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The use of the intensity gradient and average acceleration metrics to explore associations with BMI z-score in children

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Running title: Raw acceleration activity metrics.

Abstract

This study used the intensity gradient (IG) and average acceleration metrics to describe children's activity profiles and explore associations with body mass index (BMI) z-score. Two hundred and forty-six children ($n = 138$ girls) aged 9.6 ± 1.4 years wore a wrist-mounted ActiGraph wGT3X-BT accelerometer for 7 days on their non-dominant wrist. Physical activity (PA) metrics captured included: the IG which describes the intensity distribution of accelerations across the 24 h monitoring period; average acceleration which provides a measure of the volume of activity; total moderate-to-vigorous PA (MVPA) and inactive time. Acceleration was averaged over 5s epochs. Finally, BMI z-score was calculated for each participant. Average acceleration was negatively associated with BMI z-score ($p < 0.05$) independent of age and gender but not IG. The IG was negatively associated with BMI z-score independent of potential correlates and average acceleration. Total MVPA was not associated with BMI-z score. The IG and average acceleration metrics may be used to explore the independent or cumulative effects of the volume and intensity distribution of activity upon measures of health and well-being in children to inform specific activity recommendations.

Keywords: ActiGraph; accelerometer; BMI z-score; activity metrics; wrist-worn; raw acceleration.

Introduction:

The use of accelerometers to objectively quantify activity behaviours is widespread. There are several different types of accelerometers available (Actical, Actiwatch, GENEActiv, Axivity, etc), with the ActiGraph (Pensacola, FL, USA) accelerometers being one of the most commonly used by researchers when measuring physical activity (PA) levels (1). A lack of comparability in accelerometer output variables from the use of different devices, post-processing decisions, cut-points to classify activity estimates and the proprietary nature of accelerometer output has hindered the ability to compare findings across studies (2,3). The International Children's Accelerometry Database (ICAD) is one example of how waist-worn ActiGraph data can be harmonized to facilitate the pooling of data to investigate diverse research questions by ensuring outcomes are comparable. Conversely, the International Study of Childhood Obesity (ISCOLE) is a multinational cross-sectional study comprising of over 7000 children from 12 countries that employs a consistent measurement and analysis protocol of accelerometer data (4). Although ISCOLE has collected raw acceleration data, research outputs from ICAD and ISCOLE are based on ActiGraph proprietary counts which limits their comparability with studies using other accelerometer devices.

In order to facilitate comparisons between studies, a key recommendation from a panel of experts meeting held in 2009 was that accelerometer device data should be collected and saved as raw acceleration signals (5,6). Since this recommendation, GENEActiv, ActiGraph and Axivity raw acceleration research grade accelerometer devices are now commercially available and are currently used in large-scale studies to assess children's activity profiles (4,7–9). Studies that utilize raw accelerations to assess activity levels (10–12) tend to rely upon the Euclidian norm minus one (ENMO) metric to estimate time spent in activity categories using thresholds derived from the laboratory based validation study by Hildebrand and colleagues (13). Since these authors instructed participants to wear both ActiGraph and GENEActiv accelerometers on the hip and the wrist during all activities, the resultant raw acceleration thresholds are commonly used by researchers working with raw accelerations to quantify time spent in activity categories. Much like the limitations associated with the numerous count based thresholds available for ActiGraph devices (14), their utility is limited because of the laboratory protocol used to generate the raw thresholds, the lack of cross-validation in a free-living setting and the sample characteristics. Furthermore, these proposed

raw acceleration thresholds and processing methods are yet to be validated in an independent sample.

In an attempt to overcome the reliance upon population and device specific activity thresholds, Rowlands and colleagues have called for the need for acceleration metrics that are standardised, interpretable, comparable between devices and are meaningful (5,15). To address this need, Rowlands has called for raw acceleration values to be reported in future research manuscripts alongside typically reported activity variables in the form of two metrics; average acceleration and the intensity gradient (IG) (5). Average acceleration provides a measure of the volume of activity whereas the IG describes the intensity distribution of accelerations across the monitoring period. Together, these two metrics detail both the volume and intensity of activity undertaken across the monitoring period using all of the acceleration data collected. Rather than the limited data that is often used to quantify time spent in an activity category which is typical when using available thresholds.

Recently, Rowlands and colleagues examined whether independent relationships were evident for the average acceleration and IG metrics with measures of adiposity in adolescent girls and adults with type 2 diabetes (15). Findings revealed that only average acceleration was independently and negatively associated with percent body fat and body mass index (BMI) in the adult sample. In the adolescent sample, IG was independently and negatively associated with both percent body fat and BMI-z score whereas average acceleration was independently and positively associated with percent body fat. In a younger population, Fairclough et al., examined whether average acceleration and the IG were independently associated with several indicators of health and well-being in children aged 9-10 years old (16). Unlike average acceleration, the IG was found to be negatively significantly associated with BMI z-score, waist-to-height ratio (WHtR) and a composite metabolic syndrome (MetS) risk score and positively significantly associated with cardiorespiratory fitness (CRF) when controlling for the alternate metric. These findings suggest that both metrics could be used instead of laboratory derived population and device specific activity thresholds to examine the relative importance of intensity and volume of activity for a specific population or health outcome. Moreover, further work could also explore the independent or cumulative effects of the average acceleration and IG metrics upon health outcomes with findings used to inform more specific activity recommendations. Crucially, their combined use overcomes the reliance upon thresholds derived from specific populations and protocols.

The IG is a new metric and limited evidence is available that has examined the associations between both the average acceleration and IG metrics with measures of health and well-being. Moreover, Rowlands and colleagues (15) only examined data from the GENEActiv accelerometer collected from adolescent girls in England whereas Fairclough and colleagues examined data from the ActiGraph GT9X accelerometer from 9-10 y children living in a deprived English town. Whether similar findings are evident from children of a different age and geographical location is unclear. Examining the magnitude of associations between average acceleration, the IG and moderate-vigorous PA (MVPA) is important to establish whether future work could investigate the relative importance of both the volume and intensity of activity for a particular outcome or risk factor. If these variables are strongly correlated then due to the presence of multicollinearity, such investigations would not be possible using standard statistical methods. Therefore, establishing whether IG is more independent of average acceleration than MVPA will allow researchers to examine the relative importance of both the volume and intensity of activity for a particular outcome or risk factor.

Using data from the wGT3X-BT ActiGraph (ActiGraph; ActiGraph, LLC, Pensacola, FL, USA) accelerometer device, the aims of this study therefore were to: 1) examine whether the IG and average acceleration metrics were more independent from each other than MVPA and inactive time; 2) whether independent relationships were evident between the IG and average acceleration metrics with that of BMI z-score and 3) provide easily understandable activity recommendations based upon the findings of multiple regression analyses on which metric was associated with the BMI z-score.

Methods:

A convenience sample of participants were recruited from across 14 geographically representative primary schools in South Lanarkshire, Scotland from October 2017 and December 2018. Children aged 8-12 years were invited to participate but due to curriculum demands and staffing availability, the Head Teacher of each school dictated whether all eligible participants or selected classes were recruited. This resulted in the recruitment of 461 children ranging from 11 to 92 from each school. Upon approval being received from the

Ethical Committee of the University of the West of Scotland, participants and parents were provided with information packs detailing the aims of the study and their involvement.

Measures:

Participants' stature was measured barefoot to the nearest 0.1cm using a portable stadiometre (Seca Stadiometre, Seca Ltd, Birmingham, UK). Mass was measured barefoot with light clothing to the nearest 0.1kg on electronic scales (Seca Digital Scales, Seca Ltd., Birmingham, UK). From measured stature and mass, a BMI z-score was calculated relative to the UK 1990 BMI population reference data (17). Thereafter, all participants wore one ActiGraph wGT3X-BT accelerometer (ActiGraph; ActiGraph, LLC, Pensacola, FL, USA) on their non-dominant wrist (defined as the hand they do not normally write with) for 7 days. Verbal confirmation of each participant's non-dominant wrist was noted, and device placement was demonstrated. All participants were fitted with their device prior to leaving the measurement session. Prior to distribution, each accelerometer was synchronised with Greenwich Mean Time and initialized to capture data at 80Hz. Participants were instructed to wear the device at all times (i.e., 24 h per day) for 7 days, except during any water-based activities such as swimming or bathing.

Data processing:

Upon the return of each device, data was downloaded using ActiLife (Version 6.13.3; ActiGraph, Pensacola, FL, USA) and saved in raw format as .gt3x files. The .gt3x files were subsequently converted to time-stamp free .csv files which were exported into R v3.5.2 (R Foundation for Statistical Computing, Vienna, Austria, <https://cran.r-project.org/>) and processed using the GGIR package v1.9.1 (18,19). Processing in GGIR involves the detection of abnormally high values, detection of non-wear time (19) and auto-calibrates the raw triaxial accelerometer signals using local gravity as a reference (18). Furthermore, GGIR calculates ENMO (1 g) averaged over 5 s epochs and expressed in milli-gravitational units (mg) as previously described (15).

Participants were excluded from subsequent analysis if their accelerometer files demonstrated a post-calibration error greater than 0.01 g, there were less than 3 days of the week of valid wear (defined as ≥ 16 h per day (15)), or wear data was not present for each 15 min period of the 24 h cycle. We used the default non-wear setting whereby invalid data were imputed by

the average at similar time-points on different days of the week (19). Therefore, outcome variables were calculated based on the entire 24 h cycle for all included participants.

In line with Rowlands and colleagues (15), PA was expressed as average acceleration across the day (ENMO, mg), time accumulated in MVPA and time spent inactive. Time spent in MVPA was defined as the time accumulated above an acceleration of 201 mg (13) whereas time spent inactive was defined as time accumulated below 50 mg (15,20). Distribution of time spent in intensity categories of 25 mg resolution (i.e. 0-25 mg, 25-50 mg, 50-75 mg....4000 mg, >4000 mg) was determined in GGIR using the argument 'iglevels = TRUE' to describe a participant's activity intensity distribution and represented the IG. The IG is reflective of the negative curvilinear relationship between intensity and time accumulated in that intensity which can be transformed into a straight-line relationship by taking the natural log of the two wide ranging quantities of intensity and time, as previously described (15). Finally, the R^2 value (indication of the goodness of fit of the linear model) and the constant from the linear regression equation was produced in GGIR alongside the IG for each participant. The IG was always negative which reflects the reduced time accumulated within the increasing intensity categories. A higher constant and lower gradient were reflective of a steeper distribution across the intensity categories with less time accumulated at mid-range and higher intensities whereas a lower constant and higher gradient were reflective of a greater distribution of time spent across the intensity categories.

Statistical analyses

Data are presented as mean $\pm$ SD unless otherwise stated. Average acceleration (ENMO) was used as the metric to describe overall activity and the gradient of the participants log-log regression line (IG) used as the metric to describe the distribution of activity across the intensity categories. Independent t-tests were used to examine differences in descriptive characteristics between the genders. Pearson's correlation coefficients examined the inter-correlations between the activity outputs to determine whether the IG was more independent of average acceleration than MVPA and time spent inactive.

A negligible school-level effect was observed (ICC = 0.01 to 0.07) which indicated that no clustering was apparent in the dataset. Therefore, multiple linear regression analyses were used to examine whether the IG and average acceleration metrics were associated with BMI z-score (dependant variable), (Model 1). Model 2 further controlled for potential covariates

(age and sex) whereas Model 3 additionally controlled for the alternate metric to establish whether associations were independent. Analyses were then repeated using time spent in MVPA to compare the results with that from the IG metric. Finally, variables were centred prior to entry into the regression analyses with a variance inflation factor (VIF) of > 5 used to indicate the presence of multicollinearity.

Based on the findings of the multiple regression analyses, meaningful activity targets could be presented based on whether overall activity, the intensity of activity or both are important for BMI z-score. Following the recommendations provided by Rowlands and colleagues (5,15), we calculated the mean $\pm$ SD of the average acceleration metric in order to establish how much additional activity would need to be undertaken to increase overall activity levels by 1 SD. Assuming that the additional activity would replace time spent at the average acceleration, the time required for a particular activity was calculated by: $1440 \times (\text{increase in average acceleration required by activity at that intensity}) / (\text{acceleration associated with that activity} - \text{average acceleration})$. The activities used to inform recommendations were taken from Hildebrand and colleagues (13) and consisted of slow walking at approximately 3 km/h, fast walking at approximately 5 km/h and slow running at approximately 8 km/h. These activities were indicative of acceleration values of 100 mg, 200 mg and 800 mg and were used to calculate the time estimates of the additional activity recommendations. To demonstrate the potential utility of these activity recommendations, we provide examples of meaningful activity targets to increase average acceleration, the IG or both. Presenting individuals with a choice of activities that are perceived as feasible for them, may be a promising strategy that can be used to improve activity levels. Statistical analyses were conducted using IBM SPSS statistical software for Windows version 24 (IBM, Armonk, NY) and a p-value of <0.05 used to indicate statistical significance. The `loneway` command in Stata V.13 (Stata Corp. 2013. Stata Statistical Software: Release 13. College Station, Texas, USA: StataCorp LP) was used to examine if clustering was evident within the dataset.

Results

Accelerometer files were available for 436 of the 461 participants. There were 6 device malfunctions, 14 participants were absent from school on the day of accelerometer distribution and 5 reported losing their device. The accelerometer files of 190 participants were excluded from subsequent analysis (109 did not wear the device for ≥ 16 h.d⁻¹ for at least

3 days, 71 had missing data for any 15-min window over the 24-h cycle (as indicated in GGIR by the variable '24-h cycle' < 1) and 10 failed calibration) which left a final sample size of 246. There were no significant differences in BMI z-score or age between included and excluded participants, but girls were significantly more likely to be excluded than boys.

Participant characteristics are displayed in Table 1. Significant differences were evident between genders for average acceleration, MVPA and IG (All $p < 0.001$). Average acceleration was strongly positively associated with time spent in MVPA ($r = 0.95$, $p < 0.001$) and strongly negatively associated with inactive time ($r = -0.73$, $p < 0.001$). Associations between average acceleration and the IG were significant but weaker ($r = 0.56$, $p < 0.001$) than the associations between average acceleration and time spent in MVPA and inactive time. Associations between the IG and time spent in MVPA ($r = 0.51$, $p < 0.001$) and inactive time ($r = -0.21$, $p < 0.01$) followed similar directions but were weaker than those observed with average acceleration.

Findings from the regression models can be found in Table 2. Average acceleration was negatively associated with BMI z-score, but only after adjusting for age and gender in Model 2. These associations were not evident in Model 3 when the alternate activity metric (IG) entered the regression analysis. This suggests that the association between average acceleration and BMI z-score was not independent of the IG. The IG was negatively associated with BMI z-score in the unadjusted model (Model 1) and remained after adjusting for age and gender in Model 2. These associations remained in Model 3 when the alternate activity metric (average acceleration) entered the regression analysis. This suggests that the associations between the IG and BMI z-score were independent of average acceleration and that the IG may be more important for BMI z-score. In all cases, the VIF did not exceed 1.6. Time spent in MVPA was not associated with BMI z-score in either model 1 or 2 (data not reported). Due to the presence of multicollinearity (VIF's > 5), we were unable to establish the independent effects of MVPA and average acceleration.

An increase in the average acceleration of 1 SD corresponded to an increase of 13.4 mg. Increasing activity by 13.4 mg could be achieved by undertaking the following activities and replacing time at the average acceleration level with:

- 1) approximately 3.75 h of slow walking OR

- 2) approximately 1.75 h of fast walking OR
- 3) approximately 25 min of slow running

As long as the sum of the increased activity corresponds to the 13.4 mg increase needed, a combination of activities can also be recommended as follows:

4) 40 mins of slow walking (2.7 mg) AND 30 mins of fast walking (4.1 mg) AND 12 mins of slow running (6.6 mg).

5) 22 mins of slow walking (1.5 mg) AND 15 mins of fast walking (2.1 mg) AND 18 mins of slow running (9.8 mg).

Although these activity recommendations will work to increase the average acceleration by the SD of the sample, their effect upon the IG of an example participant with low average acceleration and a low IG (1 SD below the sample mean for each) can be seen in Figure 1. It was evident that activities of a lower intensity had a negative effect upon the participants IG with more positive effects seen when higher intensity activities are recommended, either in isolation or in combination with other activities.

Discussion

Our findings revealed there were significant differences in average acceleration, IG and MVPA between genders. Boys are known to be more active and engage in more MVPA than girls between 8-10 years of age which our findings support (21). The significant differences in average acceleration and IG between genders also supports the recent findings of others (16) and provides confidence in the utility of these activity metrics to distinguish between those who are more physically active. IG was more independent of overall activity, assessed using average acceleration, when compared to MVPA and inactive time. Moreover, the IG was negatively associated with BMI z-score independently of overall activity. Given the strong associations between average acceleration and MVPA, it was unsurprising that we were unable to examine the independent effects of these two variables upon BMI z-score due to the presence of multicollinearity. Nonetheless, the independent negative associations between the IG and BMI z-score is an important finding and is consistent with previous investigations (15,16). This suggests that the intensity of activity for children and adolescent

girls rather than the volume of activity may be more important for BMI z-score. Whereas in adults with type 2 diabetes, the volume of activity rather than the intensity may be more important for BMI (15). We observed higher IG (-1.99) and average acceleration (44.2 mg) values in this study compared to those noted previously for adolescent girls (-2.47 and 36.3 mg) and adults (-3.11 and 22.1 mg) (15). Conversely, despite the age of our participants being broadly similar to that of Fairclough et al., (8 – 12 years vs. 9 – 10 years), it was evident from their study that participants had higher IG and average acceleration values (-1.96 and 45.4 mg) than our participants. Since the average acceleration value reflects the volume of activity and the IG reflects the intensity of activity undertaken across the monitoring period, differences in values between the age groups are likely a reflection of the reduced PA undertaken with age (22,23).

An important attribute of both the IG and average acceleration metrics are that they are standardized and could be compared between different populations which removes the concerns of using laboratory derived thresholds (15). As these standardized metrics become more widely used, there is an opportunity to move away from the reliance upon thresholds derived from laboratory validation studies and proprietary accelerometer software to more transparent data processing methods using open-source and freely available software. We found that average acceleration and time spent in MVPA and inactive time were highly correlated which is consistent with the findings of others (15,16). Examining the independent effects of activity categories upon health outcomes is important so that an evidence base detailing the health benefits of PA can be established. As others have found too, the strong correlations between activity and intensity metrics can violate the assumption of non-collinearity within regression models which limits the use of common statistical approaches to explore the independent effects of activity metrics upon health outcomes (24,25).

As a consequence of this, researchers are often unable to establish the relative importance of both the volume and intensity of activity for a particular health outcome or risk factor. One such example of this can be seen from Boyer and colleagues who were interested in examining the associations between total volume and intensity of activity with insulin resistance in adults (26). Using two cut-points for bouts of MVPA, the authors found that one of the cut-points violated the assumptions of the linear regression analysis due to the presence of multicollinearity with the total volume measure. The other cut-point did not violate the VIF statistic and allowed the authors to establish that the total volume of activity rather than

the intensity of activity was more strongly associated with insulin resistance. Similar studies have also noted slightly stronger associations between total volume of activity and cardiometabolic risk factors when compared to measures of the intensity of activity (27). Conversely, others have reported that the intensity of activity appears more important than the volume of activity for many musculoskeletal outcomes in middle-aged women (28) and leukocyte telomere length in a racially and ethnically diverse cohort of 161,808 postmenopausal women aged 50–79 years (29).

In studies that have been able to examine the independent effects of activity metrics upon health outcomes in youths, it has been shown that age-related increases in sedentary time is associated with age-related increases in adiposity, independent of MVPA (30,31). The independent associations for MVPA were not reported by Mann et al., (30) but Schwarzfischer et al., (31) found that a shorter time spent in MVPA predicted a reduced BMI over a 5-year period. Nonetheless, this significant effect was removed once sedentary time was controlled for. In a large cross-sectional study of children aged 9-11 years of age, Katzmarzyk et al., found that higher MVPA was associated with lower odds of having high BMI z-scores, independent of sedentary time (32). The authors also reported that increased sedentary time was associated with higher BMI z-scores, but this effect was not independent of MVPA. Recently it was also reported that MVPA was positively associated with CRF and a MetS risk score, independent of average acceleration in children aged 9-10 y (16).

Whilst this body of research is reflective of the growing interest in establishing the effects of other activity categories rather than just MVPA upon health outcomes, it is also indicative of the challenge's researchers face when comparing findings between studies. For instance, differences in study methodologies, populations, accelerometer devices and cut-points used to establish time spent in intensity categories will preclude direct comparisons between study findings. For different populations and health outcomes, the relative importance of total activity and the intensity of activity will likely vary but without a consistent approach to quantify both measures, these variations may be due to different study methodologies and post-processing decisions. Using the average acceleration and IG metrics therefore, offer the opportunity to investigate the independent, additive and interactive effects of total volume and intensity of activity on a range of health outcomes without the concerns and limitations of comparing findings from studies using incomparable metrics (15,16).

To this end, the findings reported by Fairclough et al., are of particular interest (16). These findings agree with our observations that average acceleration was not significantly associated with BMI z-score once IG was controlled for within the analysis. Conversely, IG was independently associated with BMI z-score when average acceleration was controlled for. Similar observations were also evident for WHtR, CRF and a MetS risk score suggesting that the intensity of activity, rather than the volume of activity, may be more important for these variables. The authors did however note independent associations between average acceleration and a measure of global health-related quality of life (HRQoL), after controlling for IG. As the authors explain, this is the first study to document the independent relationship between IG and HRQoL which suggests that the volume of activity, rather than the intensity of activity, may be more important for HRQoL in children (16). Although these findings are based on a limited age range of children, the use of standardized metrics offer considerable opportunities for others using ActiGraph triaxial accelerometers to compare their findings with other populations and with those reported herein and elsewhere (15,16).

The need for comparable outputs between different brands of accelerometers was a key outcome from a panel of experts in 2009 (5,6). Using the open-source and freely available GGIR package for R (<https://cran.r-project.org/web/packages/GGIR/GGIR.pdf>) (18,19), researchers are able to produce the IG and average acceleration metrics when using any of the 3 research-grade accelerometers (Axivity, ActiGraph, and GENEActiv) that provide acceleration data in g. Previous investigations have suggested that average acceleration values generated from the Axivity and the GENEActiv can be considered equivalent, but is approximately 11% lower for the ActiGraph when all devices are worn on the non-dominant wrist (33). This is lower than the 15% difference in average acceleration found between the GENEActiv and the ActiGraph when worn on the waist by 10-12 year olds for 7 days in a free living setting (34).

That there is a difference in average acceleration between the GENEActiv and the ActiGraph is unsurprising and is likely attributable to the technical differences between devices (13,34,35). How these differences impact upon the acceleration outputs over a prolonged monitoring period however is unknown. To the best of our knowledge, only one published study has examined the comparability in average acceleration between the Axivity, ActiGraph, and GENEActiv devices when worn on the wrist (33). In this study participants wore all three devices on their non-dominant wrist but for only 2 hours in a stimulated living

space. Whether equivalent findings across the 3 research-grade accelerometers would be evident over a longer monitoring period is unclear. It has been suggested that the differences in the magnitude of accelerations between the GENEActiv and the ActiGraph are most evident at low accelerations such as when sitting and standing (35). Since children spend the majority of their time in sedentary pursuits which are indicative of low accelerations (36,37), it's possible that the magnitude of acceleration differences between the ActiGraph and both the GENEActiv and the Axivity when worn at the wrist over a prolonged period could be greater than the 11% differences previously reported by Rowlands and colleagues (33). Encouraging researchers to present the average acceleration values in future studies could allow data captured from the three accelerometer brands to be immediately comparable by applying an affine conversion (34). In the meantime, further work over a 7-day free-living monitoring period is recommended to determine the magnitude of acceleration differences across and between the 3 research-grade accelerometers to establish the conversion factors needed to ensure equivalency across devices.

Various governments and organizations have proposed PA guidelines which encourage increased time spent in MVPA with significant health benefits (38–41). Unfortunately, recommendations of 60 minutes per day for children may be unattainable for many individuals (23,42). Providing meaningful activity recommendations that are easily understood is vital to inform public health initiatives as well as future intervention strategies which can be developed to target a particular health outcome. Presenting individuals with a choice of feasible activities (Figure 1) therefore may be one strategy that could be used to improve activity levels and increase either average acceleration, the IG or both depending upon which is most appropriate for a given health outcome.

There is a wealth of accelerometer thresholds currently available for researchers to use with ActiGraph accelerometers and can be applied to either youth or adult populations wearing hip- or wrist-worn devices (14). Continued technological advancements will see new accelerometer devices become publicly available which will necessitate the need for further laboratory validation studies and the proposal of yet more thresholds to quantify time spent in MVPA as well as other intensity categories. As long as these new devices provide raw acceleration data, researchers are able to translate any new data in to meaningful recommendations and/or compare findings with those previously reported. In doing so, researchers would overcome the current limitations associated with the reliance upon

thresholds derived from laboratory validation studies and proprietary accelerometer software and capitalize on the wealth of wrist-worn accelerometer data currently being collected.

The cross-sectional nature of this study is a limitation as is the recruitment of participants from one location in Scotland which may limit the generalizability of our findings. Furthermore, we only collected data from accelerometers worn on the non-dominant wrist. Whether similar findings are evident when using the dominant wrist is unclear. The use of only one health outcome measure is acknowledged and further work examining the utility of the IG and average acceleration metrics with additional health outcome measures is encouraged. Strengths of this study include the use of a large sample from several schools and the inclusion of correlates known to influence activity levels in our statistical analysis which examined the influence of clustering within the dataset. A particular strength is the examination of the utility of the IG and average acceleration metrics with BMI z-score for the first time using data collected from the ActiGraph accelerometer device in a different population and age group that has previously been studied. In summary, our findings confirm the utility of the IG and average acceleration metrics as meaningful measures of an individual's entire activity profile. Future work examining the independent and additive effects of intensity and volume of activity for a particular health outcome in children and youth should report these activity metrics to facilitate comparisons with previous studies that have used wrist-worn accelerometers.

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Authors' Contributions:

GMcL and SD collected all of the data: DSB performed the statistical analysis and drafted the manuscript; DSB conceived, designed and coordinated the study and wrote the manuscript. RA helped to coordinate the study and reviewed the draft manuscript. All authors have read and approved the final version of the manuscript and agree with the order of authors. None of the authors declare competing financial interests.

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Table 1. Descriptive characteristics of participants

	Total = 246	Boys (N = 108)	Girls (N = 138)
Age (y)	9.6 ± 1.4	9.7 ± 1.3	9.5 ± 1.4
Height (cm)	139.6 ± 10.3	139.6 ± 9.4	139.6 ± 10.9
Mass (Kg)	35.9 ± 9.9	35.7 ± 9.2	36.3 ± 10.5
BMI z-score	0.5 ± 1.3	0.6 ± 1.1	0.4 ± 1.4
Average acceleration (mg)	44.2 ± 13.4	48.2 ± 16.2	41.3 ± 10.1*
MVPA (min)	58.5 ± 25.1	66.6 ± 28.4	52.3 ± 20.1*
Inactive time <50 mg (min)	1196.2 ± 54.8	1197.8 ± 58.6	1195.3 ± 52.3
Intensity gradient	-1.99 ± 0.15	-1.94 ± 0.14	-2.04 ± 0.13*
Constant	12.3 ± 0.7	12.1 ± 0.7	12.5 ± 0.7*
Variance explained (R ² , %)	93.2 ± 1.7	93.1 ± 1.6	93.2 ± 1.9

* p<0.001

Table 2. Associations between two activity metrics with BMI z-score.

	Model 1		Model 2		Model 3		Independent effect
	<u>Coefficient</u>	<u>95% CI</u>	<u>Coefficient</u>	<u>95% CI</u>	<u>Coefficient</u>	<u>95% CI</u>	<u>(Model 3)</u>
BMI z-score							
Average acceleration (mg)	-0.010	-0.20, 0.00	-0.014	-0.03, 0.00	-0.002	-0.02, 0.01	X
Intensity gradient	-1.693	-2.76, -0.63	-2.179	-3.29, -1.06	-2.100	-3.40, -0.80	✓

Significant associations are indicated in bold. Model 1 unadjusted. Model 2 adjusted for potential co-variates. Model 3 adjusted for alternative activity metric. 95% CI = 95% confidence interval. Whether associations between an activity metric were independent of the other metric is noted in the final column.

Figure caption:

Figure 1. Impact of daily activity recommendations upon the IG.

Note: All activity recommendations will also increase the average acceleration by 1 SD for an example participant (average acceleration and IG are both 1 SD below the sample mean).