained any activity (activity score > 1.0), it was classified as nonsedentary.

Analysis

Participants. Differences in characteristics were explored within samples (calibration and validation) and between groups (GMFCS I–III, GMFCS IV–V, and TDC) using a one-way ANOVA with a Bonferroni *post hoc* test at a 5% significance level.

TABLE 3. Comparison of classification accuracy, sensitivity, and specificity of identified cut points for sedentary time for GMFCS (I–V) and age groups.

Sample	Age	<i>n</i>	Ax	ROC-AUC	95% CI	Cut Point	SE %	SP %
Uniaxial								
I ^a	18–36	8	9	0.78	0.75–0.80	2	70	80
II ^a	18–36	9	12	0.74	0.71–0.76	2	64	79
III ^a	18–36	15	18	0.73	0.70–0.75	2	61	80
I–III ^a	18–24	15	19	0.78	0.75–0.80	2	71	79
I–III ^a	30–36	17	20	0.73	0.71–0.75	2	64	82
IV ^a	18–36	7	11	0.72	0.68–0.76	2	56	86
V ^a	18–36	7	10	0.61	0.54–0.68	2	30	91
IV–V ^a	18–24	7	11	0.67	0.60–0.75	2	40	99
IV–V ^a	30–36	7	10	0.71	0.67–0.75	2	51	88
TDC	18–24	8	8	0.81	0.78–0.84	2	73	87
TDC	30–36	10	10	0.74	0.70–0.78	2	64	80
Triaxial								
I ^a	18–36	7	8	0.83	0.81–0.85	40	82	73
II ^a	18–36	7	7	0.79	0.77–0.82	40	70	77
III ^a	18–36	7	9	0.81	0.79–0.83	40	70	80
I–III ^a	18–24	8	9	0.84	0.82–0.86	40	80	74
I–III ^a	30–36	13	15	0.80	0.78–0.82	40	71	78
IV ^a	18–36	1	2	0.86	0.83–0.89	10	77	82
V ^a	18–36	5	7	0.71	0.65–0.77	10	65	70
IV–V ^a	18–24	2	4	0.83	0.77–0.89	10	72	99
IV–V ^a	30–36	4	7	0.81	0.78–0.85	10	75	74
TDC	18–24	8	8	0.86	0.83–0.88	40	82	75
TDC	30–36	10	10	0.78	0.74–0.81	40	74	70

^aGMFCS level, Gross Motor Function Classification System.

TDC, typically developing children; cut point: counts per 5 s; Ax, number of assessments included; *n*, number of individual children included; ROC-AUC, receiver operator characteristic–area under the curve; CI, confidence interval; SE, sensitivity; SP, specificity.

TABLE 4. Estimates of time spent sedentary and bias between observed and predicted time spent sedentary (min).

Table 1. Estimates of time spent sedentary: bias between observed and predicted time spent sedentary (min).												
	<i>n</i>	Ax	Method	SE	SP	Total Valid Time (min) ^a		Sedentary Time (min)		Bland Altman Analysis		
						Mean	Range	Mean	Range	Bias ^b	95% LoA	<i>P</i> ^c
Uniaxial Accelerometer												
I–III ^d	23	18	Observation	—	—	18.3	7.4–34.0	7.8	0.3–24.9	—	—	—
			Cut point	74%	80%	—	—	9.4	1.8–23.4	–10.5%	–30.2% to 9.1%	<0.001
IV–V ^d	13	12	Observation	—	—	9.6	1.5–43.0	6.8	1.4–30.7	—	—	—
			Cut point	69%	93%	—	—	7.8	1.3–40.8	–1.8%	–31.0% to 27.4%	0.230
TDC	10	10	Observation	—	—	11.0	3.6–21.8	4.8	0.2–14.2	—	—	—
			Cut point	76%	93%	—	—	6.6	0.5–13.6	–17.3%	–44.3% to 8.3%	<0.011
Triaxial accelerometer												
I–III ^d	18	16	Observation	—	—	17.1	7.5–29.1	6.9	0.6–17.3	—	—	—
			Cut point	79%	72%	—	—	7.0	0.8–13.7	–1.5%	–20.0% to 16.8%	0.965
IV–V ^d	7	7	Observation	—	—	11.6	1.5–42.9	7.7	1.4–30.7	—	—	—
			Cut point	68%	91%	—	—	8.3	1.1–36.2	2.1%	–17.3% to 21.5%	0.381
TDC	10	10	Observation	—	—	11.0	3.6–21.8	4.8	0.2–14.2	—	—	—
			Cut point	82%	83%	—	—	5.2	0.5–11.0	–5.1%	–27.5% to 16.1%	0.524

^aTotal valid time = total time coded – excluded time due to therapist/parent handling.^bBias = difference between observed and cut point predicted time spent sedentary as percentage of time spent sedentary.^c*P* value: paired *t*-test for significant difference between observed and predicted time spent sedentary.^dGMFCS level, Gross Motor Function Classification System.min, minutes (1 min = 12 epochs); LoA, limits of agreement; TDC, typically developing children; Ax: number of assessments included; *n*: number of individual children included.

Calibration of cut points. A receiver operator characteristic–area under the curve (ROC-AUC) analysis (19) was conducted to derive cut points that maximize sensitivity and specificity. Counts per 5 s served as the independent variable. The dependent variable was the indicator (0, 1), where 1 = nonsedentary and 0 = sedentary. An ROC-AUC value of 1 represents perfect classification, whereas an area of 0.5 represents a complete absence of classification accuracy. ROC-AUC values of ≥0.90 are considered excellent, 0.80–0.90 good, 0.70–0.80 fair, and <0.70 poor (19). The cut point that maximized sensitivity and specificity was chosen and applied in the validation sample. Sensitivity analysis, where one child was included at only one age point in the ROC-AUC analysis, was performed to assess the effect of including some children at more than one age point. Separate analyses of the GMFCS levels (I–V) as well as ages 18–24 yr versus 30–36 months for all groups was completed to ensure age groups and GMFCS levels could be grouped together. A separate calibration analysis of children with unilateral and bilateral CP was conducted to explore any differences.

Validation of cut points. To assess the predictive validity of the cut points, sensitivity and specificity were determined in an independent sample of children. The Bland–Altman analysis was used to determine the bias and 95% limits of agreement between observed and predicted time spent sedentary. A paired *t*-test was used to test the significance differences between observed and predicted time spent sedentary at a 5% significance level. Linear regression analysis was used to test for systematic bias in prediction of time spent sedentary. The design effect of including multiple assessments from some children in the Bland–Altman analysis as well as the true sample size was calculated. Sensitivity analysis where only one assessment from each child was included was performed to assess if this altered validation results.

RESULTS

Participants. No significant differences in age, gender, GMFM, height/recumbent length, weight, or anthropometry *z*-scores between the calibration and the validation samples within the GMFCS I–III and IV–V and TDC groups were found (Table 1). There was no difference between the GMFCS I–III and the GMFCS IV–V groups, but the GMFCS I–III group was significantly lighter (*P* < 0.01) and shorter (*P* < 0.05) than the TDC group, and the GMFCS IV–V group was significantly lighter than the TDC group (*P* < 0.01). For the GMFCS I–III group, the primary motor type was bilateral spasticity (61%) with two limbs involved (i.e., spastic diplegia; 35%), followed by unilateral spasticity (i.e., hemiplegia; 30%). One child had dyskinesia (2%), and three children had hypotonia (6%). For the GMFCS IV–V group, the primary motor type was bilateral spasticity (80%) with four limbs involved (i.e., quadriplegia; 68%). The remaining five children had dyskinesia (20%).

Calibration of cut points. Results of calibration analysis can be found in Table 2. The cut point, which maximized sensitivity and specificity for all groups when using the uniaxial accelerometer, was two counts per 5-s epoch. Classification accuracy was fair for the GMFCS I–III and TDC groups and poor for the GMFCS IV–V group. For the triaxial accelerometer classification, accuracy was good for all groups, and the cut point identified for the GMFCS I–III and TDC groups was 40 counts per 5-s epoch and 10 counts per 5-s epoch for the GMFCS IV–V group. Sensitivity analysis where only one assessment for each child was included showed no difference in classification accuracy rating and the same cut point allowed sensitivity and specificity to be maximized (data not shown).

The following results can be found in Table 3. When separated according to GMFCS, there was no difference in classification accuracy rating (excellent/good/fair/poor) between the

GMFCS I, II, and III levels. The same cut points for all three GMFCS levels allowed maximization of sensitivity and specificity, and the three GMFCS levels were combined as one subgroup (GMFCS I–III). There was a difference between the classification accuracy rating of the GMFCS IV and V levels; however, the same cut points allowed maximization of sensitivity and specificity. Therefore, the two GMFCS levels were grouped together (GMFCS IV–V). There was no difference in classification accuracy rating between the two age bands (18–24 and 30–36 months) in the GMFCS I–III group, and they were grouped together (18–36 months). Although there was a difference in classification accuracy rating between age bands for the GMFCS IV–V group, the same cut point allowed maximization of sensitivity and specificity, and they were grouped together. For the TDC sample, there was a difference in classification accuracy rating between the two age bands, but the same cut point allowed maximization of sensitivity and specificity so the age bands were combined.

A separate analyses for children with unilateral and bilateral CP for the GMFCS I–III group also revealed no difference in the classification accuracy rating, and the same cut point allowed maximization of sensitivity and specificity (data not shown). The GMFCS IV–V group consisted primarily of children with bilateral spasticity, whereas other CP motor types had small sample sizes and therefore could not be compared.

Validation of cut points. The identified cut points were applied to independent samples of children, and the resulting sensitivity and specificity can be found in Table 4. The bias and 95% limits of agreement as a percentage of scored time between directly observed and accelerometer predicted time spent sedentary in the validation sample are shown in Table 4. The uniaxial GMFCS I–III and TDC cut point significantly overestimated time spent sedentary, whereas the GMFCS IV–V cut point only showed a small bias. The difference between observed and predicted time spent sedentary for the triaxial GMFCS I–III, GMFCS IV–V, and TDC cut points were minimal and nonsignificant, with similar limits of agreement. The design effect (D_{eff}) of including multiple assessments from some children with CP in the Bland–Altman analysis was minimal for all groups ($D_{\text{eff}} = 1.05\text{--}1.11$) with a true sample size of 20 and 17 children, respectively, for the GMFCS I–III uniaxial and triaxial groups, and 13 children for the uniaxial GMFCS IV–V group. The triaxial GMFCS IV–V group did not have any children where multiple assessments were used. The minimal design effect was reflected in the sensitivity analysis where only one assessment for each child was included as it showed minimal difference in bias or limits of agreement (data not shown).

In Table 4, it can be observed that children wore the ActiGraph for varying amount of time due to the length of their assessment, their level of tolerance of the ActiGraph, and the varying amounts of excluded time due to handling from the physiotherapist. Children also spent varying amounts of time sedentary as the assessment was not scripted but an assessment of self-initiated movement. Both of these factors may introduce a bias in the data as some children contributed

more epochs to analysis than others. The percentage of time spent sedentary was therefore chosen as a measure over the absolute number of time spent sedentary to minimize this bias. A linear regression analysis showed the relationship between total scored time and percentage of time spent sedentary was not significant for any group of children ($P > 0.05$). Furthermore, the observed time spent sedentary and the difference between observed and predicted time spent sedentary was not significant for any group of children ($P > 0.05$).

DISCUSSION

Australian and Canadian physical activity guidelines state children age from 1 to 5 yr should engage in active play for at least 3 h throughout the day and should not be sedentary, restrained, or kept inactive for more than 1 h at a time, except sleeping (1,36,37). There is no specific recommendation regarding the intensity of activity for this age group but rather emphasizing total volume of activity and limiting periods of sedentary behavior. One study of typically developing toddlers and several studies of typically developing preschoolers have therefore used total accelerometer wear time less time spent sedentary as a measure of total activity time (light, moderate, or vigorous) to assess whether children meet the recommendations (8,15,16).

To our knowledge, this study is the first to identify and validate ActiGraph cut points in toddlers with CP across the spectrum of functional abilities and compare it to a TDC reference group. The derived triaxial cut points for all groups (GMFCS I–III, GMFCS IV–V, and TDC) showed good classification accuracy in the calibration study, and no significant difference between observed and predicted time spent sedentary was identified in the validation sample. Because of the small group bias but wide limits of agreement ($\pm 20\%$) for individual children, it is recommended that the cut point is applied on a group-level basis only. Applying the cut points to collected data for each individual child but using the group mean and standard deviation for outcome measures such as time spent sedentary will allow the comparison of groups (e.g., intervention vs nonintervention group or TDC vs GMFCS I vs GMFCS III groups). The use of uniaxial accelerometer cut points is not recommended for any of the three groups studied. The uniaxial accelerometer cut point significantly overestimated time spent sedentary for children in GMFCS I–III and had wider limits of agreement than the triaxial cut point for children in GMFCS IV–V. The results align with the results of the previously discussed study of the uniaxial ActiGraph used in typically developing toddlers, as a significant overestimation of time spent sedentary and the wide limits of agreement were identified (39).

A study comparing the GT1M and older ActiGraph models indicates that the introduction of a low-frequency filter in the GT1M and subsequent monitors causes them to require a larger acceleration to record a nonzero activity count response (27). The filter was introduced to reduce

error in the data caused by nonhuman movement such as car riding. The GT3X+ model records raw accelerometry data in addition to the count per epoch data available in the GT1M and original GT3X, and so it allows inclusion of low-frequency accelerations in the counts per epoch data output if this is desired. Removing the low-frequency filter could potentially improve the sensitivity of the vertical axis as it would require less movement to record nonzero activity counts. The GT3X+ accelerometer was released toward the end of this present study, so for most of children, raw accelerometry data were not available. Triaxial data use vector magnitude, which includes movement in three axes and requires significant movement in one axis or slight movement in several axes for an epoch to be classified as “nonsedentary.” This allows slight movement in sedentary pursuits while still being able to differentiate between sedentary and nonsedentary behavior.

The strengths of this study include the use of a real-time direct observation criterion measure, the inclusion of an independent validation group, and the inclusion of children with CP across the spectrum of gross motor abilities, and a typically developing comparison group. Limitations include the lack of raw accelerometry data for investigation of whether removing the low-frequency filter improves the sensitivity of the vertical axis and the lack of an inclinometer to distinguish between lying, sitting, and standing still. In addition, the establishment of within-subject reliability would further improve the clinical utility of the developed cut points as they could be used to reliably establish an individual child’s level of sedentary behavior and enable it to be tracked over time.

Evidence-based recommendations regarding recommended amounts of physical activity for improving or maintaining motor function promote a healthy body composition and foster cognitive, social, and emotional development are currently lacking in the clinical management of children with CP. The use of the triaxial cut points in ambulatory (GMFCS I–III) and nonambulatory (GMFCS IV–V) toddlers with CP and TDC

will make it possible for researchers to compare the amounts of sedentary time and time in total physical activity between children with CP and TDC, as well as the duration and number of sedentary bouts for comparison to current physical activity guidelines. This allows a description of HPA and sedentary behavior patterns and enables longitudinal studies of the relationship between these modifiable lifestyle factors and health outcomes to guide physical activity recommendations specific to this population for use in clinical practice and health promotion initiatives.

CONCLUSIONS

Triaxial ActiGraph accelerometer cut points are valid for measurement of time spent sedentary in ambulatory and nonambulatory toddlers with CP and in typically developing toddlers. The use of triaxial cut points for group-level measurement of time spent sedentary in these groups of children demonstrated good classification accuracy and no significant difference between observed and predicted time spent sedentary. The use of uniaxial ActiGraph accelerometer data is not recommended for use in toddlers with CP or typically developing toddlers based on the findings of this study.

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REFERENCES

1. Australian Department of Health and Ageing. National Physical Activity Recommendations for Children 0–5 Years Australian Department of Health and Ageing [Internet]2010 [cited 2013 June 1]. Available from: http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-strateg-phys-act-guidelines#rec_0_5.
2. Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children’s physical activities: an observational study. *Med Sci Sports Exerc.* 1995;27(7):1033–41.
3. Bania T, Dodd KJ, Taylor N. Habitual physical activity can be increased in people with cerebral palsy: a systematic review. *Clin Rehab.* 2011;25(4):303–15.
4. Bell K, Boyd R, Tweedy S, Weir K, Stevenson R, Davies P. A prospective, longitudinal study of growth, nutrition and sedentary behaviour in young children with cerebral palsy. *BMC Public Health.* 2010;10(1):179.
5. Boyd R, Jordan R, Pareezer L, et al. Australian Cerebral Palsy Child Study: protocol of a prospective population based study of motor and brain development of preschool aged children with cerebral palsy. *BMC Neurology.* 2013;13(1):57.
6. Carlon SL, Taylor NF, Dodd KJ, Shields N. Differences in habitual physical activity levels of young people with cerebral palsy and their typically developing peers: a systematic review. *Disabil Rehabil.* 2013;35(8):647–55.
7. Cliff DP, Reilly JJ, Okely AD. Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0–5 years. *J Sci Med Sport.* 2009;12(5):557–67.
8. Colley R, Garriguet D, Adamo K, et al. Physical activity and sedentary behavior during the early years in Canada: a cross-sectional study. *Int J Behav Nutr Phys Act.* 2013;10(1):54.
9. Dahlseng MO, Finbraten AK, Juliusson PB, Skranes J, Andersen G, Vik T. Feeding problems, growth and nutritional status in children with cerebral palsy. *Acta Paediatr.* 2012;101(1):92–8.
10. Damiano DL. Activity, activity, activity: rethinking our physical therapy approach to cerebral palsy. *Phys Ther.* 2006;86(11):1534–40.

11. De Vries SI, Van Hirtum HW, Bakker I, Hopman-Rock M, Hirasings RA, Van Mechelen W. Validity and reproducibility of motion sensors in youth: a systematic update. *Med Sci Sports Exerc.* 2009;41(4):818–27.
12. Fowler EG, Kolobe TH, Damiano DL, et al. Promotion of physical fitness and prevention of secondary conditions for children with cerebral palsy: section on pediatrics research summit proceedings. *Phys Ther.* 2007;87(11):1495–510.
13. Hanna SE, Rosenbaum PL, Bartlett DJ, et al. Stability and decline in gross motor function among children and youth with cerebral palsy aged 2 to 21 years. *Dev Med Child Neurol.* 2009;51(4):295–302.
14. Hills AP, King NA, Armstrong TP. The contribution of physical activity and sedentary behaviours to the growth and development of children and adolescents: implications for overweight and obesity. *Sports Med.* 2007;37(6):533–45.
15. Hinkley T, Salmon J, Okely AD, Crawford D, Hesketh K. Preschoolers' physical activity, screen time, and compliance with recommendations. *Med Sci Sports Exerc.* 2012;44(3):458–65.
16. Hnatiuk J, Ridgers ND, Salmon J, Campbell K, McCallum Z, Hesketh K. Physical activity levels and patterns of 19-month-old children. *Med Sci Sports Exerc.* 2012;44(9):1715–20.
17. Hurvitz EA, Green LB, Hornyak JE, Khurana SR, Koch LG. Body mass index measures in children with cerebral palsy related to gross motor function classification: a clinic-based study. *Am J Phys Med Rehabil.* 2008;87(5):395–403.
18. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;33(1):159–74.
19. Metz CE. Basic principles of ROC analysis. *Semin Nucl Med.* 1978;8(4):283–98.
20. Oliver M, Schofield GM, Schluter PJ. Accelerometry to assess preschooler's free-play: issues with count thresholds and epoch durations. *Meas Phys Educ Exerc Sci.* 2009;13(4):181–90.
21. Oskoui M, Coutinho F, Dykeman J, Jetté N, Pringsheim T. An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. *Dev Med Child Neurol.* 2013;55(6):509–19.
22. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and Reliability of a System to Classify Gross Motor Function in Children with Cerebral Palsy. *Dev Med Child Neurol.* 1997;39:214–23.
23. Peterson MD, Gordon PM, Hurvitz EA. Chronic disease risk among adults with cerebral palsy: the role of premature sarcopenia, obesity and sedentary behaviour. *Obes Rev.* 2013;14(2):171–82.
24. Rogozinski B, Davids J, Davis R, et al. Prevalence of obesity in ambulatory children with cerebral palsy. *J Bone Joint Surg Am.* 2007;89:2421–6.
25. Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M. A report: the definition and classification of cerebral palsy April 2006. *Dev Med Child Neurol.* 2007;49:S8–S14.
26. Rosenbaum PL, Walter SD, Hanna SE, et al. Prognosis for gross motor function in cerebral palsy. *JAMA.* 2002;288(11):1357–63.
27. Rothney MP, Apker GA, Song Y, Chen KY. Comparing the performance of three generations of ActiGraph accelerometers. *J Appl Physiol.* 2008;105(4):1091–7.
28. Russell D, Rosenbaum P, Cadman D, Gowland C, Hardy S, Jarvis S. The Gross Motor Function Measure: a means to evaluate the effects of physical therapy. *Dev Med Child Neurol.* 1989;31:341–52.
29. Sanger T, Delgado M, Gaebler Spira D, Hallett M, Mink J. Classification and definition of disorders causing hypertonía in childhood. *Pediatr.* 2003;111:e89–e97.
30. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sc Med Sport.* 2011;14(5):411–6.
31. Sedentary Behaviour Research N. Letter to the editor: standardized use of the terms “sedentary” and “sedentary behaviours”. *Appl Physiol Nutr Metab.* 2012;37(3):540–2.
32. Sullivan P, Alder N, Bachlet A, et al. Gastrostomy feeding in cerebral palsy: too much of a good thing. *Dev Med Child Neurol.* 2006;48(11):877–82.
33. Surveillance of Cerebral Palsy in Europe. Surveillance of cerebral palsy in Europe: a collaboration of cerebral palsy surveys and registers. *Dev Med Child Neurol.* 2000;42:816–24.
34. Thomas S, Buckon C, Russman B, Sussman M, Aiona M. A comparison of the changes in the energy cost of walking between children with cerebral palsy and able-bodied peers over one year. *J Pediatr Rehabil Med.* 2011;4(3):225–33.
35. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. *Appl Physiol Nutr Metab.* 2010;35(6):725–40.
36. Tremblay MS, Leblanc AG, Carson V, et al. Canadian physical activity guidelines for the early years (aged 0–4 years). *Appl Physiol Nutr Metab.* 2012;37(2):345–69.
37. Tremblay MS, Leblanc AG, Carson V, et al. Canadian sedentary behaviour guidelines for the early years (aged 0–4 years). *Appl Physiol Nutr Metab.* 2012;37(2):370–91.
38. Trost S, McIver K, Pate R. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc.* 2005;37:531–43.
39. Trost SG, Fees BS, Haar SJ, Murray AD, Crowe LK. Identification and validity of accelerometer cut-points for toddlers. *Obesity.* 2012;20(11):2317–9.
40. Welk G, Eisenmann J, Schaben J, Trost S, Dale D. Calibration of the biotrainer pro activity monitor in children. *Ped Exerc Sci.* 2007;19:145–58.