Ability of cut-points for the RT3 accelerometer to detect physical activity intensity in ambulatory children and adolescents with cerebral palsy.

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Abstract

This study investigated the ability of published cut-points for the RT3 accelerometer to differentiate between levels of physical activity intensity in children with cerebral palsy (CP). Oxygen consumption (METs) and RT3 data (counts per minute) was measured during rest and five walking trials. METs and corresponding counts per minute were classified as sedentary, light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) according to MET thresholds. Counts were also classified according to published cut-points. A published cut-point exhibited an excellent ability to classify sedentary activity (sensitivity = 89.5%, specificity = 100.0%). Classification accuracy decreased when published cut-points were used to classify LPA (sensitivity = 88.9%, specificity = 79.6%) and MVPA (sensitivity = 70%, specificity = 95% - 97%). Derivation of a new cut-point improved classification of both LPA and MVPA. Applying published cut-points to RT3 accelerometer data collected in children with CP may result in misclassification of LPA and MVPA.

Keywords: accelerometer, physical activity, cerebral palsy

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Cerebral palsy (CP) is characterised by a group of permanent disorders affecting the development of movement and posture, which are attributed to disturbances that occurred in the developing fetal or infant brain (Rosenbaum et al., 2007). These disorders result in activity limitation, reduced levels of habitual physical activity, and increased sedentary behaviour (Carlon, Taylor, Dodd, & Shields, 2013; Stevens, Holbrook, Fuller, & Morgan, 2010). The detrimental effect of low levels of moderate-to-vigorous physical activity (MVPA) on cholesterol, blood pressure, overweight/obesity, and clustering of cardiometabolic risk factors in children and adolescents is well established (Janssen & Leblanc, 2010). There is also research to suggest that reduced levels of light physical activity (LPA) and increased sedentary behaviour are negatively associated with adiposity and other cardiometabolic risk factors in children (Carson & Janssen, 2011; Kwon, Janz, Burns, & Levy, 2011; Treuth, Hou, Young, & Maynard, 2005). Reducing sedentary behavior and increasing LPA may be a feasible method of reducing cardiometabolic risk in children with CP whose motor impairments, including muscle weakness, poor selective motor control, spasticity and decreased balance (Ostensjo, Carlberg, & Vollestad, 2004; Stackhouse, Binder-Macleod, & Lee, 2005), may prevent them from accumulating adequate levels of MVPA.

Research into habitual levels of sedentary, light and moderate-to-vigorous physical activity in children with CP is currently limited by the lack of validated and feasible measures of physical activity intensity (Clanchy, Tweedy, & Boyd, 2011). Methods that have been used to measure physical activity in children and adolescents with CP include doubly-labeled water (Bell & Davies, 2010; van den Berg-Emons et al., 1995), pedometers (Bjornson, Belza, Kartin, Logsdon, & McLaughlin, 2007; Stevens, Holbrook, Fuller, & Morgan, 2010), heart-

rate (HR) monitoring (van den Berg-Emons, Van Baak, Speth, & Saris, 1998), and self-report measures (Maher, Williams, Olds, & Lane, 2007; Zwier et al., 2010). Each of these methods has their limitations. Although considered a criterion measure of energy expenditure doubly-labeled water is an expensive technique and is often unfeasible to use in studies with large numbers of participants. In addition, it does not provide information about patterns of physical activity. Pedometers are useful as motivational tools to increase activity levels but they provide little information about the intensity, duration or frequency of activity. HR is influenced by factors other than participation in physical activity, such as medication, environmental factors and emotional state. There is also considerable inter-individual variation in the relationship between HR and energy expenditure. While individual calibration of HR against oxygen consumption [e.g. HR-flex method] can improve the accuracy of HR monitoring at measuring energy expenditure (Van Den Berg-Emons, Saris, Westerterp, & Van Baak, 1996) it reduces its feasibility in large, community-based studies. Self-report measures have historically been used to collect physical activity data in large samples. They are subject to bias however, particularly recall bias, cultural biases, and social desirability to appear 'physically active' (Ainsworth et al., 2012; Bringolf-Isler et al., 2012). Furthermore, they may not capture the short, sporadic bursts of activity that children typically perform (Bailey et al., 1995) and their accuracy may be reduced in children <10 years because of cognitive limitations (Sallis, 1991).

Accelerometry has gained recognition as a potentially valid and objective method of measuring physical activity without imposing a large burden on participants. Despite the large number of accelerometers commercially available only one uniaxial accelerometer (the Actigraph 7164) has been validated as a measure of physical activity in children and adolescents with CP to date (Capio, Sit, & Abernethy, 2010; Clanchy, Tweedy, Boyd, & Trost, 2011). Further research is needed into the ability of tri-axial accelerometers to measure

physical activity in children with CP (Clanchy et al., 2011). Unlike uniaxial accelerometers, which only measure acceleration in the vertical plane, tri-axial accelerometers are sensitive to acceleration in all three planes of movement. Tri-axial accelerometers therefore have the potential to measure a larger degree of acceleration than uniaxial accelerometers and improve the measurement of physical activity in people with movement abnormalities.

The RT3 is a tri-axial accelerometer that has been used to measure physical activity in typically developing (TD) children and adolescents (Hussey, Bell, Bennett, O'Dwyer, & Gormley, 2007). Like the Actigraph 7164, the RT3 provides raw data in counts per unit time. This unit is difficult to interpret unless it is converted into a more meaningful unit. It is the convention to apply count thresholds or 'cut-points' to accelerometer counts in order to express raw data as minutes spent in varying intensities of physical activity. One cut-point for discriminating between sedentary activity and LPA (Vanhelst et al., 2010) and two cut-points for discriminating between LPA and MVPA (Rowlands, Thomas, Eston, & Topping, 2004; Vanhelst et al., 2010) have been derived in TD children and adolescents. The altered relationship between energy expenditure and locomotion observed in children with CP however (Dallmeijer & Brehm, 2011), may affect the relationship between RT3 counts and physical activity intensity. Without validation these cut-points cannot be applied to children with CP with any level of confidence.

The aim of the current study was two-fold. Firstly, the aim was to assess the ability of published RT3 cut-points to detect sedentary activity, LPA and MVPA in ambulatory children and adolescents with CP. Secondly, the aim was to develop two new cut-points in children with CP, which discriminate between sedentary activity and LPA, and between LPA and MVPA, respectively, and determine if these cut-points improve classification of physical activity intensity in this population.

Method

Participants

Ambulant children and adolescents (aged 6 to 17 years) with a medically confirmed diagnosis of CP were recruited for this study through a national centre for the treatment of children and adults with physical disabilities. Participants were classified as level I, II or III on the Gross Motor Function Classification System (GMFCS) (Palisano et al., 1997). The GMFCS distinguishes between levels of motor function based on functional mobility and the need for assistive technology, particularly mobility aids (Palisano et al., 1997). Children in level I of the GMFCS are able to walk indoors and outdoors without assistance and can perform gross motor skills such as running and jumping. Children in level III require a hand-held mobility device when walking indoors and use wheeled mobility when travelling long distances. Participants were excluded from the study if they had a severe cognitive deficit, uncontrolled epilepsy or seizure activity, an acute lower limb injury, or lower limb surgery in the previous 12 months.

Physiotherapists identified 43 children who were eligible to participate and provided them with an information leaflet and invitation to participate in the study. Of the children who received the study invitation, 18 (10 boys) replied and agreed to participate. Seven participants (39%) had bilateral spastic CP; the remaining participants had unilateral spastic CP. Ten children (56%) were classified in GMFCS level I, 4 children (22%) were in level II and 4 children (22%) were in level III. Thirteen children (72%) did not require an aid to ambulate; 2 children walked with two elbow crutches; 3 children walked with the aid of a K-walker.

Ethical approval for this study was granted by the Faculty of Health Sciences ethics committee and the centre's ethics committee. All participants and their guardians completed the Physical Activity Readiness Questionnaire and provided written informed consent before testing proceeded.

Instruments

The RT3 (Stayhealthy Inc.) is a small (7.1 x 5.6 x 2.8cm), lightweight (65.2g), unobtrusive device. Its criterion validity has been established in TD children and adolescents against indirect calorimetry (Rowlands et al., 2004). The device consists of a piezoelectric element and a seismic mass which generate a variable output voltage signal when the participant moves. The size of the voltage is proportional to the applied acceleration. The voltage is filtered, amplified and sampled at a rate of 1 Hz to convert the voltage signal to a series of numbers called counts. The piezoelectric element is sensitive to accelerations in the vertical plane (x), the antero-posterior plane (y) and the medio-lateral plane (z). A resulting vector magnitude (VM) is calculated as the square root of the sum of squared activity counts for each dimension. The RT3 can provide count data for each plane or for VM in 1 min or 1 sec epochs. Data can be recorded for up to 21 days. In the current study VM data in counts per min was collected throughout the protocol.

Oxygen consumption (VO_2), measured with the Oxycon Mobile portable indirect calorimeter, was used as the criterion measure of physical activity intensity. The Oxycon Mobile has been validated as a measure of VO_2 (Rosdahl, Gullstrand, Salier-Eriksson, Johansson, & Schantz, 2010) and has been used as a criterion method of measuring energy cost in children (Arvidsson, Slinde, Larsson, & Hulthen, 2007). Each participant wore a soft, flexible, gas-collection mask and an analyser unit (950 g) attached to a chest harness throughout the protocol. Participants also wore a Polar HR monitor throughout the test. Gas, flow, and HR data were sent telemetrically to the calibration and receiver unit which was connected to a personal computer before being processed in the PC-software (JLAB). Volume calibration, ambient gas calibration and reference gas calibration (reference gas tank: 16% O_2, 5% CO_2) were performed immediately prior to each test using the in-built automated procedures. The Oxycon was synchronised with the RT3 prior to each test.

Procedures

Participants' height and body mass were measured in bare feet and light clothing using standard protocols. The RT3, Oxycon and HR monitor were attached to the participant. The RT3 was attached to the right hip, or the least affected side of the body in the case of participants with significant asymmetry, in the mid-axillary line. Pilot testing was conducted to determine activities that allowed participants to reach a level of light, moderate and vigorous physical activity, while also being safe to complete. The protocol comprised of a 10 min rest period, a 6 min over-ground walking trial, and four, 5 min, treadmill activities at 1 $km.h^{-1}$, 2 $km.h^{-1}$, 4 $km.h^{-1}$ and 6 $km.h^{-1}$. The over-ground walking trial was completed on a 70m corridor. Participants were instructed to "walk as far as possible for 6 min" in order to maximally exert themselves. A researcher walked behind the participant during the trial to monitor comfort and give standardised verbal encouragement. All participants were given a 5 min familiarisation period with the treadmill before completing the protocol. Participants rested in a seated position between each activity until their HR and VO_2 returned to baseline values.

Data Processing

On completion of the protocol, data was downloaded from the RT3. VM data from the RT3 and VO_2 data from the Oxycon was examined visually to check for time synchronisation and any indication of equipment malfunction. Due to the range of motor impairment in the sample not all participants completed every activity. In addition, the Oxycon Mobile failed to record data for one participant during the over-ground walking trial. The final 2 min of VO_2 and VM data for each activity was extracted and used in data analysis. Data is expressed as the mean VO_2 and mean VM per minute ($ml.kg.min^{-1}$ and counts per minute, respectively). Metabolic equivalent (MET) values were calculated for each activity by dividing VO_2 by resting metabolic rate (RMR). RMR was predicted for each participant from their sex, age

and weight using the Oxford equations (Henry, 2005). METs and corresponding VM counts per minute were then categorised as sedentary activity, LPA and MVPA. Sedentary activity was defined as < 2.0 MET; LPA was defined as 2.0-2.9 MET; MVPA was defined as ≥ 3.0 MET (Garber et al., 2011). Mean VM counts per minute were also classified as sedentary, light or moderate-to-vigorous according to the cut-points identified in Table 1. Average velocity of each participant during the over-ground walking trial was calculated by dividing the total distance completed by 6 min.

Data Analysis

Mean and standard deviations are reported for all values. The ability of published cut-points to detect sedentary activity, LPA and MVPA in children with CP was assessed using a classification analysis whereby the sensitivity [true positives/(true positive + false negatives)] and specificity [true negatives/(true negatives + false positives)] of the cut-points were determined. False positives were defined as minutes classified as a certain intensity that should not have been classified as such. False negatives were defined as minutes not classified as the category to which they belonged. In addition, Cohen's kappa coefficient was used to assess the degree to which published cut-points applied to the sample of children and adolescents with CP.

A receiver operating characteristic (ROC) curve analysis was conducted to derive two new RT3 cut-points that discriminated between sedentary activity and LPA, and between LPA and MVPA, respectively, in children and adolescents with CP. ROC curve analysis provides sensitivity and specificity values for all possible decision thresholds, thereby overcoming the limitation of a single sensitivity and specificity pair and allowing evaluation of the overall accuracy of the test. It is frequently used in clinical research as a way of determining a threshold that can accurately identify individuals at risk, or in this case active, (true positives) without falsely identifying those not at risk, or inactive, (false positives).

ROC curves have been proposed as a means of maximising both sensitivity and specificity when selecting accelerometer cut-points for reasons described in detail elsewhere (Jago, Zakeri, Baranowski, & Watson, 2007; Welk, 2005).

Two ROC curves were calculated by assigning an indicator variable to counts according to their corresponding MET intensity classification (i.e. 1 = LPA, 0 = sedentary activity; 1 = MVPA, 0 = LPA). Area under the curve (AUC) values were calculated for the ROC curve-derived cut-points to determine classification accuracy. Sensitivity, specificity and kappa values were also calculated using the new thresholds. Sensitivity, specificity, and AUC values of ≥ 0.90 (90%) were considered excellent, 0.80-0.89 (80-89%) good, and 0.70-0.79 (70-79%) fair. Kappa coefficients of 0.21 - 0.40 were considered fair, 0.41 - 0.60 were considered moderate, 0.61 - 0.80 were considered good, and 0.81 - 1.00 were considered excellent (Landis & Koch, 1977).

Analyses were conducted using MedCalc for Windows, version 12.7.1.0 (MedCalc Software, Ostend, Belgium) and Analyse-*It* for Microsoft Excel, version 2.26. Statistical significance was set at an alpha level of 0.05 (two-sided).

Results

Participants' age, height, weight and BMI across GMFCS level are presented in Table 2. Three participants were classified as obese and one child was classified as 'thin' according to the World Health Organisation BMI references for children and adolescents (de Onis et al., 2007). VO_2 in ml.kg.min^{-1} and METs, and VM recorded for all activities are presented in Table 3. Increases in MET values coincided with an increase in VM counts across activities. Table 4 presents the sensitivity, specificity and kappa values for the published cut-points in the sample of children with CP. For sedentary activity, the Vanhelst cut-point demonstrated excellent classification accuracy and excellent agreement with data collected in children with CP. For LPA, the Vanhelst cut-points exhibited good sensitivity, good specificity and fair

agreement. Both the Vanhelst MVPA cut-point and the Rowlands MVPA cut-point correctly classified 21 out of 30 bouts of MVPA in children and adolescents with CP, resulting in fair sensitivity and moderate agreement with criterion data.

ROC curve analysis identified an optimal cutpoint of 51.9 counts per minute, for discriminating between sedentary activity and LPA, resulting in an AUC value of 96.5% (95% CI: 84.6 - 99.8). The ROC curve-derived cut-point for identifying MVPA was > 689.3 counts per minute. This cut-point resulted in an AUC value of 89.6% (95% CI: 77.4 - 96.6). The range of counts for each physical activity category are presented in Table 5. These cut-points exhibited excellent sensitivity and specificity for classifying sedentary activity, and good sensitivity and excellent specificity for classifying both LPA and MVPA (Table 4). All kappa coefficients for these cut-points were > 0.70 (Table 4).

Discussion

The results of this study demonstrate that the RT3 can detect increases in physical activity intensity in children with CP. A published cut-point calibrated by Vanhelst et al. (2010) may be used to classify sedentary activity in children with CP, as it demonstrated excellent agreement with criterion data collected in this population. As physical activity intensity increased however, the ability of published cut-points to correctly classify physical activity declined. For LPA, the agreement between cut-points and criterion data was only fair, largely because of the inability of the upper cut-point to discriminate between LPA and MVPA. Only 70% of MVPA was correctly classified as such when two cut-points developed in TD children were applied to data collected in children with CP. This suggests that if a published RT3 cut-point is used to measure physical activity in children and adolescents with CP, misclassification of LPA and MVPA may moderate the association between activity and health.

The second aim of this study was to determine if the development of new cut-points could improve classification of physical activity intensity in children with CP. ROC curve analysis demonstrated that the RT3 could successfully distinguish between sedentary activity, LPA, and MVPA, in children and adolescents with CP. Newly developed cut-points resulted in excellent classification accuracy, with AUC values of ≥ 90%.

The ROC curve-derived cut-point of ≤ 51.9 counts per minute to classify sedentary activity was only 10 counts per minute higher than the published cut-point, resulting in only a slight improvement in sensitivity and no change in specificity. This finding may have been expected given that resting energy expenditure does not differ between children with CP and TD children (Bell & Davies, 2010; Rose, Haskell, & Gamble, 1993; van den Berg-Emons et al., 1995). The cut-point of > 689.3 counts per minute yielded by ROC curve analysis to classify MVPA was however significantly lower than the published cut-points, resulting in higher sensitivity (87%) but lower specificity (92%). It is up to the researcher when choosing a cut-point to determine if a lower sensitivity or a lower specificity is more acceptable. In this case the authors believe that because of the well-established relationship between MVPA and health in children (Andersen et al., 2006; Ekelund et al., 2012; Ried-Larsen et al., 2013), it is important to limit the underestimation of MVPA. A lower cut-point may therefore be appropriate for children with CP.

Three factors possibly contributed to the discrepancy between the ROC curve-derived cut-point and the published cut-points for MVPA. Firstly, the Rowlands cut-point was originally identified using multiple linear regression analysis. Cut-points derived from regression analysis are generally higher than those derived from ROC curve analysis (Welk, 2005). It has been illustrated that regression analysis results in accelerometer cut-points that exhibit high specificity values but relatively low sensitivity values when cross-validated in an independent sample (Welk, 2005). This is apparent in the current study in which the

Rowlands cut-point exhibited excellent specificity (97%) but only fair sensitivity (70%) for classifying MVPA, indicating poor discriminative ability of the cut-point. As the Rowlands cut-point has not been cross-validated in a group of TD children as part of the original study or in subsequent studies, its rate of misclassification in the current sample cannot be compared to that in a sample of TD children and adolescents.

Unlike the Rowlands cut-point, the Vanhelst MVPA cut-point was derived using an ROC curve and therefore the discrepancy between cut-points cannot be attributed to differences in analysis. The discrepancy may, however, be a result of the different methods used to classify physical activity intensity. In the current study, indirect calorimetry was used as the criterion measure of physical activity intensity in order to capture individual variation in metabolic cost. A criterion measure of energy expenditure was not used to classify physical activity intensity when calibrating the Vanhelst cut-points; instead activities were classified as sedentary, light, moderate and vigorous according to the expected MET value of the activity. This method may have resulted in misclassification of some activity intensities, particularly locomotor activities as the metabolic cost of walking at a given speed can vary considerably between children (Frost, Bar-Or, Dowling, & Dyson, 2002). Cross-validation of the Vanhelst cut-point in an independent sample of TD children resulted in excellent sensitivity (98%), good specificity (84%), and excellent agreement, however, between the calibration and validation groups ($\kappa = 0.91$) (Vanhelst et al., 2010). This suggests that a cut-point of > 950 counts per minute is appropriate to identify MVPA in TD children but does not appear sensitive enough to discriminate between LPA and MVPA in children and adolescents with CP.

The more liberal cut-point for MVPA yielded in the current study may be explained by the altered relationship between energy expenditure and ambulation in children and adolescents with CP. Children with CP have a slower maximal walking speed than their TD

peers (Dallmeijer & Brehm, 2011). The energy cost of locomotion is also increased, by as much as 3-fold, in children with CP compared to typically developing children, depending on their degree of functional impairment (Unnithan, Clifford & Bar-Or, 1998). As a result it is likely that children with CP will reach a moderate-to-vigorous intensity at a slower walking speed. This slower walking speed results in a smaller acceleration and a proportionally lower RT3 count output. Published cut-points may therefore be too high to detect MVPA in children with CP and a lower cut-point may be necessary to avoid misclassifying MVPA in this population.

It has been suggested that using a tri-axial accelerometer, rather than a uniaxial accelerometer, may improve the measurement of physical activity in children with CP (Clanchy et al., 2011). The Actigraph 7164 uniaxial accelerometer has previously demonstrated reasonable agreement with time spent in MVPA measured using a criterion method (when MVPA was defined using a single cut-point developed in TD children) (Capio, Sit, & Abernethy, 2010). The results of this study, however, cannot be compared to the results of the current study because of methodological differences. When published cut-points for the Actigraph 7164 were validated using a similar protocol to that used in the current study, sensitivity and specificity values for classifying sedentary and light activity in children with CP were poorer than values observed in the current study (Clanchy, Tweedy, Boyd, & Trost, 2011). A published Actigraph 7164 cut-point for MVPA (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008), however, exhibited good sensitivity (81.8%) and excellent specificity (100.0%).

Differences in how accelerometer data is internally processed means that direct comparisons cannot be made between count data from two accelerometer models (Chen & Bassett, 2005). It, therefore, cannot be conclusively determined if differences in the accuracy of the Actigraph 7164 and the RT3 are due to errors in raw data collection or errors in the

conversion of count data to physical activity intensity. Without accurate cut-points, however, accelerometer raw data is of limited use. It is likely that some of the difference in the classification accuracy of cut-points for the Actigraph 7164 and the RT3 can be attributed to differences between samples. The sample of children with CP used to validate the Actigraph 7164 cut-points was more able than that in the current study with only 10% (vs 22%) of participants classified in GMFCS level III, and only 14% (vs 28%) requiring a mobility aid. There is significant variation in the energy efficiency of gait among children with CP, with the energy cost of locomotion being higher in children classified in GMFCS level III compared to levels I and II (Kerr, Parkes, Stevenson, Cosgrove, & McDowell, 2008). This variation in energy efficiency is captured by the sample in the current study and may have contributed to the poor classification accuracy of published RT3 cut-points for LPA and MVPA.

The present study has some limitations that should be addressed. Firstly, while the sample size is similar to that of other validation and calibration studies (Clanchy et al., 2011; Hussey et al., 2009; Rowlands et al., 2004) it is acknowledged to be small. As a result we were unable to investigate if the ability of RT3 cut-points to correctly classify physical activity intensity differs across GMFCS level. It is possible, however, that differences exist and that specific cut-points are required for each GMFCS level. Also, the diversity in functional ability among the sample, although reflective of the variation in the target population, resulted in an unequal number of bouts of sedentary activity, LPA and MVPA being collected. An unequal number of observations in each group may have inflated some sensitivity or specificity values and reduced others. It is strongly recommended that future research be conducted to cross-validate the ROC curve-derived cut-point in an independent group of ambulatory children and adolescents with CP.

Secondly, only three participants reached a vigorous level of activity (≥ 6.0 MET). Moderate and vigorous MET thresholds were therefore combined and compared to a single cut-point for MVPA. Although this allows for comparison to the current physical activity guidelines for children of 60 min of MVPA daily (US Department of Health and Human Services, 2008) future studies should investigate the ability of the RT3 to detect vigorous physical activity in children and adolescents with CP. Finally, although age, sex and weight specific RMR values were used to calculate METs these were based on published equations. Individual measurement of RMR may have improved the estimation of activity intensity. Equipment and time limitations prevented RMR measurements from being performed.

In conclusion, the RT3 presents as an objective and feasible method of measuring physical activity in ambulatory children and adolescents with CP. RT3 counts increased in line with increasing physical activity intensity. Participants were also compliant with the device and no monitor malfunction was observed. Although a published cut-point can be used to measure sedentary behaviour in children with CP, using published cut-points to classify physical activity in children with CP may result in underestimation of MVPA and overestimation of LPA. A cut-point of 689.3 counts per minute is presented to potentially improve the measurement of LPA and MVPA in ambulatory children and adolescents with CP and allow the RT3 to be used in future studies of habitual physical activity.

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Table 1

Cut-points for the RT3 accelerometer derived in typically developing children and adolescents

Author	Sample	Criterion measure	Activities	Analysis	Cut-point
(Rowlands et al., 2004)	n = 19 19 boys, 0 girls Mean age: 9.5 ± 0.8 yr	Indirect Calorimetry	Sitting quietly, hopscotch, kicking a ball, four treadmill activities at 4.0, 6.0, 8.0, and 10.0 $km.h^{-1}$	Multiple regression analysis	MVPA: > 970 counts per minute
(Vanhelst et al., 2010)	n = 40 20 boys, 20 girls Age range: 10-16 yr	None	Resting, playing a parlour game, kicking a ball, four treadmill activities at 1.5, 3.0, 4.0, and 6.0 $km.h^{-1}$	ROC curve analysis	SED: < 41 counts per minute LPA: 41-950 counts per minute MVPA: > 950 counts per minute

Note. MVPA, moderate-to-vigorous physical activity; ROC, receiver operating characteristic; SED, sedentary activity; LPA, light physical activity

Table 2

Descriptive characteristics for participants across Gross Motor Function Classification Scale (GMFCS) level

	Total (n=18)		GMFCS Level I (n=10)		GMFCS Level II (n=4)		GMFCS Level III (n=4)	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (yr)	11.4	3.2	11.5	3.8	10.0	2.2	12.5	1.9
Height (cm)	147.0	18.5	149.5	21.1	140.0	20.1	147.6	10.3
Body mass (kg)	44.6	16.9	46.5	20.9	37.0	12.0	47.3	8.2
BMI ($kg.m^{-2}$)	20.0	4.5	19.8	5.2	18.5	1.8	21.9	4.7

Table 3

Mean walking speed, oxygen consumption, and VM counts for rest, the over-ground walking trial, and treadmill activities.

	Speed $km.h^{-1}$		n (GMFCS level [I/II/III])	VO_2 $ml.kg.min^{-1}$		VO_2 METs		VM counts per minute	
Activity	*M*	*SD*		*M*	*SD*	*M*	*SD*	*M*	*SD*
Rest	-		18 (10/4/4)	5.4	1.6	1.2	0.3	9.3	15.4
Over-ground walking	3.6	1.3	17 (9/4/4)	22.4	6.0	5.0	1.1	2027.7	724.0
Treadmill walking	1.0		15 (9/3/3)	11.7	2.5	2.6	0.5	464. 7	166.1
Treadmill walking	2.0		11 (7/3/2)	13.7	2.5	3.1	0.8	678.3	201.8
Treadmill walking/jogging	4.0		5 (5/0/0)	15.9	5.7	3.5	1.1	1402.4	352.9
Treadmill walking/jogging	6.0		2 (2/0/0)	-		-		-	

Note. Unable to calculate mean and standard deviation for treadmill walking/jogging at $6.0km.h^{-1}$ due to the small number of participants who completed this activity

Table 4

Sensitivity and specificity for the cut-points developed in the current study and for published cut-points calibrated on typically developing children and adolescents

Intensity	Cut-point	Sensitivity (%)	Specificity (%)	Kappa coefficient
Sedentary (n = 19)	Vanhelst	89.5	100.0	0.92* (0.82 - 1.00)
	Current study	94.7	100.0	0.96* (0.89 - 1.00)
Light (n = 18)	Vanhelst	88.9	79.6	0.57* (0.38 - 0.77)
	Current study	83.3	89.8	0.71* (0.52 - 0.90)
Mod-to-vig (n = 30)	Rowlands	70.0	97.3	0.69* (0.52 - 0.86)
	Vanhelst	70.0	94.6	0.66* (0.48 - 0.84)
	Current study	86.7	91.9	0.79* (0.64 - 0.94)

Note. *$p < 0.001$
Mod-to-vig, moderate-to-vigorous

Table 5

Thresholds for vector magnitude counts at different physical activity intensities

Intensity	Sedentary	Light	Moderate-to-vigorous
Range (counts per minute)	≤ 51.9	51.9 - 689.3	> 689.3