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TITLE: Cut-point-free accelerometer metrics to assess children's physical activity: an example using the school day

Running head

Accelerometer physical activity metrics

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Abstract

The aims were to (i) investigate associations between a novel accelerometer metric: the minimum acceleration value above which the most active 30-minutes were accumulated during the school day ($M30_{ACC}$), and health indicators, and (ii) demonstrate that applying an equivalent cut-point to the $M30_{ACC}$ metric gives comparable prevalence results as a moderate-to-vigorous physical activity (MVPA) cut-point approach. Two-hundred-and-ninety-six children (age 9-10-years) wore wrist-mounted accelerometers for 7-days. School day MVPA and $M30_{ACC}$ were calculated. Body mass index (BMI), waist-to-height ratio (WHtR), and cardiorespiratory fitness (CRF) were also measured. Mixed linear models investigated associations between $M30_{ACC}$ and health indicators. Agreement between ranked MVPA and $M30_{ACC}$ values was assessed using percent agreement, kappa, sensitivity, and specificity statistics. $M30_{ACC}$ thresholds associated with health indicators were 213 mg (BMI), 206 mg (WHtR), and 269 mg (CRF) for girls. The equivalent values for boys were 234mg (BMI), 230 mg (WHtR), and 327 mg (CRF). Less than half of girls and 75% of boys accumulated 30 minutes of school day MVPA. Just less than 50% of girls and >80% of boys had $M30_{ACC}$ values ≥ 200 mg, which is equivalent to brisk walking. Agreement between MVPA and $M30_{ACC}$ tertiles was high, reflected by the sensitivity and specificity values of > 90%. Results demonstrate the utility of $M30_{ACC}$ as a PA metric that is not heavily influenced by researcher decisions. $M30_{ACC}$ has potential as an accelerometer-specific metric for generating PA guidelines related to health indicators, and easily understood forms of activity such as brisk walking.

Keywords

Accelerometer, cut-points, physical activity, guidelines, acceleration, children, school

Introduction

International physical activity (PA) guidelines recommend that to confer health benefits, children and young people accumulate at least 60-minutes of daily moderate-to-vigorous PA (MVPA) during the week ^{1,2}. Schools are frequently highlighted as key environments for children's PA engagement, and in 2013 this was exemplified in the US by the Institute of Medicine recommendations that children spend 30-minutes of the school day in MVPA ³. In the UK the target of *30 active minutes* during the school day is used to assess primary schools' PA provision and whether children are sufficiently active in the school environment ^{4,5}. This recommendation that children accrue 30 active minutes in school was introduced in the 2016 Childhood Obesity Strategy ⁴, and has subsequently been used in national surveillance reporting of children's PA levels ⁵, and in large-scale PA promotion activities ^{6,7}. The premise for 30 active minutes is that children spend up to half of their weekday waking hours in the school environment, where they have opportunities through physical education, recess, and active classroom breaks to achieve half of the 60-minutes daily MVPA recommended for health. However, there are inherent challenges in assessing this 30-minutes goal, which relate to the accurate measurement of MVPA.

Accelerometers are frequently the method of choice in school-based PA studies and have been used at scale to provide estimates of volume and intensity of PA ^{8,9}. Accelerometers therefore represent the best option for accurately estimating how active children are during school. PA estimates from accelerometers are traditionally based on a cut-point approach. Cut-points are a way to quantify accumulated time in PA intensity thresholds by calibrating accelerometer data against a criterion measure, such as indirect calorimetry ¹⁰. Cut-points enable accelerometer data to be presented and interpreted in relation to public health

guidance (e.g., 60-minutes daily MVPA for children). Free-living PA estimates derived from cut-points are though prone to bias, because the cut-points used are specific to the original calibration protocols and sample populations ¹¹. Thus, a challenge to researchers is that use of different cut-points results in vastly different estimates of PA and compliance to PA guidelines ¹². Furthermore, there is no consensus on which accelerometer cut-points are most appropriate, and a number of researcher-driven decisions can significantly affect the resultant PA estimates from accelerometers (e.g., choice of cut-points, wear location, wear time criteria, device type, etc) ^{10,13}. For these reasons, comparing accelerometer-derived school day MVPA between studies and reporting prevalence of children achieving 30 active minutes is problematic, unless researchers have used the same methods and decisions in each study, which seldom happens.

Recently, Rowlands argued that these inherent problems with accelerometer data could be addressed by the adoption of standardised accelerometer metrics ¹¹. These metrics are largely independent of researcher decision-making, and do not rely on protocol and population-specific cut-points to generate useable and relevant acceleration values that can be related to PA ¹¹. The proposed metrics were average acceleration, which provides an indication of PA volume, and intensity gradient, which represents the PA intensity profile over the recorded time period ^{11,14}. We have recently demonstrated that in primary school children, these metrics were sensitive to hypothesised between-group differences in PA and were associated with health indicators ¹⁵. Extending this work, Rowlands et al. recently introduced another accelerometer metric, which describes the minimum acceleration value above which a person's most active X minutes are accumulated ¹⁶. For children's PA guidelines for example, this could be operationalised as the minimum acceleration value above which

the most active 60-minutes are accumulated over a day (i.e., $M60_{ACC}$). This directly measured acceleration metric is population-independent, is not subject to the limitations of cut-points derived from accelerometer calibration protocols¹⁰, and captures intensity irrespective of whether a person's activity intensity exceeds a cut-point (i.e., no person scores zero). As an alternative to reporting prevalence of achieving the 60-minutes daily MVPA guideline based on accelerometer cut-points, $M60_{ACC}$ would provide acceleration values to differentiate between the intensity of children's most active 60-minutes, based on measured accelerations. Rowlands et al. exemplified the utility of this metric by illustrating how presenting percentile values and translating them post-hoc to indicative health-related activities such as brisk walking, facilitates determining the proportion of children meeting PA guidelines¹⁶. The Mx_{ACC} metric has only previously been reported once¹⁶. The current study is novel because it is the first to specify the minimum acceleration value for the most active 30-minutes in the school day ($M30_{ACC}$), and to investigate how this metric relates to important indicators of youth health status.

The purpose of this study was to apply the $M30_{ACC}$ accelerometer metric to data collected in primary school children to explore its utility for reporting the most active 30-minutes during the school day. The aims were to (i) investigate associations between the $M30_{ACC}$ metric and health indicators, and (ii) demonstrate that applying an equivalent cut-point to the $M30_{ACC}$ metric will give similar, and therefore comparable prevalence results as an MVPA cut-point approach.

Materials and Methods

Participants

This is a secondary analysis of data collected in the Active Schools: Skelmersdale (AS:Sk) Project (ClinicalTrials.gov registration: NCT03283904). The methods have been described previously^{17,18} but are outlined briefly here. Year 5 children (age 9-10-years) from seven primary schools situated in a low socioeconomic status (SES) town in north-west England, where the prevalence of overweight/obesity is above the national average¹⁹, were recruited to the study. Phase 1 was a cross-sectional observation study¹⁸, Phase 2 tested the feasibility of PA intervention components²⁰, and Phase 3 was a pilot multicomponent PA intervention¹⁷. Data from Phases 1 and 3 (baseline only) were included in the present study. Data collection took place between October and December 2016 (Phase 1) and between September and October 2017 (Phase 3). Ethical approval was granted by Edge Hill University's Research Ethics Committee (reference # SPA-REC-2015-330) and informed consent and assent were provided by the participants' parents/carers, and the participants themselves, respectively.

Measures

Body mass index and Waist circumference

Height was measured using a portable stadiometer (Leicester Height Measure, Seca, Birmingham, UK), and body mass was measured using calibrated scales (813 model, Seca). Body mass index (BMI) was calculated for each participant and International Obesity Task Force BMI cut-points applied to classify the participants as normal weight or overweight/obese (underweight participants were grouped into the normal weight category)²¹. BMI of ≥ 19.85 was applied as the threshold for overweight²¹. Waist circumference was measured using an anthropometric tape measure, and waist-to-height ratio (WHtR) was

calculated as a measure of central obesity ²². WHtR of ≥ 0.5 was used as the threshold for central obesity ²³. For all measurements the participants wore shorts and t-shirt with shoes removed.

Cardiorespiratory fitness

The 20-m multistage shuttle run test (20-m SRT) was conducted to provide an estimate of cardiorespiratory fitness (CRF). This test has been used extensively with participants of a similar age to those in the current study ²⁴. Classification of being 'unfit' relative to cardiometabolic risk was determined if girls and boys completed <25 and <33 20-m SRT laps, respectively ²⁵.

Socioeconomic status

Neighbourhood-level socioeconomic status (SES) was calculated for each child using the 2015 Indices of Multiple Deprivation (IMD) (Department for Communities and Local Government, 2015). The IMD is a UK government-produced deprivation measure for England comprising income, employment, health, education, housing, environment, and crime. IMD rank scores were generated from parent-reported home postal codes using the National Statistics Postcode Directory database. Every neighbourhood in England is ranked from one (most deprived area) to 32,844 (least deprived area). IMD rank scores were collapsed into deciles with decile 1 containing the most deprived neighbourhoods and decile 10 the least deprived.

Physical activity

Participants wore an ActiGraph GT9X triaxial accelerometer (ActiGraph, Pensacola, FL, USA) on the non-dominant wrist for $24 \text{ h} \cdot \text{d}^{-1}$ over seven days which was set to record at 30 Hz and

100 Hz for Phases 1 and 3, respectively. Data were downloaded using ActiLife version 6.11.9 (ActiGraph, Pensacola, FL, USA) and saved in raw format as GT3X files, before being converted to raw csv file format for signal processing in R (<http://cran.r-project.org>) using the GGIR package version 1.7-1²⁶. Signal processing in GGIR included autocalibration using local gravity as a reference, detection of sustained abnormally high values, detection of non-wear, and calculation of the average magnitude of dynamic acceleration corrected for gravity (Euclidean norm minus 1 *g*; ENMO;²⁶). ENMO values were averaged over 5-s epochs and expressed in milli-gravitational units (*mg*). Accelerometer non-wear was based on the SD and value range of the accelerations at each axis, calculated for 60-minute windows with a 15-minute sliding window (18). By default, GGIR imputed non-wear data by the average at similar time points on other days of the week. Participants were excluded if the ActiGraph files demonstrated post-calibration error greater than 0.01 *g*, and/or less than 3 valid school days of wear. A valid day was defined as accelerometer wear for 100% of the school day (i.e., zero minutes non-wear).

Individual school start and end times were defined in the GGIR *qwindows* parameter to ensure that the accelerometer data were analysed for this time window only. School day durations for the seven schools ranged from 365 to 385 minutes. The following metrics were generated in GGIR for each valid week day: average acceleration (*mg*; argument *do.enmo* = TRUE), intensity gradient (intensity distribution,¹⁴; argument *iglevels* = TRUE), and acceleration above which the most active 30 minutes were accumulated (M30_{ACC}; *mg* (e.g., *qlevels* parameter = c(355/385) for a 385-minutes school day). Published ENMO prediction equations were used to classify the MVPA cut-point as 200 *mg*²⁷ (*mvpthreshold* parameter = c(200)). PA metrics for valid days were averaged to represent school weekday PA values. The

prevalence of achieving the 30 active minutes guideline was calculated using two methods: (1) averaged for the week and (2) on every valid day. To illustrate the comparability of the M30_{ACC} metric to the MVPA cut-point approach, when using equivalent cut-points, we calculated (1) the prevalence of achieving a M30_{ACC} guideline using the 200 mg MVPA threshold as the active 30-minutes school day guideline and (2) prevalence results using the MVPA 200 mg cut-point approach. Applying the 200 mg threshold to M30_{ACC} would be expected to provide similar prevalence results as for the active 30-minutes school day guideline using the 200 mg cut-point.

Statistical analysis

Descriptive statistics were calculated for each variable using mean (SD) for continuous variables and percentage for categorical variables. Percentiles (5th, 10th, 25th, 50th, 75th, 90th, 95th) were calculated for boys and girls for M30_{ACC} and MVPA to illustrate the distribution of values for both metrics from the least to the most active participants. Mixed linear regression was used to predict M30_{ACC} values indicative of 'healthy' levels of BMI, WHtR, and CRF. These analyses were conducted separately for boys and girls and were adjusted for school-level clustering, project phase, SES, and BMI or CRF, depending on the health indicator under consideration. To examine whether applying an equivalent acceleration threshold to the M30_{ACC} metric gives comparable prevalence results as an MVPA cut-point approach, ranked values for each metric were organised into tertiles. Percent agreement, kappa, sensitivity, and specificity were calculated for corresponding tertiles (e.g., upper MVPA vs. upper M30_{ACC}). Analyses were conducted using MLwiN version 3.02 (University of Bristol, UK) and IBM SPSS Statistics version 25 (IBM, Armonk, NY).

Results

Data were available for 296 children (156 girls) who wore the accelerometers for (mean (SD) 376.9 (6.5) min·school day⁻¹ for 3.9 (0.6) days (data file ‘M30ACC school day data for OSF.xlsx’ accessible from <https://osf.io/ctyrw/>). Descriptive characteristics of the sample are in Table 1. According to BMI values, 28.9% of the participants were overweight/obese, based on WHtR 23.7% had central obesity, and 53.0% were classed as unfit. Mean IMD decile was 2.5 (2.1) which indicates that most participants resided in areas of relatively high deprivation.

Table 1. Descriptive characteristics of the participants (Mean (SD) or percentages)

	All	Girls	Boys
Age (y)	10.0 (0.4)	9.9 (0.4)	10.0 (0.4)
Height (cm)	139.3 (6.7)	139.2 (7.1)	139.2 (6.2)
Weight (kg)	37.2 (17.2)	38.4 (22.1)	35.9 (8.7)
BMI [†] (kg·m ²)	18.6 (3.6)	18.8 (3.8)	19.3 (3.3)
Healthy weight (%)	71.1	69.0	73.5
Overweight/obese (%)	28.9	31.0	26.5
Waist circumference (cm)	62.3 (10.0)	64.4 (9.8)	64.2 (10.3)
WHtR [‡]	0.46 (0.07)	0.46 (0.07)	0.46 (0.07)
Not centrally obese (%)	76.3	72.3	80.9
Centrally obese (%)	23.7	27.7	19.1
20-m SRT [§] laps	29.6 (14.8)	27.0 (12.3)	32. (16.8)
Fit (%)	47.0	50.0	43.7
Unfit (%)	53.0	50.0	56.3
IMD [¶] decile	2.5 (2.1)	2.7 (2.3)	2.3 (1.8)

Notes. [†]BMI = body mass index; [‡]WHtR = waist-to-height ratio; [§]20-m SRT = 20 metre shuttle run test; [¶]IMD = Indices of Multiple Deprivation

The average acceleration and intensity gradient during the school day were 91.5 (30.5) mg and -1.71 (0.16), respectively. The mean minimum acceleration for the most active accumulated 30-minutes of the school day (M30_{ACC}) was 242.7 (99.3) mg, and mean school day MVPA was 34.3 (14.8) minutes. For each of the accelerometer PA metrics, boys were significantly more active than girls ($p < .001$; Table 2).

Table 2. Accelerometer physical activity metrics (mean (SD) or percentages)

	All	Girls	Boys	<i>p</i>
Wear time (min·school day ⁻¹)	376.9 (6.5)	377.4 (6.4)	376.4 (6.5)	.19
No. school days valid wear)	3.9 (0.6)	3.9 (0.6)	3.8 (0.6)	.15
Average acceleration (mg)	91.5 (30.5)	79.5 (24.1)	104.8 (31.7)	<.001
Intensity gradient	-1.71 (0.16)	-1.75 (0.16)	-1.66 (0.15)	<.001
M30 _{ACC} [†] (mg)	242.7 (99.3)	205.0 (69.5)	284.8 (111.4)	<.001
MVPA [‡] (min·school day ⁻¹)	34.3 (14.8)	28.6 (12.7)	40.5 (14.7)	<.001

Notes. [†]M30_{ACC} = minimum acceleration for the most active accumulated 30 minutes; [‡]MVPA = moderate-to-vigorous physical activity

The applicability of sex-specific M30_{ACC} thresholds anchored to BMI, WHtR, and CRF were investigated using adjusted mixed linear regression models. The regression equations were solved to generate the M30_{ACC} thresholds associated with being normal weight (BMI), not having central obesity (WHtR), and being ‘fit’ in relation to CRF (20-m SRT performance) (Table 3). For girls, the thresholds were 213 mg (BMI), 206 mg (WHtR), and 269 mg (CRF). The values for boys were 234 mg (BMI), 230 mg (WHtR), and 327 mg (CRF).

Table 3. M30_{ACC}[†] and MVPA[‡] thresholds related to health indicators

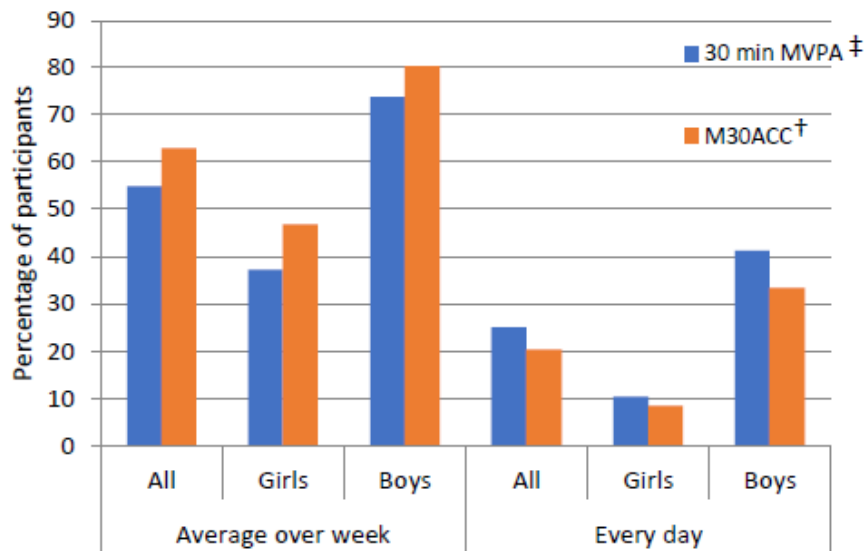
Girls	Threshold	Equation	Boys	Threshold	Equation
M30 _{ACC}	(mg)		M30 _{ACC}	(mg)	
BMI [§]	213	257.3 mg + (-2.23 x 19.85)	BMI	234	268.3 mg + (-1.73 x 19.85)
WHtR [¶]	206	215.1 mg + (-18.0 x 0.5)	WHtR	230	190.9 mg + (77.3 x 0.5)
CRF ^{††}	269	257.3 mg + (0.47 x 25.0)	CRF	327	268.3 mg + (1.8 x 33.0)

Notes: [†]M30_{ACC} = minimum acceleration for the most active accumulated 30 minutes; [‡]MVPA = moderate-to-vigorous physical activity; [§]BMI = body mass index; [¶]WHtR = waist-to-height ratio; ^{††}CRF = cardiorespiratory fitness

Thirty active school day minutes, averaged for the week and on every valid day were achieved by 54.9% and 24.9% of the sample, respectively. When a 200 mg threshold was applied to the M30_{ACC} data, 63.0% of the participants achieved this averaged for the week, and 20.2%

achieved it on every valid day of the week. In all cases, more boys than girls met the respective guidelines (Figure 1).

Figure 1. Prevalence of achieving school day guidelines for 30-minutes MVPA and M30_{ACC}

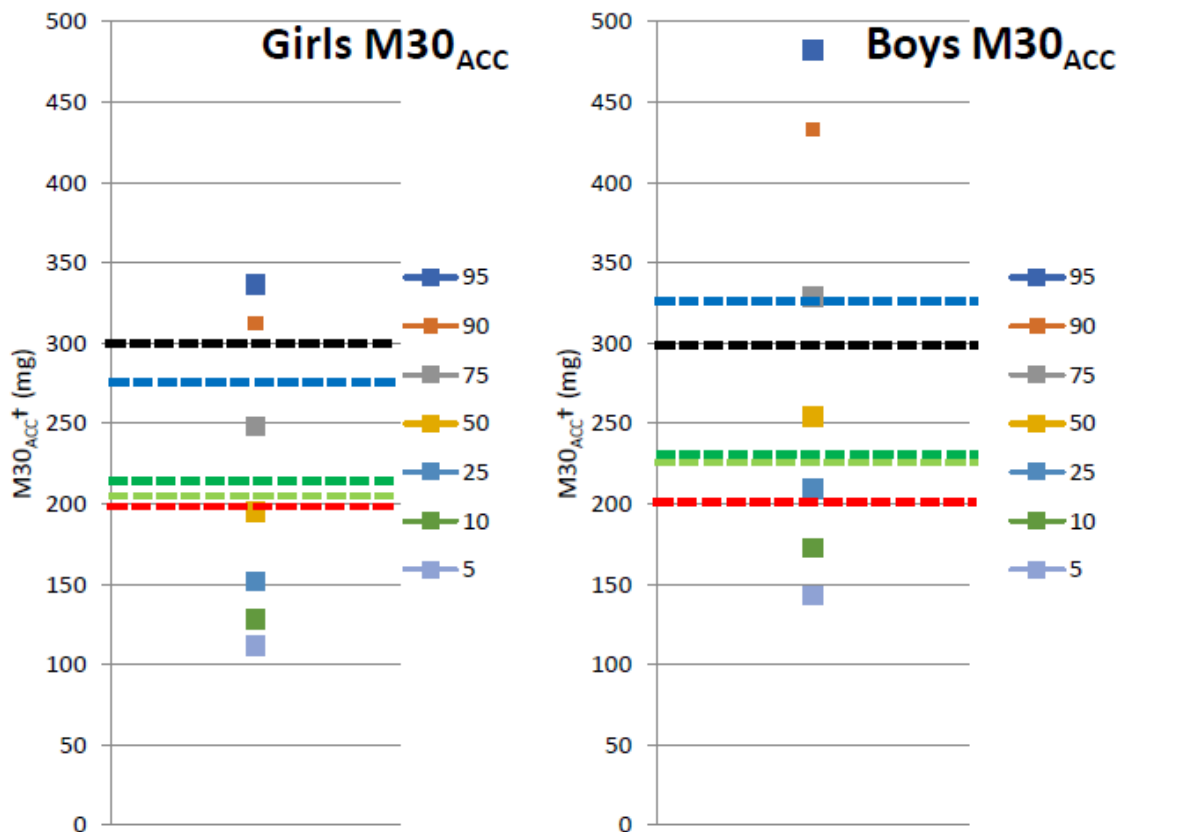


Notes. †M30_{ACC} = minimum acceleration for the most active accumulated 30 minutes;
‡MVPA = moderate-to-vigorous physical activity

M30_{ACC} and MVPA percentiles for boys and girls are presented in Figures 2 and 3, respectively, to illustrate the distribution of values for both metrics for the least to the most active participants. Just less than 50% of girls and ~80% of boys had average minimum accelerations of 200 mg during their most active accumulated 30-minutes, which is equivalent to brisk walking²⁷. When the M30_{ACC} threshold was 300 mg (i.e., greater intensity than fast walking²⁷) < 15% of girls had their most active 30-minutes with a minimum acceleration at this level, while 65% of boys achieved this threshold. The M30_{ACC} thresholds that related to overweight and central obesity were achieved by >45% of the girls and >60% of the boys. The girls' M30_{ACC} threshold related to CRF (270 mg) was achieved by <20% of the sample, with 25% of the boys achieving the equivalent threshold of 327 mg. Less than half of the girls and ~75% of boys

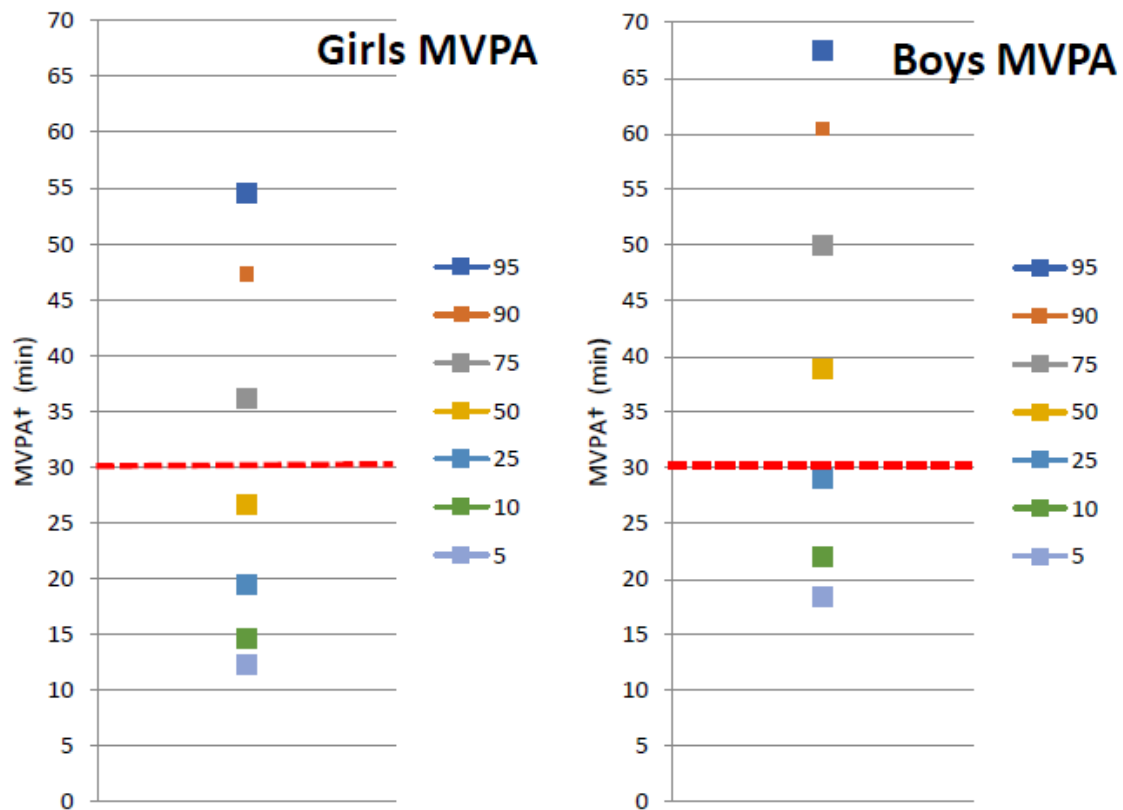
accumulated 30-minutes of school day MVPA based on a 200 mg cut-point. A significant proportion of the sample would therefore be categorised as 'inactive', relative to the 30-minutes school day MVPA target.

Figure 2. Percentile distributions of girls (left panel) and boys (right panel) M30_{ACC} values



Notes: †M30_{ACC} = minimum acceleration for the most active accumulated 30 minutes; red dotted line = 200 mg/brisk walking threshold (28); dark green dotted line = BMI OW threshold; light green dotted line = WHtR obesity risk threshold; blue dotted line = Unfit CRF threshold; black dotted line = 300 mg/fast walking threshold (28).

Figure 3. Percentile distributions of girls (left panel) and boys (right panel) MVPA values



Notes: †MVPA = moderate-to-vigorous physical activity; red dotted line = 30 min MVPA threshold (based on 200 mg cutpoint)

Agreements between categories of school day MVPA and M30_{ACC} were examined to investigate whether applying an equivalent cut-point to the M30_{ACC} metric gives comparable prevalence results as an MVPA cut-point approach (Table 4). Agreement between MVPA and M30_{ACC} tertiles when the same 200 mg threshold was applied, ranged from 89.2% to 94.6%. These high levels of agreement between the MVPA cut-point method and classification of school day activity levels using M30_{ACC} were reflected in the Kappa scores (0.76 to 0.86) and values for sensitivity and specificity, which exceeded 90%.

Table 4. Agreement between proportions of participants categorised in upper, middle, and lower MVPA tertiles with corresponding M30_{ACC}† tertiles

Tertile	Agreement (%)	Kappa	Sensitivity (%)	Specificity (%)
Upper	93.9	0.86	91	95
Middle	89.2	0.76	94	92
Lower	94.6	0.88	92	96

Note: †M30_{ACC} = minimum acceleration for the most active accumulated 30 minutes

Discussion

This study used the school day context to examine the utility of a directly measured acceleration PA metric to report the prevalence of achieving 30 active school day minutes. We found that when $M30_{ACC}$ was considered relative to health indicators, acceleration thresholds were lower for BMI and WHtR and higher for CRF, suggesting that the metric can be used to differentiate between the PA intensities required for distinct health indicators. The proportion of children achieving 30 active school day minutes was broadly comparable when the same 200 mg threshold was applied to MVPA and the $M30_{ACC}$ metric, though this varied depending on how compliance to the guideline was operationalised. There was also strong classification agreement between MVPA and $M30_{ACC}$ tertiles.

The $M30_{ACC}$ thresholds associated with BMI and WHtR approximated the 200 mg MVPA cut-point reported by Hildebrand and colleagues that is indicative of brisk walking²⁷. These findings are consistent with prospective and cross-sectional studies reporting favourable associations between objectively-assessed MVPA and adiposity outcomes²⁸. The higher $M30_{ACC}$ thresholds associated with CRF reflect the need for more intense PA to stimulate cardiorespiratory adaptations. The respective girls' and boys' thresholds were ~30 mg lower and higher than the 300 mg value that is derived from Hildebrand et al.'s mixed-sex sample, and that is indicative of activity more intense than fast walking²⁷. Considering that 269 mg and 327 mg were minimum thresholds for the most active 30-minutes, it likely that this accumulated period included intermittent bouts of more intense activity, such as running, which would elicit higher accelerations (e.g., >800 mg;²⁷). Brisk walking is an activity that is very accessible and easy for children to do without the need for specialist spaces or

equipment, or adult supervision. Similarly, running is a simple activity that children can regularly engage in through intermittent or sustained bouts of varying durations (e.g., playground 'chase' games, structured physical education or sports activities). School-based walking and running programmes and interventions are growing in popularity²⁹⁻³² and have demonstrated potential to enhance PA levels^{30,31}, and benefit adiposity and CRF outcomes³¹. Thus, promoting these simple activity modes, alongside physical education, recess, and active classroom breaks is advocated to enable primary school children to achieve the 30 active minutes target⁴. The M30_{ACC} thresholds associated with 'healthy' BMI, WHtR, and CRF suggest that this metric can differentiate between the lower and higher intensity ends of the MVPA spectrum. Furthermore, the 68 mg sex difference in the M30_{ACC} CRF threshold provides support for the metric to distinguish between the relative PA intensities of girls and boys, which in our sample were reflected by the girls' lower CRF.

When a 200 mg threshold was used for MVPA, 55.5% of participants achieved the 30-minutes school day recommendation averaged over the week, compared to 63.0% of participants achieving this minimum level of acceleration for their most active 30-minutes. The 30-minutes guideline operationalised as achievement on every day, resulted in prevalence values of 24.9% (MVPA) and 20.2% (M30_{ACC}). Though not identical, the similarities in the prevalence of achieving 30 active school day minutes and M30_{ACC} values >200 mg indicate that both metrics accommodate the duration and intensity components of MVPA. Strong classification agreement was observed between cut-point-derived MVPA and M30_{ACC} tertiles when both metrics used a 200 mg threshold. The high sensitivity values illustrate that >90% of participants would likely be classified into an M30_{ACC} tertile that was the same as the corresponding MVPA tertile (e.g., upper MVPA and M30_{ACC} tertiles). These are important

findings which demonstrate that the limitations of cut-points for generating MVPA estimates and compliance with guidelines ¹¹ may be overcome by using the minimum acceleration accumulated over the equivalent time period ¹⁶. For example, MVPA cut-points are population and calibration protocol-specific, which limits comparability with other studies ¹¹. Moreover, participants may fail to do any activity at an intensity above the cut-points, therefore scoring zero when MVPA is the metric under consideration ¹⁶. Conversely, M30_{ACC} values are based on recorded accelerations and meaningful data are generated for all participants, because no-one scores zero. Furthermore, post-hoc anchoring of acceleration thresholds to easily recognised and understood activity modes (e.g., brisk walking ²⁷) will aid interpretability and translation of these PA metrics ¹¹. Prevalence of achieving 30 active school day minutes and M30_{ACC} values >200 mg differed by sex and method of operationalisation (i.e., weekly average or every day). This has been reported previously for self-report and accelerometer data ^{33,34}, and our findings demonstrate that the M30_{ACC} metric was consistent with these expected differences.

A strength of this study was the 100% school day accelerometer wear time criteria which meant that the data were fully representative of the participants' activity levels during the school day. The inclusion of the BMI, WHtR, and CRF measures allowed us to analyse and present the data relative to relevant health indicators. The design though was cross-sectional, which limits any causal inferences being made between the PA metrics and the health indicators. Furthermore, the non-randomised, low SES, and relatively active sample of 9-10 year olds were recruited from one geographical area and the data were analysed in relation to the school setting. Thus, the potential for the findings to be generalised to other demographic groups elsewhere, and to other contexts such as free-living may be limited.

Accelerometer sampling frequencies differed between Phases 1 and 3, but as the lower rate was 30 Hz this difference is unlikely to have influenced the outcome metrics³⁵. The health indicators were represented by field-based measures. Even though these are strongly associated with laboratory methods, their accuracy is lower, and this may have influenced the outcome of the M30_{ACC} regression analyses.

In conclusion, we found that exemplar M30_{ACC} thresholds that were associated with adiposity and CRF differentiated between the relative PA intensities of girls and boys, and reflected moderate through to more vigorous intensity PA. In the context of the school day we found that the proportion of participants achieving 30 active school day minutes anchored to a 200 mg cut-point and M30_{ACC} > 200 mg were similar. Furthermore, the high levels of agreement between MVPA and M30_{ACC}, demonstrated the strong classification accuracy of the M30_{ACC} metric. Using the school day context, the findings demonstrate that a standardised, easy to interpret, and population-independent accelerometer metric that is associated with health indicators can be used to assess compliance with the 30 active minutes guideline and compare PA between groups. The high degree of comparability of this approach due to the minimal influence of researcher decision-making is a key advantage over cut-points for assessing prevalence of achieving PA guidelines. Cut-point-free metrics such as M_X_{ACC} have potential to provide standardised and comparable accelerometer outcomes that relate to physical activity guidelines. However, to improve the interpretation and application of this metric, more research is needed to establish normative acceleration ranges that represent common types of activities undertaken by youth.

Perspective

Accelerometer estimates of time spent in different PA intensities lack comparability between different studies ¹⁰ because of the wide range of PA intensity cut-points that are used, which leads to substantially different conclusions about how active people are. In this study we applied an alternative 'cut-point-free' accelerometer metric: the minimum acceleration value for the most active accumulated 30 minutes (M30_{ACC}) ¹⁶, in the context of the school day. This metric is derived from measured accelerations, accounts for relative intensity differences, and in this study was associated with indicators of adiposity and CRF in girls and boys. Moreover, prevalence of compliance to PA guidelines was similar when M30_{ACC} and a traditional MVPA cut-point approach were compared. This study further demonstrates the potential of this new metric as an alternative to cut-points, that can be interpreted and understood in the context of everyday activities such as brisk walking.

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