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Research article

Relationships between accelerometer-assessed physical activity and health in children: impact of the activity-intensity classification method

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Abstract
It is unknown whether relationships detected between physical activity intensity and health differ according to accelerometer thresholds used [sample-specific thresholds (SSTs), published thresholds (PTs) or the individualized activity-related time equivalent (ArteACC)]. SSTs were developed through ActiGraph calibration in 52 boys, aged 8-10 years. The boys subsequently wore an ActiGraph for seven days. SSTs, PTs and ArteACC for moderate (MPA) and vigorous (VPA) activity were applied. Waist circumference (WC), peak oxygen consumption (VO_{2peak}) and blood pressure were assessed. After applying SSTs, 48.9% of boys achieved 60+ minutes of daily MVPA, compared with 8.5% with PTs and 100% with ArteACC. MPA and VPA were correlated with WC and VO_{2peak}, regardless of whether PTs or SSTs were used (WC: MPA $r = -0.37$ to -0.43; VO_{2peak}: $r = 0.34$ to 0.39, $p < 0.05$). With ArteACC, only VPA was correlated with WC ($r = -0.39$, $p < 0.01$) and VO_{2peak} ($r = 0.35$, $p < 0.05$). Relationships with blood pressure were statistically non-significant. Although estimates of the quantity of activity differed according to thresholds used, relationships detected with health were consistent regardless of whether SSTs or PTs were employed. There was no advantage of using SSTs or individualized thresholds. Researchers are encouraged to use PTs to ensure greater comparability between studies.

Key words: ActiGraph, activity guidelines, MVPA, thresholds.

Introduction

The ability to generate accurate and detailed physical activity data is essential to explore the relationship between physical activity, health, growth and development in children. Accelerometers are recognized as one of the most effective ways to produce objective information (frequency, duration, intensity) on children's habitual physical activity (Rowlands, 2007), which is typically sporadic in nature (Bailey et al., 1995; Baquet et al., 2007). This data can be used to investigate the relationship between total physical activity or minutes of moderate to vigorous physical activity (MVPA) and health (Dencker and Andersen, 2008) and to assess the percentage of children meeting activity guidelines (Riddoch et al., 2007).

The way in which physical activity data is measured and expressed can affect conclusions that arise from the data (Masse et al., 2005). Accelerometer output is a dimensionless unit commonly referred to as 'counts'. As these counts are arbitrary, researchers have calibrated counts with energy expenditure to give biological meaning to the output (Freedson et al., 2005). This has resulted in the publication of count thresholds allowing researchers to calculate the amount of time spent at differing intensities of activity. However, the array of thresholds available in the literature for use with the ActiGraph accelerometer (Freedson et al., 1997; Mattocks et al., 2007; Puyau et al., 2002; Reilly et al., 2003; Sirard et al., 2005; Treuth et al., 2004) has led to inconsistency in the field, making comparability between studies difficult. It has been recommended that researchers should not add to the confusion by presenting additional thresholds if available published thresholds are appropriate (Welk, 2005).

However, as inter-individual variability in accelerometer counts is high for any given activity (Ekelund et al., 2003) it is possible that sample-specific or individualized thresholds may be more appropriate than generalized thresholds when detecting relationships with health. One approach to determining whether individualized or sample-specific thresholds offer any advantage over published thresholds is to test whether relationships detected between activity intensity and health differ according to the threshold used.

The most appropriate choice of accelerometer epoch for physical activity assessment in children is still unclear. In a review of objective assessment of physical activity in children, Freedson and colleagues (2005) concluded that more research was required to identify a specific epoch length to ensure that children's short bouts of activity are captured. These authors also theorized that, considering children's vigorous bouts of activity are typically short and sporadic in nature (Nilsson et al., 2002), epochs as short as 5 s may be necessary. The use of short epochs for measuring children's activity complements previous observational research (Bailey et al., 1995) which found high intensity activities lasted on average 3 s. Support for shorter epochs is also provided from more recent research, which using accelerometer-assessed habitual physical activity in children (Baquet et al., 2007), demonstrated that sampling intervals of <10 s should be used to capture periods of ≥vigorous intensity activity (which account for a large percentage of children's daily physical activity). In children, physiological responses affecting growth and development may vary according to activity patterns (i.e., growth related hormones may alter their responses in response to the tempo of activity) (Rowland, 1998), therefore use of shorter accelerometer epochs permits exploration of activity pattern-health relationships in children. Therefore, there appears to be a real need to consider the utility of short accelerometer epochs for habitual physical activity assessment in children.

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Until recently, accelerometers were only capable of storing activity data collected using epochs of <60 s for a limited number of days. The ActiGraph GT1M (ActiGraph, LLC, Pensacola, FL), can be programmed to collect high-frequency physical activity (i.e., 1 s, 2 s, 5 s, 10 s epochs). The epoch length does not affect the total volume of activity accumulated per day (total counts, mean counts). However, time spent in higher intensity activities can be underestimated when using longer epochs with children (Nilsson et al., 2002). A 2 s epoch is the shortest epoch that will allow over seven days of activity to be collected, which is the recommended monitoring period for children (Welk, 2005). The use of a 2 s epoch permits very short bursts of activity which are typical of children to be captured. Whether a 2 s epoch is useful for identifying relationships between habitual physical activity and health could help determine an appropriate epoch length for physical activity assessment in children.

For the purpose of this study, sample-specific and individualized thresholds were derived through calibration research with the present sample of boys (see Methods). Individualized thresholds were based on the activity-related time equivalent based on accelerometry (ArteACC) (Ekelund et al., 2003), which uses individual accelerometer counts during reference activities and total counts to determine time spent in activities equivalent to the reference task. This method accounts for individual differences (e.g., stride pattern, efficiency of movement and/or body size) that could influence accelerometer counts and energy costs of movement (Stone et al., 2007). The ArteACC method has been validated in adolescents and was significantly related to activity energy expenditure per kilogram calculated from the doubly-labelled water method (Ekelund et al., 2003). The published thresholds used were from recent ActiGraph calibration research (Mattocks et al., 2007) on a large sample (N=246; 110 boys, aged 12 years) which is part of an ongoing, U.K. based birth cohort (N=5595) (Ness, 2004).

Therefore, the aim of this study was to examine whether relationships between time spent in moderate and vigorous physical activity and various health outcomes (waist circumference, aerobic fitness and blood pressure) in boys differ according to how activity intensity is classified [i.e., using sample-specific thresholds (SSTs), published thresholds (PTs) (Mattocks et al., 2007) and the ArteACC (Ekelund et al., 2003)].

Methods

Participants

Fifty-four boys, 8 to 10 years of age, were recruited from primary schools in Devon. The experimental protocols received Institutional Ethics Committee approval and written parental and child consent was obtained.

Procedure

Laboratory-based ActiGraph calibration was conducted to produce SSTs for sedentary behaviour, moderate, vigorous and hard activity and ArteACC for activities equivalent to walking (>moderate) and equivalent to jogging (>vigorous). Following seven days of habitual physical activity measurement between October 2006 and March 2007, health variables (waist circumference, aerobic fitness and blood pressure) were measured.

Development of SSTs

Children were familiarized with procedures and baseline anthropometric measurements were recorded. Stature and seated stature were measured to the nearest 0.1 cm and body mass to the nearest 0.1 kg. Children wore an ActiGraph on the right hip during all activities. Calibration of all ActiGraphs (n = 32) was within acceptable limits (CV = 3%) (Chen and Bassett, 2005; Welk, 2005).

ActiGraph data (counts·$2s^{-1}$) were recorded during three minutes of slow walking (4 km·hr^{-1}), brisk walking (6 km·hr^{-1}) and running (8 km·hr^{-1}) on a treadmill and during standing still for one-minute (sedentary), playing catch for three-minutes and jumping on the spot for one-minute. These data were used for the development of SSTs for sedentary behaviour, moderate (MPA), vigorous (VPA) and hard intensity physical activity and ArteACC for ≥ MPA and ≥VPA.

Habitual physical activity

Participants wore an ActiGraph accelerometer for seven consecutive days. A 2 s epoch was used to capture the rapid transitions in activity typical of children (Bailey et al., 1995). Each child was asked to wear his ActiGraph at all times and remove the device only for water-based activities. A daily log sheet was provided to record any times the monitor was taken off and the reason for doing so. The raw data were analyzed using customized software (ActiGraph Analysis 1.0, Exeter, U.K.). For inclusion in data analysis, each participant needed a minimum of 10 hours of wearing time for at least three weekdays and one weekend day (Rowlands et al., 2008). Activity data were analyzed from 6:00 AM to 9:00 PM (Rowlands et al., 2008). Physical activity logs were used in combination with visual inspection of data to determine whether there were significant periods of non-wear time (i.e., data missing for a period of ≥1 hr in duration), and if so, this day was eliminated from analyses. Standard exclusion criteria do not exist; definitions of non-wear time range from 10 consecutive minutes of zero counts (Eiberg et al., 2005) to one hundred and eighty minutes of consecutive zeros (Van Coervering et al., 2005).

Classification of activity intensity

Accelerometer data were converted into minutes per day of moderate and vigorous physical activity using the SSTs, PTs and ArteACC. Time spent in sedentary behaviour and in hard physical activity was also calculated from SSTs. Hard physical activity represented very intense activity (i.e., ≥10 METs). Children performed vigorous on-the-spot jumping at a set pace controlled by an independent researcher performing this activity. An accelerometer threshold for hard intensity activity may be appropriate for investigating activity-health relationships since very vigorous activity is associated with lower odds of being overweight in early childhood (Metallinos-Katsaras et al., 2007) and is known to decline from early adolescence to adulthood in males (van Mechelen et al., 2000). The PTs used are from calibration research in a large sample of children from the U.K. (Mattocks et al., 2007).

Table 1. Descriptive characteristics of children [validation group (n = 40) and cross-validation group (n = 12)].

	Validation group (n =40)			Cross-validation group (n = 12)		
VARIABLE	Mean or median	*SD or IQR	Range	Mean or median	*SD or IQR	Range
Age (y)	9.4	.6	8.0-10.3	9.4	.5	8.4-10.1
Height (m)	1.35	.09	1.09-1.55	1.34	.05	1.27-1.42
Weight (kg)	30.0**	27.4, 34.6	17.4-50.7	32.1**	27.0, 34.5	22.3-52.0
Body mass index ($kg·m^{-2}$)	16.9**	15.4, 18.6	13.7-26.3	17.9	3.2	13.7-25.6
Sitting height (cm)	68.5	3.9	60.0-80.0	68.9	3.4	65.0-74.0
Waist circumference (cm)	57.4**	49.3, 65.5	45.8-76.1	59.5	7.7	49.2-78.8

***SD = standard deviation, IQR = inter-quartile range, **Median and IQR presented**

Moderate physical activity (MPA^{PT}) was classified as 3581-6130 $counts·min^{-1}$ and vigorous physical activity ($\geq VPA^{PT}$) as >6130 $counts·min^{-1}$.The ArteACC is determined from the total daily activity counts ($counts·day^{-1}$) divided by reference activity counts ($counts·min^{-1}$) (Ekelund et al., 2003). An average of mean counts obtained during slow walking and brisk walking (4 $km·hr^{-1}$ and 6 $km·hr^{-1}$) and mean counts during jogging (8 $km·hr^{-1}$) for each individual were used to calculate the activity-related time equivalent for walking ($MVPA^{ArteACC}$) and jogging ($\geq VPA^{ArteACC}$) respectively.

Measurement of health variables

Waist circumference (WC) was measured, as an indicator of abdominal fatness, 4 cm above the umbilicus (Rudolf et al., 2004) and recorded to the nearest 0.1 cm. Systolic and diastolic blood pressure (SBP and DBP, mm Hg) were measured using a semi-automatic blood pressure recorder (Critikon Dinamap™, GE Medical Systems, WI, USA) in the supine position.

Aerobic fitness was assessed through respiratory gas analysis during a multi-stage treadmill test to exhaustion. An online breath-by-breath analyzer (Cortex Metalyzer® 3B; Leipzig, Germany) measured expired air on a continuous basis. The treadmill test consisted of three-minute stages, beginning with a slow walk at 4 $km·hr^{-1}$ at a 0% gradient. For the next two stages, the gradient was kept constant at 0%, however speed was increased to 6 $km·hr^{-1}$ and then 8 $km·hr^{-1}$. Speed then remained constant throughout the test, with the inclination increasing by 1% every 1-min until voluntary exhaustion. A maximal effort was defined by one or more of the following: facial flushing, sweating, hyperpnoea and/or unsteady gait; HR levelling off at >195 bpm; $R \geq 1.00$; subjective decision by the observer that the participant could not continue (Armstrong and Fawkner, 2007). Aerobic fitness was presented relative to body mass [VO_{2peak} ($ml·kg^{-1}·min^{-1}$)].

Statistical analyses

Descriptive statistics were calculated for all variables (mean, standard deviation (SD), range). Variables that were not normally distributed were log-transformed and median and inter-quartile range (IQR) values displayed.

Receiver operator characteristic analysis was utilized to establish accelerometer thresholds to discriminate between activity intensities on part of the sample (n = 40) and these thresholds were cross-validated on remaining participants (n = 12). A sedentary threshold was determined from accelerometer counts measured during standing compared to ball toss; a moderate threshold from slow compared to brisk walking; a vigorous threshold from brisk walking compared to running; a hard threshold from running compared to jumping. Data from two children were incomplete and were eliminated from analyses. Threshold values were evaluated from sensitivity, specificity, and area under the receiver operator characteristic curve (AUC). Sensitivity and specificity of the thresholds were assessed in the cross-validation sample and Cohen's Kappa (Cohen, 1960) used to evaluate the percent agreement.

Summary activity data were calculated using sample-specific thresholds (MPA^{SST}, VPA^{SST}) and compared to data obtained using published thresholds (MPA^{PT}, $\geq VPA^{PT}$). Differences between MPA^{SST} and MPA^{PT}, and VPA^{SST} and $\geq VPA^{PT}$, respectively, were examined using paired t-tests.

Relationships between physical activity (total physical activity (TPA), MPA, VPA) and health measures [WC, VO_{2peak}, resting SBP and DBP] were examined using Pearson product moment correlations. Correlations of health measures with sedentary time and hard physical activity were carried out to investigate relationships at the extremes of the intensity spectrum. As few thresholds are available for sedentary and hard activity, only SSTs were used for this analysis. Where data were not normally distributed, variables were log transformed prior to analysis. All analyses were performed using SPSS version 11 and Graph Pad Prism version 6.

Results

Participant characteristics

Accelerometer data for all calibration reference activities were collected for 52 participants (mean age, 9.4 ± 0.6 y). Descriptive data for the developmental group and the cross-validation group are presented in Table 1. There were no differences between groups for all descriptive variables ($p < 0.05$). Descriptive data for ActiGraph output and predicted METs for each reference activity are presented in Table 2. Descriptive data for participants with valid habitual physical activity data (n = 47) are presented in Table 3.

Calibration

The validation study demonstrated optimal sensitivity and specificity at cut-offs of 10, 97, 167, and 321 $counts·2s^{-1}$ for sedentary, moderate, vigorous and hard physical activity. Reported sensitivity, specificity and AUC were high (sensitivity > 70%, specificity > 80%, AUC > 0.865, $p < 0.001$). Threshold values, when applied to the cross-validation group, yielded excellent sensitivity, specificity, and percent agreement for distinguishing between sedentary and very light, light and moderate, and vigorous and

Table 2. ActiGraph output and METs [mean (SD)] for each activity.

Intensity	Predicted METs*	ActiGraph (counts·min^{-1})	ActiGraph (counts·2s^{-1})
Sedentary (standing quietly)	1.2	24 (54)	0.8 (1.8)
Very light (catching ball)	2.5	1563 (879)	52.1(29.3)
Light (walking, 4 km·hr^{-1})	3.2	2163 (783)	72.1 (26.1)
Moderate (walking, 6 km·hr^{-1})	4.3	4242 (1092)	141.4 (36.4)
Vigorous (running, 8 km·hr^{-1})	6.7	5661 (1155)	188.7 (38.5)
Hard (jumping on the spot)	10	12402 (2970)	413.4 (99.0)

* METs estimated from previously published work. METs for standing and catching: (Ridley and Olds, 2008): mean adult METs; METs for walking, 4 km·hr^{-1}, walking, 6 km·hr^{-1}, running, 8 km.hr^{-1}: (Harrell et al., 2005); METs for jumping: (Ainsworth et al., 2000): moderate jumping, code=#15552.

hard activities (sensitivity > 91%, specificity > 83%, *kappa* > 0.75), but were less successful at distinguishing moderate from vigorous activity (58.3%, 66.7%, *kappa* = 0.25).

Comparison of thresholds

The SSTs were converted into counts·min^{-1} for MPA (2910-5010 counts·min^{-1}) and VPA (5010-9630 counts·min^{-1}) to allow comparisons with published thresholds (MPA = 3581-6130 counts·min^{-1}; ≥VPA = > 6130 counts·min^{-1}). There were significant differences between thresholds with mean time in MPA and VPA being greater when analyzed using SSTs than when using PTs ($p < 0.01$) (Table 4).

Time accumulated in moderate and vigorous physical activity was combined to determine the proportion of children meeting current UK physical activity guidelines of at least 60 minutes of MVPA per day. Using sample-specific thresholds, 48.9% of children achieved 60+ minutes of daily MVPA. Using published thresholds, only 8.5% of children met these guidelines and when using the ArteACC, all children met the guidelines.

Activity and health relationships

Total physical activity was negatively associated with waist circumference ($r = -0.36$, $p < 0.05$) and positively related to VO_{2peak} ($r = 0.35$, $p < 0.05$). No relationships with blood pressure were evident.

Both MPA and VPA were negatively correlated with waist circumference regardless of whether published thresholds or sample-specific thresholds were used to classify activity intensity ($r = -0.37$ to -0.43, $p < 0.05$) (Table 5). When ArteACC was used to classify intensity, only VPA was negatively correlated with waist circumference ($r = -0.39$, $p < 0.01$).

Peak VO_2 was positively correlated with MPA and VPA ($r = 0.34$ to 0.39, $p < 0.05$). The magnitude of the correlations was similar irrespective of whether activity intensity was classified using PTs, SSTs or ArteACC, with the exception of MVPA (ArteACC), where no significant relationship was detected ($r = 0.25$, $p > 0.05$).

Relationships between blood pressure and activity were largely non-significant, but of a similar magnitude for MPA and VPA assessed from PTs and SSTs. For diastolic, but not systolic, blood pressure the relationships determined from VPA classified using the ArteACC were also of similar magnitude.

Only SSTs were available for sedentary and hard activity (Table 6). Time spent sedentary was not related to any health measures. Time in hard physical activity was negatively associated with WC ($r = -0.34$ $p < 0.05$) and positively associated with VO_{2peak} ($r = 0.34$, $p < 0.05$). As with MPA and VPA, no relationships with blood pressure were evident.

Discussion

This study aimed to determine whether the method of classification of moderate and vigorous physical activity from accelerometer data affects relationships detected with known risk factors for obesity and metabolic disorders in boys (Andersen et al., 2008). This is important as there are a wide variety of published thresholds available and it is unclear whether there are advantages to creating sample-specific or individualized thresholds.

Relationships detected with waist circumference, fitness and blood pressure were consistent regardless of whether sample-specific or published thresholds were employed. The use of the individualized ArteACC did not offer any benefit over sample-specific and published thresholds when detecting relationships between activities equivalent to jogging and the health outcomes and was unable to detect relationships between activities equivalent to walking and health outcomes. The present study highlights the novel idea that although inter-

Table 3. Descriptive characteristics of children with valid habitual physical activity data.

VARIABLE	Mean or median	*SD or IQR	Range
Sample size	47		
Age (y)	9.2**	9.0, 9.9	8.3-10.1
Height (m)	1.34 **	1.30, 1.40	1.09-1.55
Weight (kg)	31.3**	27.3, 34.9	17.4-52.0
Body mass index (kg·m^{-2})	16.9**	15.4, 18.8	13.7-26.3
Sitting height (cm)	68.7	3.8	60.0-80.0
Waist circumference (cm)	58.1**	54.5, 62.4	45.8-78.8
VO_{2peak} (ml·kg^{-1}·min^{-1})	46.2	6.7	35.0-60.0
Systolic blood pressure (mmHg)	104.0**	97.0, 110.3	87.3-133.7
Diastolic blood pressure (mmHg)	62.3**	60.0, 65.7	48.0-78.7

*SD = standard deviation, IQR = inter-quartile range. **Median and IQR presented

Table 4. Total physical activity (TPA; counts·day^{-1}) and minutes per day of moderate (MPA) and vigorous physical activity (VPA) derived from sample-specific thresholds (SSTs), published thresholds (PTs) and the activity-related time equivalent (ArteACC).

VARIABLE	Mean or median	*SD or IQR	Range
TPA (counts·day^{-1})	498864	108355	248867-754736
MPA^{SST} (min·day^{-1})	38.1[a]	9.5	13.8-62.0
MPA^{PT}(min·day^{-1})	31.2	8.6	11.4-52.9
MVPA^{ARTEACC} (min·day^{-1})	149.5 **	131.5, 193.0	107.8-246.3
VPA^{SST} (min·day^{-1})	16.1 [a,]**	14.8, 23.9	7.8-34.4
≥VPA^{PT} (min·day^{-1})	8.6 **	7.6, 13.4	4.1-22.3
≥VPA^{ARTEACC} (min·day^{-1})	86.6 **	75.1, 103.7	45.1-190.0

[a]Significantly higher than PT threshold (p<0.01), *SD = standard deviation, IQR = inter-quartile range, **Median and IQR presented

individual differences in biomechanical efficiency of movement for a given activity may occur between children, controlling for these with individualized accelerometer-intensity thresholds does not appear to improve activity-health relationships. These findings are especially relevant for large, population-scale physical activity measurement surveys in children for which the ArteACC method is not feasible. It is of interest to note that relationships determined between higher intensity activity and health variables did not differ from those with MPA and VPA and that no relationships were evident between health variables and sedentary behaviour. In the present study, ≥moderate intensity activity was deemed equivalent to ≥4.3 METs. This would have included activities equal to, or greater than, a brisk walk. In studies where health outcomes were more strongly related to activities of ≥vigorous intensity, moderate intensity activity was typically defined as ≥3 METs (Dencker and Andersen, 2008). Similar relationships between higher intensity activity, MPA, VPA and health variables in children have been reported (Dencker and Andersen, 2008). Recently, Tolfrey and colleagues (2008) showed that 60 minutes of moderate and vigorous intensity intermittent exercise resulted in similar improvements in postprandial lipaemia in boys. It may be that as long as the activity is sufficiently moderate (i.e., equivalent to a brisk walk/≥4 METs), health benefits in childhood are possible.

This study is limited by a small sample size (n = 47) and homogeneity of participants included (i.e., boys only tested, narrow age range (age 8-10 years)). This may have influenced reported SST's, which had low sensitivity and specificity with regards to differentiating moderate from vigorous intensity physical activity. However, although the sample-specific thresholds were developed on a small sample, the activity-health relationships detected were similar to those detected by the thresholds determined through calibration research on a large population of UK children (Mattocks et al., 2007), despite a difference of 671 counts·min^{-1} for the MPA threshold and of 1120 counts·min^{-1} for the VPA threshold. Differences in the study sample and calibration design may explain these discrepancies. For example, in the study by Mattocks et al., boys (who were slightly older than those in the present study) performed walking and jogging activities (self-paced) around an indoor jogging track to better simulate free-living conditions. In contrast, the present study asked boys to walk and jog at prescribed speeds on a treadmill. Although the current study did not test a variety of published thresholds, thresholds between 2910 (moderate physical activity) and 9630 (hard physical activity) counts·min^{-1} detected similar relationships with health variables. This indicates that the choice of moderate or vigorous threshold used to classify activity intensity appears to be relatively unimportant for determining relationships with waist circumference, fitness and blood pressure in boys, provided the thresholds relate to activities of at least 4 METs or brisk walking. The lower end of this range is in accordance with a recent review (Reilly et al., 2008), which suggested that thresholds greater than 3000 to 3600 ActiGraph counts·min^{-1} were appropriate to classify MVPA in children. Accelerometer thresholds based on ≥4 METs have been used for describing ≥moderate intensity activity in a number of studies with children (Harrell et al., 2005; Mattocks et al., 2007; Reilly et al., 2008; Treuth et al., 2004) based on the argument that 3 METs may not truly reflect moderate intensity activity in children. It is however important to note that it is not just a case of which accelerometer thresholds correspond to certain METs; it is also a matter of how to define certain intensity in terms of number of METs. This last point is important since body mass specific values for 1 MET change considerably from age1 year to age 18 years

Table 5. Pearson's correlation coefficients for total physical activity (TPA) and time in moderate (MPA) and vigorous physical activity (VPA) (characterized using sample-specific thresholds (SSTs), published thresholds (PTs) and the activity-related time equivalent (ArteACC)) vs. fitness (VO_{2peak}), fatness (WC) and blood pressure (SBP, DBP) measurements in all children with valid measurements (n = 47).

VARIABLE	WC (cm)	VO_{2peak} (ml·kg^{-1}·min^{-1})	SBP (mm Hg)	DBP (mm Hg)
TPA (counts·day^{-1})	-.36 *	.35 *	-.09	-.10
MPA^{SST} (min·day^{-1})	-.37 *	.34 *	-.22	-.20
MPA^{PT}(min·day^{-1})	-.43 **	.38 *	-.29	-.25
MVPA^{ARTEACC} (min·day^{-1})	-.21	.25	.13	.05
VPA^{SST} (min·day^{-1})	-.42 **	.39 *	-.21	-.17
≥VPA^{PT} (min·day^{-1})	-.38 **	.36 *	-.16	-.11
≥VPA^{ARTEACC} (min·day^{-1})	-.39 **	.35 *	.00	-.10

* p < 0.05, **p < 0.01.

Table 6. Pearson's correlation coefficients for time spent sedentary and in hard physical activity (characterized using sample-specific thresholds), vs. fitness (VO_{2peak}), waist circumference (WC) and blood pressure (SBP, DBP) measurements in all children with valid measurements (n = 47).

VARIABLE	WC (cm)	VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	SBP (mm Hg)	DBP (mm Hg)
Sedentary ($min \cdot day^{-1}$)	.19	-.20	-.01	.06
Hard physical activity ($min \cdot day^{-1}$)	-.34 *	.34 *	.08	.07

* $p < 0.05$.

and there is considerable inter-individual variation in motor patterns and breathing rates when performing a given activity. Predicted energy costs for children and youth can be problematic. A compendium of energy costs for fifty-one activities for use with children with energy costs expressed as METs was recently provided (Ridley and Olds, 2008) and may be of some assistance.

Total activity was significantly related to both waist circumference (r = -0.36, $p < 0.05$) and aerobic fitness (r = 0.35, $p < 0.05$). These correlations were of a similar magnitude to those for MPA, VPA and hard physical activity. The literature is divided over whether total activity or activity intensity is more strongly related to health outcomes in children (Dencker and Andersen, 2008). Our findings are encouraging as total activity is a simple measure to report and is unaffected by intensity thresholds, allowing direct comparability between studies.

Other than determining relationships between different intensities of activity and health, one of the key uses of accelerometer thresholds is to determine the amount of time spent in MVPA. Key public health goals are to determine the percentage of children meeting physical activity guidelines, to establish compliance and monitor secular trends in physical activity. It is clear that intensity thresholds do matter for estimation of prevalence. This has been highlighted in recent work (Cliff and Okely, 2007; Guinhouya et al., 2006) which assessed discrepancies in time spent in MVPA when using thresholds reported by Sirard et al. (Sirard et al., 2005), Puyau et al. (2002) and Trost et al. (2002). In the current study the proportion of children meeting public health guidelines (Strong et al., 2005) varied from 8.5% (published thresholds) through 48.9% (sample-specific thresholds) to 100% (individualized thresholds). These discrepancies can be attributed to the use of lower accelerometer thresholds to classify ≥moderate intensity activity (i.e., individualized thresholds < SSTs (2910 $counts \cdot min^{-1}$) < PTs (3581 $counts \cdot min^{-1}$)) rather than differences in the children's activity levels (Rowlands et al., 2007). The idea that changes in adherence to physical activity guidelines will occur to a greater extent when using very low thresholds was presented by Troiano and colleagues (2008), who found that adherence varied very little with thresholds >1200 $counts \cdot min^{-1}$, however small changes in threshold values of <1000 $counts \cdot min^{-1}$ were associated with large changes in the prevalence of adherence. Since the classification of ≥moderate physical activity varies from study to study, any differences in adherence likely reflect the use of different accelerometer thresholds to classify the lower end of moderate intensity (Dencker and Andersen, 2008; Reilly et al., 2008). This inconsistency in threshold choice and use slows progress on activity-prevalence research in children and national policy making. It is important to reach consensus on appropriate accelerometer thresholds for quantifying children's MVPA to simplify comparison of physical activity levels across populations and subpopulations and progress the field.

Conclusion

In conclusion, choice of threshold did not impact on relationships detected between activity and various health outcomes (waist circumference, aerobic fitness and blood pressure) in boys, providing the moderate threshold was at least equivalent to an average brisk walk (i.e., ≥4 METs). This indicates that studies investigating relationships between activity and these health outcomes may be comparable, even where different thresholds have been employed. However, as in previous research (Cliff and Okely, 2007; Guinhouya et al., 2006), this study has demonstrated that intensity thresholds clearly matter when reporting the percentage of children meeting MVPA guidelines. Therefore, despite the lack of impact of threshold on relationships between these health outcomes and activity, to enable comparability between activity prevalence studies a consensus on the thresholds to be used is needed. Although the published thresholds used in this study (Mattocks et al., 2007) were developed on a large sample of children following the recommendations for calibration research (Welk, 2005), it was restricted to children aged 12 years. It was recently indicated (Reilly et al., 2008) that thresholds may not need to be age-specific as average counts during sedentary, moderate and vigorous activity were similar for groups of children aged 3 to 10 years. Therefore, it would be useful to evaluate the appropriateness of the published thresholds (Mattocks et al., 2007) for other age groups.

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Key points

- Standardized accelerometer intensity thresholds for evaluating children's physical activity do not exist, therefore determining whether relationships between activity and health differ when using different thresholds is of interest.
- Although prevalence estimates differ according to the choice of accelerometer intensity threshold, relationships detected between activity and various health outcomes in boys are similar, providing the moderate threshold is at least equivalent to an average brisk walk (i.e., ≥4 METs).
- Standardization of thresholds between samples should not impact on relationships determined with health and would allow comparability of prevalence estimates.

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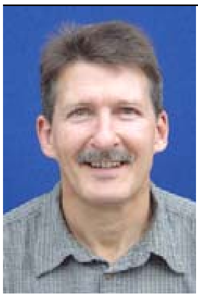

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