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Validity of accelerometry for predicting physical activity and sedentary time in ambulatory children and young adults with cerebral palsy

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ABSTRACT

Background: /Objectives: This study aimed to validate five published ActiGraph (AG) cut-off points for the measurements of physical activity (PA) and sedentary time (ST) in ambulatory children and young adults with cerebral palsy (CP). Additionally, four energy expenditure (EE) prediction equations based on AG counts and activPAL (AP) steps were examined in this population, using oxygen uptake (VO₂) as the criterion.

Methods: Four male and six female participants with CP (Gross Motor Function Classification System levels I–III, ages 9–21 years) completed seven activities while simultaneously wearing an AG, AP monitor and indirect calorimetry unit. VO₂ was measured on a breath-by-breath basis using the indirect calorimetry and was converted into EE using metabolic equivalents. AG counts were classified as sedentary, light PA (LPA) or moderate-to-vigorous PA (MVPA) using five cut-off points: Puyau, Evenson, Romanzini, Clanchy and Baque. The predicted EE was computed using three AG-based equations (Freedson, Trost and Truth) and an AP step-based equation.

Results: Based on 1920 available data points from the 10 participants, Baque ($r = 0.896$, $\kappa = 0.773$) and Clanchy ($r = 0.935$, $\kappa = 0.721$) AG cut-off points classified PA and ST most accurately. All the equations overestimated EE during sitting activities and underestimated EE during rapid walking. The Freedson, Trost and AP equations exhibited systematic bias during rapid walking, as their differences from the criterion measure increased progressively with increasing activity intensity.

Conclusions: The AG accurately classified PA and ST when the Baque and Clanchy cut-off points were used. However, none of the available AG or AP equations accurately predicted the EE during PA and ST in children and young adults with CP. Further development is needed to ensure that both devices can estimate EE accurately in this population.

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Introduction

Cerebral palsy (CP) is a non-progressive disorder that affects movement and posture.¹ CP is the most common pediatric physical disability, affecting 2.11 per 1000 live births worldwide² and 1.3 per 1000 children in Hong Kong.³ According to previous reports, children and adolescents with CP are less physically active, spend more time in sedentary behaviors, and have a lower level of aerobic

fitness than their peers with typical development (TD).^{4,5} People with CP also face a higher risk of developing cardiovascular diseases.⁶ General physical activity (PA) guidelines suggest that children and adolescents with TD should participate in at least 60 min of moderate-to-vigorous PA per day.⁷ Similar daily PA recommendations have also been advocated for people with CP.⁶

Accurate measurements of free-living PA are essential for studies of surveillance, assessments of the associations between PA and health outcomes, as well as evaluations of the efficacy of PA interventions in people with CP.⁸ Currently, the ActiGraph (AG) accelerometer is one of the most widely used wearable devices for the quantification of PA and sedentary time (ST) in both children

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and adolescents with TD⁹ and CP¹⁰ under free-living conditions. Various AG count cut-off points have been developed to classify ST, light PA (LPA) and moderate-to-vigorous physical activity (MVPA) in children and adolescents with TD,^{11–13} and some of these cut-off points have been applied to young people with disabilities, including CP.¹⁴ Methodologically, however, the atypical gait patterns of people with CP make it difficult to calibrate accelerometers.¹⁵ Meanwhile, only three AG count cut-off points were developed specifically for youth with disabilities, specifically for ambulatory children with CP¹⁶ and for children with acquired brain injury.¹⁷ Although a study by Clanchy reported a slightly lower cut-off point for MVPA in children with CP than the previously developed Evenson cut-off point, these two cut-off points did not differ significantly with regard to classification accuracy.¹⁶ No studies have compared the performances of commonly used cut-off points with respect to classification accuracy across varying levels of activity intensity (e.g., sitting, standing and moving) in young people with CP. In addition to the count-defined activity intensity, validation studies have also yielded equations for predicting the energy expenditure (EE), a measure expressed as kcal·min⁻¹ or metabolic equivalent (MET), based on AG counts in children and adolescents with TD.^{11–13} However, the accuracies of three equations for children and young adults with disabilities, including CP, have not been assessed.

The activPAL (AP), a device that distinguishes between sitting, standing and stepping postures, is also used commonly to monitor PA under free-living conditions.¹⁸ This device is worn on the thigh, where its unique location provides robust information about the body posture and transitions between postures. The associated software indirectly estimates the MET values using a step rate-based equation.¹⁸ Previous studies have validated this equation in children aged 4–6 years,¹⁹ 5–12 years²⁰ or adolescents/young adults aged 15–25 years.²¹ These findings support the use of the AP as a valid tool for measuring ST and PA. However, the AP equation has not been validated for children and young adults with CP.

To address the aforementioned gaps in previous validation studies of the AG or AP, this study aimed to examine: (1) the accuracy of the five established AG cut-off points for classifying PA and ST in ambulatory children and young adults with CP and (2) the agreement of three AG count-based and one AP step-based EE prediction equations in this population according to the oxygen uptake (VO₂).

Methods

Participants

Invitations were sent to seven special schools in xx that accommodate children and young adults (age: ≤ 21 years) with CP. One school agreed to participate in this study. The inclusion criteria were (1) an age of ≥ 6 years; (2) confirmed medical diagnosis of CP within Gross Motor Function Classification System (GMFCS) levels I–III by physical therapists; and (3) an ability to follow instructions during the test. Parental consent forms were sent to student's parents or guardians via the school. Written informed consent was obtained from parents of six female and four male students. Ethical approval for this study was granted by the Research Ethics Committee of Hong Kong Baptist University (#FRG2/16–17/097).

Procedures

All data were collected at the participating school. VO₂ and accelerometers data were collected from each participant on the same day in two rooms provided by the school. One room was quiet and used for resting, sitting and standing activities. The other room

was equipped with a motorized treadmill and used for walking activities. On the test day, each participant initially arrived at the quiet room and was asked to rest for at least 30 min. S/he was then attached to the two accelerometers, a Polar heart rate monitor (M400, Polar Ltd. USA) and an indirect calorimetry mask (Vmax metabolic cart, Sensor Medics, USA) by the trained research assistants. The VO₂ was measured in the quiet room for at least 15 min with the participant in the supine position to determine the resting metabolic rate (RMR). Subsequently, each participant was asked to perform seven activities, including sitting and reading, sitting and watching television, standing still, standing with upper body movement, slow walking at 2.0 km/h, brisk walking at 3.0 km/h, and rapid walking at 4.0 km/h. These activities were chosen to represent different types of sedentary activities and various levels of intensity based on previous studies.^{16,17} Each activity was performed for at least 5 min to ensure that a steady state could be achieved during the final 2-min period of each activity. Treadmill activities were stopped under two circumstances: at the suggestion of the school physical therapists²² or if the participant felt that s/he was uncomfortable or physically unable to continue the activity. A rest period was allowed between each walking activity, and the following activity was not initiated until the participant's heart rate returned to the baseline level. All participants were familiar with the use of the treadmill, as this equipment is used in their school rehabilitation programs.

Instruments

Indirect calorimetry (Vmax metabolic cart, SensorMedics, USA) was used as the criterion measure. Each participant wore a soft, flexible gas-collection mask attached to a gas machine during each activity. S/he also wore a Polar heart rate monitor throughout the test. Heart rate data were used only to monitor intensity and were not included in the data analyses. Breath-by-breath gas data were collected and averaged every 15 s. Volume, ambient-gas calibrations and reference-gas calibrations were performed before commencing the tests in each of the two rooms.

The AG monitor (ActiGraph GT3X-BT monitor; ActiGraph LLC, Pensacola, FL, USA) is a small, lightweight (19 g) and unobtrusive device. Each participant wore an AG monitor around the right hip. The counts/second in both the vertical axis (VA) and vector magnitude (VM) were downloaded and integrated into units of counts per 15 s. An activPAL3C™ monitor (PAL Technologies Ltd, UK) was affixed to the anterior middle right thigh using a 3 M Tegedam dressing. Data were sampled at a frequency of 20 Hz. The AP step counts were determined based on 15-s Excel files generated by the associated software. The EE during each activity was calculated using the embedded formula and the following default values: 1.25 METs for a sitting/lying position, 1.4 METs for a standing position and 3 METs for walking at 120 steps/minute.¹⁸

Data reduction

Each participant's body weight, body height and date of birth were provided by the school. Both accelerometers were initialized and downloaded from the same computer and synchronized with the metabolic cart using the internal system time. AG data were downloaded using ActiLife software v6.13.3 (ActiGraph, USA), while AP data were downloaded using activPAL software (v7.2.38). The resting VO₂ was averaged over a period of 5–8 min to calculate the RMR. The VO₂ was synchronized with each 15-s data set obtained from the two side-by-side accelerometers during each activity. Four variables (AG counts in VA, AG counts in VM, AP steps and VO₂ data) were included in the analyses using data from the final 2-min period of each activity, resulting in 32 data points per participant

for each activity (4 variables \times 8 timepoints of measurement) and a total of 2240 data points (32×10 participants \times 7 activities). As shown in Table 4, the three walking activities were not completed in one, three, and six participants, respectively. As a result, a total of 1920 available data points were analyzed after excluding incomplete treadmill activities. For each activity, the EE in METs or $\text{kcal} \cdot \text{min}^{-1}$ was measured using indirect calorimetry and calculated dividing by RMR. Based on these MET values, each activity was classified as ST (<1.5 METs), LPA ($1.5 \leq \text{LPA} < 3$ METs) and MVPA (≥ 3 METs), and these categorizations were used to determine the classification accuracies of the AG cut-off points shown in Table 1.^{17,23–25} The exception was the Clanchy cut-off point, which defined MVPA as ≥ 4 METs.¹⁶ In addition to the two cut-off points validated among children with disabilities,^{16,17} three additional cut-off points were also included in previous validation studies.^{23–25} Each 15-s count or step value was quadruplicated to calculate the predicted EE based on the equations summarized in Table 2.²¹ As the Trost equation provides estimates in $\text{kcal} \cdot \text{min}^{-1}$, the measured RMR was converted from mL/kg/min to $\text{kcal} \cdot \text{min}^{-1}$ using the methods described by Baque and colleagues,¹⁷ so as to compare the Trost equation based measures with the indirect calorimetry results.

Statistical analysis

The classification accuracy was evaluated using Spearman correlation (r) and kappa (κ) coefficients of comparisons between the five AG cut-off points and METs measured using indirect calorimetry. The following ratings suggested by Landis and Koch²⁶ were used to interpret the κ coefficients: poor (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00). Paired t -tests and mean differences [95% confidence intervals (CI)] were used to assess the validity of four AG count-based and the AP step-based predicted EE equations. A Bland–Altman plot was used to assess the agreement between the predicted and measured EE values. SPSS for Windows, version 25.0 (IBM, USA) was used for the statistical analyses. Statistical significance was set at a p value < 0.05 .

Results

All 10 participants (mean age: 14.9 ± 4.2 years; mean body weight: 40.5 ± 13.7 kg) completed the test. The sample included one child aged 9 years, one young adult aged 21 years, and 8 adolescents aged between 13 and 19 years. Three participants were classified as GMFCS level I, six participants were GMFCS level II and one participant was GMFCS level III. The classification accuracies of

the AG cut-off points are shown in Table 3. The Baque ($\kappa = 0.773$) and Clanchy ($\kappa = 0.721$) cut-off points determined activity classification demonstrated substantial agreement with that measured using indirect calorimetry. Both of them showed strong correlations with the criterion measure ($r = 0.896$ for Baque, $r = 0.935$ for Clanchy). The other three cut-off points (Puyau, Evenson and Romanzini VA) exhibited moderate agreement (κ ranging from 0.458 to 0.560), while Romanzini VM showed substantial agreement ($\kappa = 0.675$) with the criterion measure.

Table 4 presents the measured EE values, predicted EE values from the AG counts and AP steps and the mean differences and 95% CIs for all activities. The three AG equations overestimated the EEs during sitting activities and underestimated the EEs during rapid walking. For the AP equation, the EEs predicted by the step counts differed significantly from the measured EEs for all activities except standing with upper body movement. Specifically, the AP equation overestimated the EEs during sitting, standing and slow walking, while underestimated the EEs during brisk and rapid walking. The Bland–Altman plots further illustrate the agreements between the four equations used to predict the EEs and the criterion measure as determined using indirect calorimetry (Fig. 1). Across all activities, the mean bias and 95% limits of agreement for the Freedson, Trost, Treuth and AP prediction equations were -0.05 ($-2.15, 2.05$), -0.28 ($-2.18, 2.74$), -0.54 ($-2.37, 1.29$) and 0.04 ($-2.60, 2.68$), respectively. Separate plots for the Freedson (Fig. 1a) and Treuth (Fig. 1c) equations exhibit systematic biases for vigorous PA (i.e., >6 METs). Specifically, the predicted EEs were consistently lower than the measured EEs and the difference between the two methods increased progressively with increasing activity intensity. The AP equation also revealed systematic bias, such that the differences between the predicted and measured EEs increased with greater activity intensity (Fig. 1d).

Discussion

This study examined the accuracies of five commonly used AG cut-off points (including one CP-specific cut-off) to classify the intensities of PA and ST in children and young adults with CP. This study was the first of its kind to validate the equations used to predict EE from the AG and AP data collected from individuals with CP. The Baque and Clanchy AG cut-off points demonstrated good classification accuracy across all activities. None of the EE prediction equations accurately predicted the EE across all activities in this population. The bias between the predicted and measured EE was greater for vigorous intensity PA (i.e., rapid walking) than for the other activities.

Despite the widespread use of accelerometers to evaluate

Table 1
Commonly used AG cut-off points for children and adolescents with or without disabilities.

Source	Activities	AG model (VA or VM)	Participants' age (n)	Specific cut-off points ^a			Applicable population	
				ST	LPA	MVPA	Typically developing	Disabled
Puyau et al., 2002	Walking, running and free-living activities	7164 (VA)	6–16 (26)	0–800	801–3199	≥ 3200	Yes	–
Evenson et al., 2008	Walking, running and free-living activities	7164–2.2 (VA)	5–8 (33)	0–25	26–573	≥ 574	Yes	–
Romanzini et al., 2014	Walking, running and free-living activities	GT3X (VA) GT3X (VM)	10–15 (79)	0–46 0–180	47–606 181–756	≥ 607 ≥ 757	Yes	–
Clanchy et al., 2011	Sitting, walking	7164 (VA)	8–16 (30)	0–25	26–502	≥ 503	–	CP (GMFCS I–III)
Baque et al., 2017	Sitting, walking and step-up	GT3X (VM)	8–17 (27)	0–100	101–468	≥ 469	–	Acquired brain injury

^a Shown as counts per 15 s, except for Puyau et al. (counts/minute). AG, ActiGraph; GMFCS, Gross Motor Function Classification System; CP, cerebral palsy; LPA, light intensity physical activity; MVPA, moderate to vigorous physical activity; ST, sedentary time; VA, vertical axis; VM, vector magnitude.

Table 2
Equations for predicting EE using AG counts and AP steps for children and adolescents.

Source	Participants' age (n)	EE prediction equation	Activities
Freedson et al., 1998	6–18 (80)	EE (METs) = 2.757 + (0.0015 × CPM) - (0.08957 × age) - (0.000038 × CPM * age)	Treadmill walking, running
Trost et al., 1998	10–14 (30)	EE (kcal·min ⁻¹) = -2.23 + (0.0008 × CPM) + 0.08 × weight (kg)	Walking, running
Treuth et al., 2004	13–14 (74)	EE (METs) = 2.01 + 0.000856 * (CPM)	Walking, running and free-living activities
AP software	NA	EE (MET/h) = (1.4 × d) + (4–1.4) × (c/120) × d	NA

AG, ActiGraph; AP, activPAL; CPM, counts/minute (based on vertical axis); EE, energy expenditure; METs, metabolic equivalent. For the AP equation, c = cadence (steps per minute), d = activity duration (in hours).

Table 3
Classification accuracy of each AG cut-off point.

Source	Spearman (r)	Kappa coefficient (κ)	SEE
Puyau et al., 2002 (VA)	0.840	0.458	0.030
Evenson et al., 2008 (VA)	0.888	0.585	0.029
Romanzini et al., 2014 (VA)	0.886	0.560	0.029
Romanzini et al., 2014 (VM)	0.886	0.675	0.028
Clanchy et al., 2011 (VA)	0.935	0.721	0.026
Baque et al., 2017 (VM)	0.896	0.773	0.026

AG, ActiGraph; SEE, standard error of the estimate; VA, vertical axis; VM, vector magnitude. All p values are <0.001.

children and adults with TD, few calibrations studies have been conducted in individuals with CP. Our observation that the Baque and Clanchy cut-off points yielded more accurate classifications than the other cut-points was not surprising, as both cut-off points were developed specifically for children and youth with CP¹⁶ or acquired brain injury.¹⁷ Nonetheless, both Baque et al.¹⁷ and Clanchy et al.¹⁶ observed almost perfect agreement between their cut-off points and the criterion measure, whereas we observed lower levels of agreement. This discrepancy may be explained partly by the inclusion of different activities in the validation protocols. Our study protocol included a wide spectrum of activities, such as standing and vigorous intensity PA (i.e., rapid walking), which were not performed in the two previous validation studies. The overall discriminatory accuracies of these cut-off points across varying intensity levels may have been compromised. Notably, the Evenson cut-off points, which were used commonly in previous studies of

children and adolescents with CP,^{10,27} only exhibited moderate agreement with the criterion measure in our study. This finding was inconsistent with that of a previous study,¹⁶ suggesting that both the Evenson and CP-specific Clanchy cut-off points for MVPA (503 vs. 574 counts/15 s) yielded similar classification accuracies in children and youth with CP.¹⁶

In this study, neither the AG- nor AP-based equations yielded accurate predictions of EE across a spectrum of activities. Similar to previous studies of youth with TD,^{28,29} none of the AG-based EE prediction equations provided accurate point estimates of EE across varying activity intensities for participants with CP. Each AG-based equation, however, accurately predicted the mean EE during one (standing still for Trost and slow walking for Treuth equations) or two (standing with upper body movement and brisk walking for Freedson) activities. Moreover, the Treuth equation which was calibrated using a wide range of free-living activities,¹³ did not outperform the two other equations (Freedson and Trost) that were based on treadmill walking and jogging.^{11,12} In fact, equivocal findings were reported for the same equation across different studies. For example, the Freedson equation was found to overestimate the EE during walking activities at different speeds in a sample of 10–18-year-olds,²⁸ but, underestimated the EEs of physical activities at different intensities in children aged 7–13 years.²⁹ The underlying causes of the discrepancies in the literature have not been defined clearly. However, the discrepancies may be partly due to differences in accelerometer models, the activities selected for the calibration protocols and the classification and measurement of METs according to the criterion method. In

Table 4
Measured and predicted EE determined using equations based on AG counts and AP steps and the mean differences (95% CI) for all activities.

Activity	n	Measured EE by indirect calorimetry (METs) ^a	Freedson		Trost		Treuth		AP	
			Predicted EE (METs)	Mean difference (95%CI)	Predicted EE (kcal·min ⁻¹)	Mean difference (95%CI) ^c	Predicted EE (METs)	Mean difference (95%CI)	Predicted EE (METs)	Mean difference (95%CI)
Sitting and reading	10	0.91 ± 0.28	1.42 ± 0.38 ^b	-0.51 (-0.62, -0.41)	1.01 ± 1.10 ^b	-0.22 (-0.45, 0)	2.01 ^b	-1.10 (-1.16, -1.04)	1.25 ^b	-0.34 (-0.40, -0.28)
Sitting and watching television	10	0.86 ± 0.20	1.42 ± 0.38 ^b	-0.56 (-0.65, -0.46)	1.01 ± 1.10 ^b	-0.25 (-0.47, -0.03)	2.01 ^b	-1.15 (-1.19, -1.10)	1.25 ^b	-0.39 (-0.43, -0.34)
Standing still	10	1.08 ± 0.20	1.42 ± 0.38 ^b	-0.34 (-0.45, -0.24)	1.01 ± 1.10	-0.06 (-0.26, 0.14)	2.01 ^b	-0.93 (-0.98, -0.89)	1.40 ^b	-0.32 (-0.37, -0.28)
Standing with upper body movement	10	1.57 ± 0.65	1.48 ± 0.47	0.09 (-0.09, 0.27)	1.05 ± 1.07 ^b	0.31 (0.09, 0.52)	2.06 ± 0.14 ^b	-0.49 (-0.63, -0.35)	1.56 ± 0.51	0.01 (-0.18, 0.19)
Slow walking mean (range) speed: 1.8 (1.0–2.0) km/h	9	3.19 ± 0.57	2.73 ± 0.97 ^b	0.46 (0.21, 0.70)	2.05 ± 1.08 ^b	0.75 (0.59, 0.91)	3.16 ± 0.60	0.02 (-0.14, 0.19)	3.63 ± 0.37 ^b	-0.44 (-0.60, -0.27)
Brisk walking mean (range) speed: 2.8 (2.5–3.0) km/h	7	4.54 ± 0.98	4.70 ± 0.95	-0.17 (-0.50, 0.17)	3.35 ± 1.57 ^b	0.51 (0.28, 0.75)	4.82 ± 0.70 ^b	-0.29 (-0.47, -0.10)	4.15 ± 0.28 ^b	0.39 (0.09, 0.68)
Rapid walking mean (range) speed: 3.9 (3.6–4.0) km/h	4	8.04 ± 2.58	6.20 ± 1.43 ^b	1.84 (1.26, 2.43)	5.58 ± 2.62 ^b	2.17 (1.33, 3.01)	6.57 ± 1.67 ^b	1.48 (0.94, 2.02)	4.50 ± 0.57 ^b	3.54 (2.60, 4.48)

AG, ActiGraph; AP, activPAL; CI, confidence interval; EE, energy expenditure; METs, metabolic equivalents; VA, vertical axis; VM, vector magnitude.

^a Measured METs = (activity VO₂ ml/kg/min)/(individual resting VO₂ ml/kg/min).

^b Significant differences when compared with measured EE; p < 0.05, paired-t test.

^c Trost equation-predicted EE was compared with the measured EE and expressed in kcal·min⁻¹.

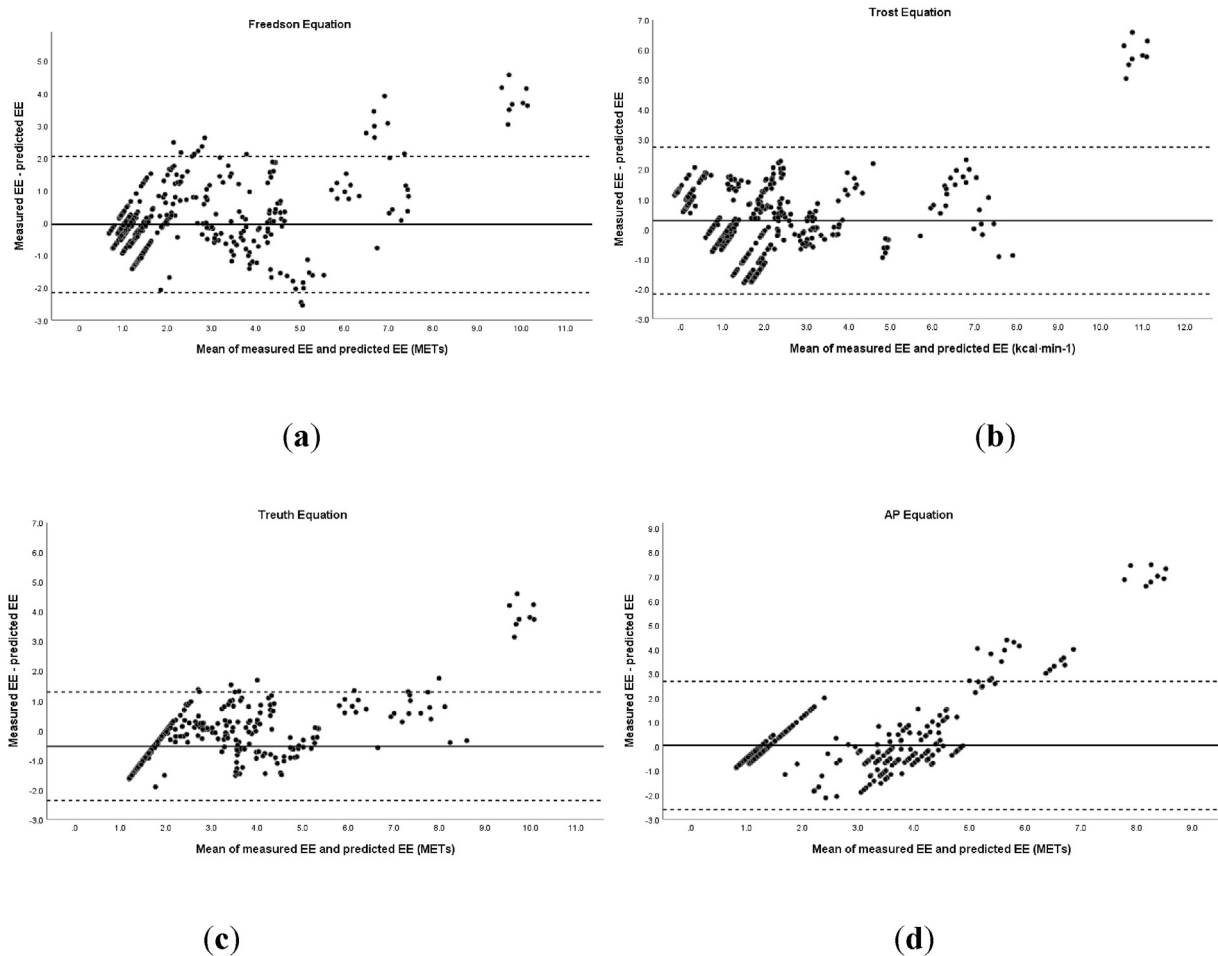


Fig. 1. Bland–Altman plots for the four EE prediction equations and all activities. The black line indicates the mean bias, and the dotted lines are the upper and the lower 95% limits of agreement.

addition, some researchers developed a two-regression model, rather than a standard single regression model, to distinguish between continuous walking or jogging and free-living intermittent activities in children.⁹ However, the use of this new model did not yield better estimates of EE than the traditional model, but only yielded a smaller level of individual bias in children.²⁹ It is clear that accurate measures of EE require a CP-specific validation of the AG.

The AP uses a built-in algorithm equation to predict METs based on the cadence (i.e., the number of steps accumulated in 1 min). The positioning of this device on the anterior upper thigh enables the accurate discrimination of lying/sitting, standing and stepping postures. To the best of our knowledge, only two studies have examined the validity of the embedded AP equation for estimating the EE in children with TD.^{19,20} The findings of both studies were consistent with those of our study; specifically, the AP equation overestimated the METs for sedentary behavior but underestimated those for MVPA. More importantly, EE was underestimated to a greater extent for activities with higher MET values, indicating a systematic bias. Cadence-based estimates of EE are limited by the assumption of continuous walking throughout the test period, which may not accurately reflect real-life walking conditions.³⁰ The AP equation requires a cadence threshold of 240 steps/minute for the classification of vigorous PA (≥ 6 METs). However, it is not common for individuals to maintain such a high step rate per minute.³¹ Therefore, the current AP equation is not appropriate for the estimation of EE in people with or without

disabilities. Rather than calculating point estimates of EE, the AP equation might be useful for categorizing activities and estimating the minutes spent in ST and PA at different intensities.³¹

This study had several limitations. First, the sample size was small, and only some participants completed all the walking activities. Consequently, the data analyses could not be stratified by the GMFCS level. Only one participant was classified as GMFCS III. Therefore, our findings are not generalizable to children with CP who are classified into higher GMFCS levels. Trost et al.¹⁵ suggested that GMFCS-specific thresholds for MVPA could be used to provide more accurate assessments of PA. A small sample may affect the statistical power; however, we were still able to detect the differences in EE between the accelerometers and the criterion measure. Second, the participants' body weights were assessed by the school teacher approximately one month before the study and were not measured directly on the test day. The participants' body weights were assumed to have remained relatively stable over this 1-month period. Nonetheless, the strengths of this study included the use of indirect calorimetry as the criterion measure and the direct measure of the RMR for each participant. Previous validation studies applied direct observations³² or used equations to estimate the RMR.^{16,17,33}

Conclusions

The Baque and Clanchy AG cut-off points yielded highly accurate

classifications of PA and ST in children and young adults with CP. However, none of the available AG- and AP-based equations accurately predicted the EEs for PA and ST in this population. Future studies using AG to compare PA participation for individuals with TD and CP should note the differences in appropriate cut-off points for these two populations. Further development is needed to ensure that both devices can estimate of EEs accurately in this population.

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Declaration of competing interest

The authors declare no conflicts of interest.

CRediT authorship contribution statement

Ruirui Xing: Investigation, Writing - original draft. **Wendy Yajun Huang:** Conceptualization, Funding acquisition, Methodology, Formal analysis, Writing - review & editing, Supervision, Project administration. **Cindy Hui-ping Sit:** Methodology, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jesf.2020.06.006>.

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