LIVERPOOL JOHN MOORES UNIVERSITY

LJMU Research Online

Fairclough, SJ, Rowlands, AV, Taylor, S and Boddy, LM

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

http://researchonline.ljmu.ac.uk/id/eprint/11382/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Fairclough, SJ, Rowlands, AV, Taylor, S and Boddy, LM (2019) Cut-point-free accelerometer metrics to assess children's physical activity: an example using the school day. Scandinavian Journal of Medicine and Science in Sports. ISSN 0905-7188

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

http://researchonline.ljmu.ac.uk/

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

Running head
Accelerometer physical activity metrics

Authors
Stuart J. Fairclough[1], Alex V. Rowlands[2,3,4], Sarah Taylor[5], Lynne M. Boddy[6]

[1]Movement Behaviours, Health, and Wellbeing Research Group, Department of Sport and Physical Activity, Edge Hill University, Ormskirk, UK

[2]Diabetes Research Centre, University of Leicester, Leicester General Hospital, Leicester, UK

[3]NIHR Leicester Biomedical Research Centre, UK

[4]Alliance for Research in Exercise, Nutrition and Activity (ARENA), Sansom Institute for Health Research, Division of Health Sciences, University of South Australia, Adelaide, Australia

[5]Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland[1]

[6]Physical Activity Exchange, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

Corresponding author
Stuart J Fairclough: Email stuart.fairclough@edgehill.ac.uk

Acknowledgements

We are grateful to the children and teachers for their participation in the project, and West Lancashire Sport Partnership for their assistance with the data collection. The study was funded by West Lancashire Sport Partnership, West Lancashire Leisure Trust, and Edge Hill University. AVR is with the NIHR Leicester Biomedical Research Centre, and the Collaboration for leadership in Applied Health Research and Care (CLAHRC) East Midlands.

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 m*g* (BMI), 206 m*g* (WHtR), and 269 m*g* (CRF) for girls. The equivalent values for boys were 234m*g* (BMI), 230 m*g* (WHtR), and 327 m*g* (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 m*g*, 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 protocols [10], 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 guidelines [16]. The Mx_{ACC} metric has only previously been reported once [16]. 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 average [19], were recruited to the study. Phase 1 was a cross-sectional observation study [18], Phase 2 tested the feasibility of PA intervention components [20], and Phase 3 was a pilot multicomponent PA intervention [17]. 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 $\geq$19.85 was applied as the threshold for overweight [21]. 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 $h \cdot d^{-1}$ 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 1.7-1 [26]. 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 (m*g*). 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 (m*g*; argument *do.enmo* = TRUE), intensity gradient (intensity distribution, [14]; argument *iglevels* = TRUE), and acceleration above which the most active 30 minutes were accumulated ($M30_{ACC}$; m*g* (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 m*g* [27] (*mvpathreshold* 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 m*g* MVPA threshold as the active 30-minutes school day guideline and (2) prevalence results using the MVPA 200 m*g* cut-point approach. Applying the 200 m*g* threshold to $M30_{ACC}$ would be expected to provide similar prevalence results as for the active 30-minutes school day guideline using the 200 m*g* 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) m*g* 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) m*g,* 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	*p*
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 (m*g)*	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
$M30_{ACC}$† (m*g*)	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 m*g* (BMI), 206 m*g* (WHtR), and 269 m*g* (CRF). The values for boys were 234 m*g* (BMI), 230 m*g* (WHtR), and 327 m*g* (CRF).

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

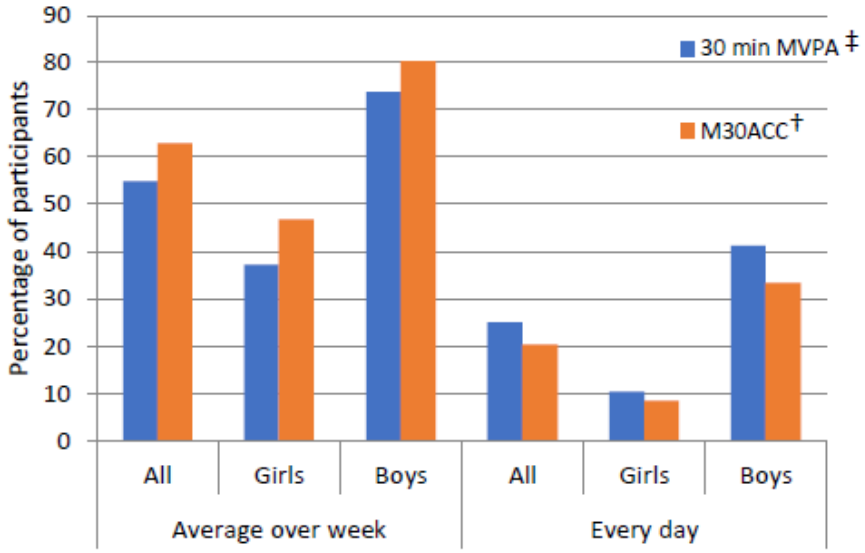
Girls $M30_{ACC}$	Threshold (m*g*)	Equation	Boys $M30_{ACC}$	Threshold (m*g*)	Equation
BMI§	213	257.3 m*g* + (-2.23 x 19.85)	BMI	234	268.3 mg + (-1.73 x 19.85)
WHtR¶	206	215.1 m*g* + (-18.0 x 0.5)	WHtR	230	190.9 mg + (77.3 x 0.5)
CRF††	269	257.3 m*g* + (0.47 x 25.0)	CRF	327	268.3 mg + (1.8 x 33.0)

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 m*g* 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 $M30_{ACC}$

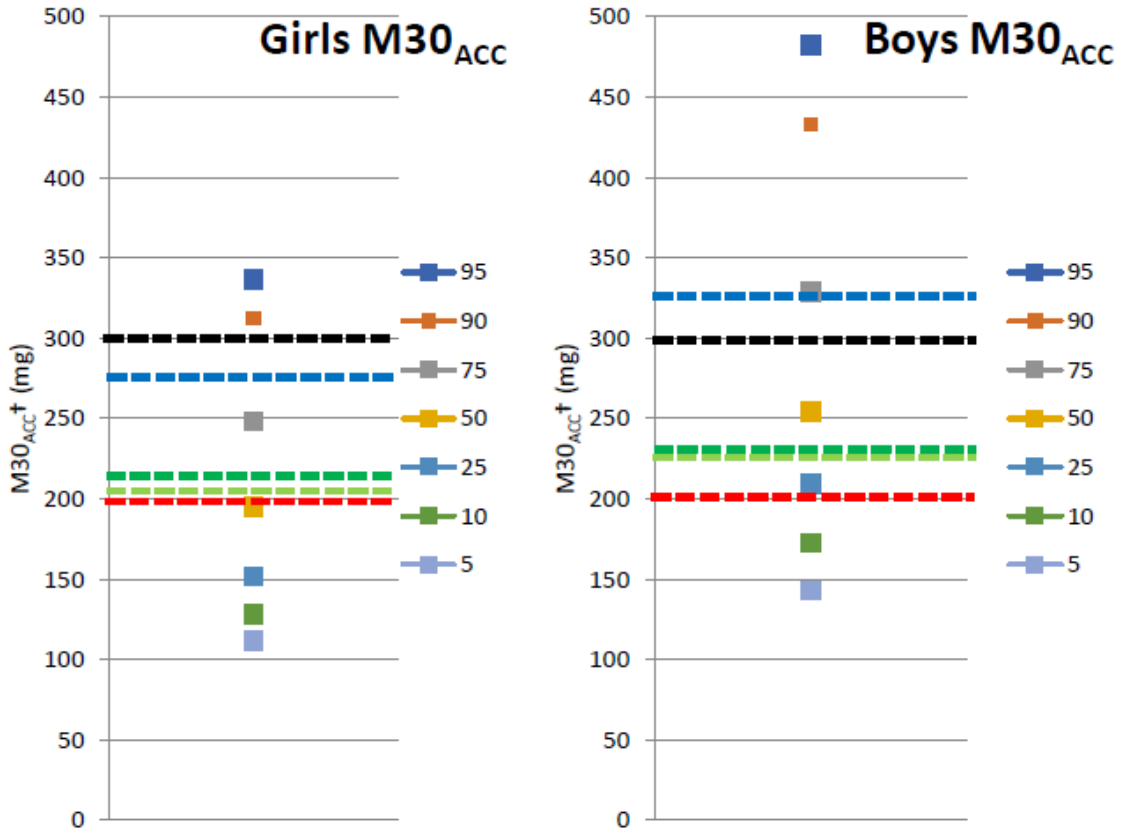


Notes. †$M30_{ACC}$ = minimum acceleration for the most active accumulated 30 minutes; ‡MVPA = moderate-to-vigorous physical activity

$M30_{ACC}$ 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 m*g* during their most active accumulated 30-minutes, which is equivalent to brisk walking [27]. When the $M30_{ACC}$ threshold was 300 m*g* (i.e., greater intensity than fast walking [27]) < 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 m*g*. Less than half of the girls and ~75% of boys

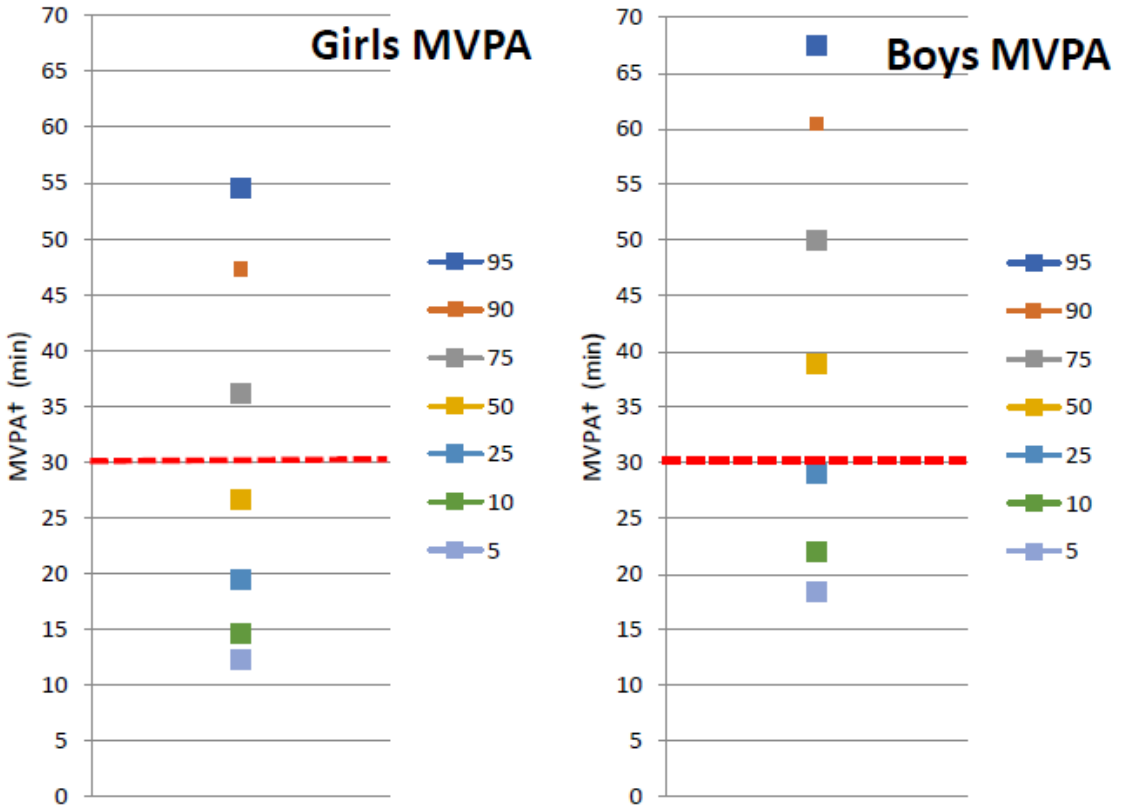
accumulated 30-minutes of school day MVPA based on a 200 m*g* cut-point. A significant proportion of the sample would therefore be categorised as 'inactive', relative to the 30-minutes school day MVPA target.

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 m*g*/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 m*g*/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 m*g* 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 m*g* 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 m*g* 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 m*g* MVPA cut-point reported by Hildebrand and colleagues that is indicative of brisk walking [27]. These findings are consistent with prospective and cross-sectional studies reporting favourable associations between objectively-assessed MVPA and adiposity outcomes [28]. 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 m*g* lower and higher than the 300 m*g* value that is derived from Hildebrand et al.'s mixed-sex sample, and that is indicative of activity more intense than fast walking [27]. Considering that 269 m*g* and 327 m*g* 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 m*g*; [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 popularity [29-32] and have demonstrated potential to enhance PA levels [30,31], and benefit adiposity and CRF outcomes [31]. 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 target [4]. 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 m*g* 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 m*g* 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 m*g* 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 m*g* 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 m*g* 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 metrics [35]. 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 m*g* cut-point and $M30_{ACC}$ > 200 m*g* 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 Mx_{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.

References

1. Chief Medical Officers. Start Active, Stay Active. A report on physical activity for health from the four home countries. London: DH; 2011. 26 p.
2. DHHS. Physical Activity Guidelines for Americans, 2nd Edition. Washington, DC: DHHS; 2018. 8 p.
3. Institute of Medicine. Educating the Student Body. Taking Physical Activity and Physical Education to School. Washington DC: Institute of Medicine;2013. 6 p.
4. Department of Health. Childhood Obesity. A Plan for Action. London: DH;2016. 7 p.
5. Sport England. Active Lives: Children and Young People. 2018; https://www.sportengland.org/research/active-lives-children-and-young-people/. Accessed October 25, 2018.

6. Youth Sport Trust. Active 30:30. 2019; https://www.youthsporttrust.org/active3030. Accessed January 4, 2019.

7. Youth Sport Trust. Active School Planner. 2019; https://activeschoolplanner.org/. Accessed January 4, 2019.

8. Jago R, Macdonald-Wallis C, Solomon-Moore E, Thompson J, L., Lawlor D, A., Sebire S, J. Associations between participation in organised physical activity in the school or community outside school hours and neighbourhood play with child physical activity and sedentary time: a cross-sectional analysis of primary school-aged children from the UK. Br Med J Open. 2017;7:e017588. doi: 10.1136/bmjopen-2017-017588.

9. Griffiths LJ, Cortina-Borja M, Sera F, et al. How active are our children? Findings from the Millennium Cohort Study. Br Med J Open. 2013;3:e002893. doi: 10.1136/bmjopen-2013-00289.

10. Migueles JH, Cadenas-Sanchez C, Tudor-Locke C, et al. Comparability of published cut-points for the assessment of physical activity: Implications for data harmonization. Scand J Med Sci Sports. 2019;29:566-574.

11. Rowlands AV. Moving forward with accelerometer-assessed physical activity: Two strategies to ensure meaningful, interpretable, and comparable measures. Pediatr Exerc Sci. 2018;30:450-456.

12. Pedišić Ž, Bauman A. Accelerometer-based measures in physical activity surveillance: current practices and issues. *Br J Sports Med.* 2015;49(4):219-223.

13. Migueles JH, Cadenas-Sanchez C, Ekelund U, et al. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. Sports Med. 2017;37:1821-1845.

14. Rowlands AV, Edwardson CL, Davies MJ, Khunti K, Harrington DM, Yates T. Beyond cut-points: Accelerometer metrics that capture the physical activity profile. Med Sci Sports Exerc. 2018;50:1323-1332.

15. Fairclough SJ, Taylor S, Rowlands AV, Boddy LM, Noonan RJ. Average acceleration and intensity gradient of primary school children and associations with indicators of health and well-being. J Sports Sci. 2019;37:2159-2167.

16. Rowlands AV, Sherar LB, Fairclough SJ, et al. A data-driven, meaningful, easy to interpret, population-independent accelerometer outcome variable for global surveillance. bioRxiv. 2019; doi: https://doi.org/10.1101/604694.

17. Taylor S, Noonan R, Knowles Z, et al. Evaluation of a pilot school-based physical activity clustered randomised controlled trial—Active Schools: Skelmersdale. Int J Environ Res Public Health. 2018;15:doi:10.3390/ijerph15051011.

18. Taylor S, Curry W, Knowles Z, Noonan R, McGrane B, Fairclough SJ. Predictors of segmented school day physical activity and sedentary time in children from a northwest England low-income community. Int J Environ Res Public Health. 2017;14:doi:10.3390/ijerph14050534.

19. Collins S. The Seven Wards: A Focus on Skelmersdale. Preston, England: Lancashire County Council;2015. 13 p.

20. Taylor SL, Noonan RJ, Knowles ZR, McGrane B, Curry WB, Fairclough SJ. Acceptability and feasibility of single-component primary school physical activity interventions to inform the AS:Sk Project. Children. 2018;17:doi:10.3390/children5120171.

21. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. Br Med J. 2000;320:1240-1244.

22. Mokha JS, Srinivasan SR, DasMahapatra P, et al. Utility of waist-to-height ratio in assessing the status of central obesity and related cardiometabolic risk profile among normal weight and overweight/obese children: The Bogalusa Heart Study. BMC Pediatr. 2010;10:73.doi:10.1186/1471-2431-10-73.

23. Mehta SK. Waist circumference to height ratio in children and adolescents. Clin Pediatr. 2015;54:652-658.

24. Tomkinson GR, Carver KD, Atkinson F, et al. European normative values for physical fitness in children and adolescents aged 9–17 years: Results from 2 779 165 Eurofit performances representing 30 countries. Br J Sports Med. 2018;52:1445-14563.

25. Boddy LM, Thomas NE, Fairclough SJ, et al. ROC generated thresholds for field-assessed aerobic fitness related to body size and cardiometabolic risk in schoolchildren. PLoS ONE. 2012;7(9):e45755.

26. van Hees VT, Fang Z, Langford J, et al. Autocalibration of accelerometer data for free-living physical activity assessment using local gravity and temperature: an evaluation on four continents. J Appl Physiol. 2014;117:738-744.

27. Hildebrand M, Van Hees VT, Hansen BH, Ekelund U. Age-group comparibility of raw accelerometer output from wrist- and hip-worn monitors. Med Sci Sports Exerc. 2014;46:1816-1824.

28. Poitras VJ, Gray CE, Borghese MM, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. Appl Physiol Nutr Metab. 2016;41:S197-S239.

29. Chalkley AE, Routen AC, Harris JP, Cale LA, Gorely T, Sherar LB. Marathon Kids UK: Study design and protocol for a mixed methods evaluation of a school-based running programme. Br Med J Open. 2018;8:e022176.doi:10.1136/bmjopen-2018-022176.

30. Carlin A, Murphy MH, Nevill A, Gallagher AM. Effects of a peer-led Walking In ScHools intervention (the WISH study) on physical activity levels of adolescent girls: A cluster randomised pilot study. Trials. 2018;19(1):31doi:10.1186/s13063-017-2415-4.

31. Chesham RA, Booth JN, Sweeney EL, et al. The Daily Mile makes primary school children more active, less sedentary and improves their fitness and body composition: a quasi-experimental pilot study. BMC Med. 2018;16(1):64.doi:10.1186/s12916-018-1049-z.

32. Breheny K, Adab P, Passmore S, et al. A cluster randomised controlled trial evaluating the effectiveness and cost-effectiveness of the daily mile on childhood obesity and wellbeing; the Birmingham Daily Mile protocol. BMC Public Health. 2018;18(1):126.doi:10.1186/s/12889-0517-5019-8.

32. De Vries SI, Hopman-Rock M, Bakker I, Van Mechelen W. Meeting the 60-min physical activity guideline: Effect of operationalization. Med Sci Sports Exerc. 2009;41:81-86.

34. Williamson C, Kelly P, Strain T. Different analysis methods of Scottish and English child physical activity data explain the majority of the difference between the national prevalence estimates. BMC Public Health. 2019;19:171.doi: 10.1186/s12889-019-6517-7.

35. Zhang S, Murray P, Zillmer R, Eston RG, Catt M, Rowlands AV. Activity classification using the GENEA: Optimum sampling frequency and number of axes. Med Sci Sports Exerc. 2012;44:2228-2234.