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Individual calibration of accelerometers in children and their health-related implications

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Article

Title Page

Title: Individual calibration of accelerometers in children and their health-related implications

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Abstract

This study compared children's physical activity (PA) levels, the prevalence of children meeting current guidelines of ≥60 minutes of daily moderate to vigorous PA (MVPA), and PA-health associations using individually calibrated (IC) and empirical accelerometer cutpoints. Data from 75 (n = 32 boys) 10-12 year old children were included in this study. Clustered cardiometabolic (CM) risk, directly measured cardiorespiratory fitness (CRF), anthropometric and 7 day accelerometer data were included within analysis. PA data were classified using Froude anchored IC, Evenson et al., 2008 (Ev) and Mackintosh et al., 2012 (Mack) cutpoints. The proportion of the cohort meeting ≥60mins MVPA/day ranged from 37%-56% depending on the cutpoints used. Reported PA differed significantly across the cutpoint sets. IC LPA and MPA were predictors of CRF (LPA: standardised $\beta = 0.32$, $p = 0.002$, MPA: standardised $\beta = 0.27$ $p = 0.013$). IC MPA also predicted BMI Z-score (standardised $\beta = -0.35$, $p = 0.004$). Ev VPA was a predictor of BMI Z-score (standardised $\beta = -0.33$, $p = 0.012$). Cutpoint choice has a substantial impact on reported PA levels though no significant associations with CM risk were observed. Froude IC cut points represent a promising approach towards classifying children's PA data.

Introduction

Regular participation in physical activity (PA) in childhood is associated with reduced cardiometabolic risk (Andersen, Riddoch, Kriemler, & Hills, 2011), improved bone health (Boreham & McKay, 2011), reduced adiposity (McMurray & Ondrak, 2013), and improved psychological well-being (Biddle & Asare, 2011). PA guidelines state that children should accrue at least 60 minutes of daily moderate to vigorous PA (MVPA) to receive health benefits (WHO, 2010). The accurate measurement of PA is essential to investigate the associations between PA and health, estimate the prevalence of inactivity, and identify children in need of intervention. Accelerometry is the most commonly used objective method for assessing free-living PA in children, and has acceptable validity and reliability (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013). Despite this, no consensus exists with regards to the treatment of accelerometer data and inconsistent use of cutpoints presents challenges when quantifying the prevalence of inactivity (Ekelund, Tomkinson, & Armstrong, 2011), making comparisons between studies (Hislop, Bulley, Mercer, & Reilly, 2012) and establishing the relationship between PA and health outcomes (Bailey, Boddy, Savory, Denton, & Kerr, 2013).

Previous research has compared the classification accuracy of published thresholds (PTs) in youth using calibration studies, and recommended that researchers use Evenson's (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008) cutpoints to classify children's PA (Trost, Loprinzi, Moore, & Pfeiffer, 2011). However, the empirical cutpoints examined by Trost et al. (2011) applied universal cutpoints to all children, with only one age-specific cutpoint included in the analysis (Freedson, Pober, & Janz, 2005). Such cutpoints fail to account for wide variations in accelerometer counts observed between children when engaging in PA at equivalent intensities (Rowlands, 2007). Subsequently researchers have proposed the use of individually calibrated (IC) approaches to improve the classification of children's PA (Mackintosh, Fairclough, Stratton, & Ridgers, 2012).

One method of deriving individual cutpoints, particularly when using hip-mounted accelerometers, is to adjust cutpoints to account for limb length using relevant biomechanical theory. The Froude (Fr) number (Minetti, 2001) offers one solution to the standardisation of cutpoints for individuals, by taking the length of a given characteristic, in this case leg length, into account. Froude numbers are calculated using the equation: Fr = $v^2/g*l$ where ‘v’ is the speed, ‘g’ represents gravitational acceleration and ‘l’ is the length of the characteristic. The theory of dynamic similarity suggests that geometrical bodies have similar gait dynamics if the Fr number is kept constant (Alexander, 1989). For example, the Fr number of 0.25 represents optimum walking speed and Fr 0.5 is the point at which running occurs in most bipedal bodies, including humans (Kram, Domingo, & Ferris, 1997). Therefore for a given Fr number and related walking speed gait dynamics should be relatively consistent between participants, which in turn allows for a simple method of creating individualised and comparable thresholds. Despite its potential utility, few studies have utilised the Froude approach to individually calibrate accelerometer cutpoints (Boddy et al., 2014). As PA is positively associated with health, the potential to better examine these relationships with more precise estimates of PA is important, especially as relationships between PA and variables such as CRF and adiposity are often weaker than may be expected. To date no have examined differences in reported PA or PA-health associations between IC and empirically derived group level cutpoints. Therefore, the aims of this study were to compare children’s physical activity (PA) levels, the prevalence of children meeting current guidelines of 60 minutes of daily moderate to vigorous PA (MVPA), and PA-health associations using individually calibrated Fr (IC) and empirical accelerometer cutpoints.

Methods

Participants and Settings

The data for this analysis were taken from the REACH Year 6 study (Boddy et al., 2014). Seventy-five children (n = 32 boys) 10-12 years of age agreed to take part in the study which had ethical clearance from the respective institutional ethics committees. The study was conducted in Liverpool, England (2010, n = 39) and Belfast, Northern Ireland (2011, n = 35). Each participant attended one school-based blood sampling session and one laboratory testing session. Participants also wore an accelerometer to quantify PA over seven days.

Procedure and Measurements

Anthropometrics: Stature, sitting stature to the nearest 0.1cm (Seca Ltd. Birmingham, UK) and body mass to the nearest 0.1kg (Seca Ltd. Birmingham, UK) were assessed using standard techniques (Lohman, Roche, & Martorell, 1988). Waist circumference was measured to the nearest 0.1cm. Body mass index (BMI), BMI Z-scores (Cole, Freeman, & Preece, 1995) and somatic maturation (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002) were calculated. High-resolution ultrasound (Terason, t3000; Aloka, London, UK) was used to assess flow mediated dilation (FMD) and % FMD calculated using the equation: ((Peak artery diameter - Baseline artery diameter)/ Baseline artery diameter)*100) was calculated. Blood pressure (BP) was measured on the left arm after 15mins rest in a supine position using an automated BP monitor (Omron Healthcare UK Limited, Miton Keynes, UK).

Cardiorespiratory fitness assessment: After treadmill familiarisation, participants completed an individually calibrated continuous, incremental (2mins stages) treadmill (both sites: HP Cosmos, Traunstein, Germany) protocol to volitional exhaustion using online gas analysis (Liverpool: Jaeger Oxycon Pro, Viasys Health Care, UK, Ulster: COSMED, Quark, Italy) to measure peak oxygen uptake (VO_2peak). Treadmill speeds for the first two stages of the test were anchored to Froude numbers 0.25 (MPA) and 0.5 (VPA) for each participant. For this study leg length was used as the characteristic. An example equation to calculate treadmill speed for an individual with a leg length of 0.67m for a Fr number of 0.25 would be: treadmill speed (m/s) = $\sqrt{(0.25*(9.81* 0.67))}$, which would result in a speed of 1.28 m/s or 4.61 km/h. Participants wore an ActiGraph accelerometer (ActiGraph GT1M, MTI Health Services, Pensacola, FL) at the right hip and heart rate monitor (Polar Electro Oy, Kempele, Finland) set to record using 5 second epochs throughout the treadmill protocol. The highest 15-second average oxygen uptake was used to represent VO_2peak (ml/kg/min) for each participant.

Blood sampling: On a different day to the laboratory visits, children attended their school sites to provide a fasting venous blood sample. Experienced phlebotomists obtained ~ 10ml of venous blood following an overnight fast. Samples were taken between 8.30 and 10.30am. After providing a sample children were given breakfast. Blood samples were transported to the pathology laboratories at Alder Hey Children's Foundation NHS Trust or the Ulster Hospital for analysis. Blood was analysed for triglycerides, cholesterol, high density lipoprotein cholesterol (HDL-c), glucose, adiponectin, and high sensitivity C-reactive protein (CRP) using assay methods that were standardised between sites. Blood markers were used in combination with FMD%, blood pressure and waist circumference to calculate a clustered cardiometabolic risk score by standardising individual risk components and summing them to create a continuous clustered risk variable. This approach has been used in several similar studies (Andersen, Hasselstrom, Gronfeldt, Hansen, & Karsten, 2004; Anderssen et al., 2007; Boddy et al., 2014; Buchan, Young, Boddy, & Baker, 2014).

Physical activity assessment: Children wore an ActiGraph (ActiGraph GT1M) uniaxial accelerometer on their right hip during waking hours for seven consecutive days. The monitors recorded activity using 5 second epochs to account for the sporadic nature of children's physical activity (Baquet, Stratton, Van Praagh, & Berthoin, 2007). Periods of 20 minutes of consecutive zero counts (1 minute spike tolerance) were used to define a non-wear period and these periods were subtracted from daily wear time (Catellier et al., 2005). Children were included within analysis if they wore the monitor for a minimum of 9 hrs on any three days (Mattocks et al., 2008).

PA data were classified into light (LPA), moderate (MPA), vigorous (VPA) and moderate to vigorous PA (MVPA) intensities using three sets of intensity cutpoints: two sets of empirical cutpoints: Evenson et al., 2008 (Ev) and Mackintosh et al., 2012 (Mack). The Mack thresholds were generated from data derived from a field-based observational protocol with children of the same age and from a similar geographical location as those included within this study and were included to provide an additional comparison. PA was also classified using individually calibrated (IC) cut points. Sedentary time was defined as ≤100 counts per minute for all cut point sets (Fischer, Yildirim, Salmon, & Chinapaw, 2012). Individually calibrated cut points were generated using the data from the VO_2peak treadmill protocol. Froude 0.25 and 0.50 represent the thresholds for optimum walking speed and the transition between walking and running. The average counts for the middle 90 seconds (18 epochs) of the two Fr stages (Fr 0.25 and Fr 0.50) were used to represent MPA and VPA thresholds for each individual. The middle 90 seconds were selected to avoid the transitional periods between the Fr.25 (walking) and Fr.5 (running). To examine the energy cost associated with each Fr threshold metabolic equivalents were calculated for Fr.25 and Fr.5 stages using the gas analysis data (1 MET = 4.59 VO_2 ml/kg/min; (Ridley & Olds, 2008) and compared to the energy costs outlined by Harrell et al. (2005). This gas analysis data was simply used to assess the MET values associated with the Fr stages for each individual.

Data analysis

Differences in anthropometrics, clustered risk, VO_2peak, sedentary time and PA components (MPA, VPA, MVPA) were examined by sex using MANCOVA, controlling for accelerometer wear time. The prevalence of those reaching ≥60mins MVPA per day was calculated for each cutpoint set. Differences in PA intensities were examined using repeated measures ANOVAs by cutpoint. To investigate the association between PA components and health markers (VO_2peak, BMI Z-score, waist circumference, clustered cardiometabolic risk) multiple regression was employed controlling for sex, maturation, BMI and wear time. For each dependent variable three multiple regression models, one for each cutpoint, were created. Where BMI was used as a dependent variable it was excluded as a covariate. All analyses were completed using SPSS V21.0 (SPSS Inc, IBM). Alpha was set at $P \leq 0.05$.

Results

Unadjusted mean participant characteristics and adjusted mean anthropometric, VO_2peak, sedentary time and PA values for boys and girls are illustrated in tables 1 and 2 respectively. Boys were significantly less mature, had higher VO_2peak and accrued more LPA and MPA than girls.

TABLE 1 ABOUT HERE

TABLE 2 ABOUT HERE

The IC cut points ranged from 1234-4476 counts per minute for MPA and 3192-9357 counts per minute for VPA The mean oxygen consumption (VO_2 $ml \cdot kg^{-1} \cdot min^{-1}$) and MET values (1 MET = 4.59 VO_2 $ml \cdot kg^{-1} \cdot min^{-1}$) achieved during the treadmill stages Fr0.25 and Fr.5 were 20.1$ml \cdot kg^{-1} \cdot min^{-1}$ (SD = 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$), 4.4 METs and 31.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (SD = 7.4 $ml \cdot kg^{-1} \cdot min^{-1}$) 6.8 METs respectively. These values are proximal to those commonly used to represent MPA (≥4 METS+) and VPA (≥6 METS) in the PA literature. Data from Harrell et al (2005) calculated for children aged 8-12 years confirm that participants were working at an intensity approximately equivalent to moderate intensity during Fr 0.25 (Harrell et al. (2005) values: VO_2 = 18.3 $ml \cdot kg^{-1} \cdot min^{-1}$) and approaching high intensity activity during Fr 0.50 (Harrell et al. (2005) values: VO_2 = 38.5 $ml \cdot kg^{-1} \cdot min^{-1}$).

The proportion of children meeting ≥60mins/day MVPA varied depending on the cutpoints used. According to the Mack cutpoints 56% met ≥60mins/day MVPA, whereas 49% and 37% achieved 60mins according to Ev and IC cutpoints respectively.

The results of the repeated measures ANOVAs between cutpoint sets can be viewed in Table 3. Significantly higher MPA was reported using the Mack (MPA = 51.6 mins/day) cutpoints in comparison to the Ev (MPA = 38.4 mins/day) and IC cutpoints (MPA = 44.3 mins/day). Ev cutpoints (VPA = 25.9 mins/day) recorded higher VPA than Mack (17.8 mins/day) and IC

(13.0 mins/day). Significantly less LPA was observed using the Mack (195 mins/day) cutpoints in comparison to IC (209 mins/day) and Ev (200.3 mins/day), the difference between IC and Ev LPA was also statistically significant.

TABLE 3 ABOUT HERE

Results of multiple regression found that IC LPA and MPA were significant predictors of VO_2peak (R^2 for the model = 0.55, LPA: standardised beta = 0.32, t= 3.24, p = 0.002, MPA: standardized beta = 0.27, t = 2.57, p = 0.013) IC MPA was also a significant predictor for BMI Z-score (R^2 for the model = 0.31, standardised beta =- 0.35, t = -2.96, p = 0.004). Ev VPA was a significant predictor for BMI Z-score (R^2 for the model = 0.32, standardized beta = -0.33, t = -2.59, p = 0.012), Mack data were not significant predictors for any health variables, however Mack VPA approached statistical significance as a predictor for BMI Z-score (R^2 for the model = 0.29, VPA standardized beta = -0.23, t = -1.98, p = 0.052). No significant PA-clustered risk score associations were observed irrespective of cut point set used.

Discussion

The aims of this study were to compare children's physical activity (PA) levels, the prevalence of children meeting current guidelines of 60 minutes of daily moderate to vigorous PA (MVPA), and PA-health associations using individually calibrated Fr (IC) and empirical accelerometer cutpoints. In this study the proportion of the cohort meeting current guidelines for daily MVPA ranged from 37% - 56% depending upon the cut point used. A number of studies have shown differences in PA prevalence depending on the choice of cut points used to analyse data (Hislop et al., 2012; Reilly et al., 2008). For example, a review by Ekelund et al. (2011) highlighted that the reported prevalence of children and young people meeting current PA guidelines ranged across six studies from 1% and 100%, with authors suggesting that the variability could be largely attributed to the different intensity cutpoints used between studies. At a 4 MET intensity (approximate to MPA) recommended counts per minute have ranged widely from 1400 to 3600 (Cain et al., 2013). In this study, IC cut points derived from the treadmill-based protocol ranged from 1234-4476 for MPA, with a mean MET value of 4.4 (range 2.49-7.04 METs) and 3192-9357 for VPA (mean MET value of 6.8, range 3.83-12.33 METs). This demonstrates the substantial variation that exists in the biomechanical efficiency of movement (e.g. stride length, stride pattern) between children of a similar age completing the same activity, and provides support for the use of IC cut points that take account of individual differences.

This study also revealed significant differences in the classification of LPA, MPA and VPA depending upon the cutpoint used. The discrepancies in the classification of PA intensities observed may be in part due to the differing methods used to define each of the cutpoint thresholds. For example, the IC cut points used in this study were derived from the application of biomechanical theory, which is in contrast to the empirical cut points derived from laboratory based (Ev) or field-based (Mack) energy expenditure. Although it is well documented that the application of different cut points results in differences in estimates of activity intensity (Trost et al., 2011), to date, none of the published papers have compared the classification of activity intensity between IC and empirical cut points. Our findings suggest that researchers should be cautious about the universal application of cut points which fail to account for individual differences between participants, particularly with evidence suggesting wide variations in step counts between children when engaging in PA at equivalent intensities (Rowlands, 2007). The application of more specific cutpoints may provide an opportunity to reduce sample size requirements within studies due to better estimates of primary outcome measures.

Despite calls for raw data processing techniques to remove the reliance on proprietary counts based data, this approach still requires the use of cutpoints or acceleration thresholds to classify raw acceleration signals, therefore the findings of this study apply in the raw data analysis context. To remove the requirement of cutpoints, pattern recognition or machine learning approaches to classify accelerometer data have been proposed Despite the potential utility of this approach the majority of PA research conducted to date using accelerometers still utilises proprietary counts data and apply group level thresholds to the data, therefore the IC approach proposed within this paper is recommended. The range in prevalence and classification of PA resulting from the application of different cut points underscores the need for a consensus on accelerometer thresholds to quantify PA intensity. The array of thresholds used by researchers makes comparison between studies problematic, leading to conflicting conclusions (Hislop et al., 2012). The inconsistent use of these thresholds is also a major issue when attempting to quantify the prevalence of inactivity (Ekelund et al., 2011), has impacted upon PA policy making for children (Bailey et al., 2013) and the relationships between PA and health outcomes (Bailey et al., 2013). For example, in their comparison of three published thresholds (Chu, McManus, & Yu, 2007; Rowlands, Thomas, Eston, & Topping, 2004; Vanhelst et al., 2010) Bailey et al. (2013) reported a range of different associations between PA and health outcomes such as blood pressure, waist circumference, cardiorespiratory fitness and metabolic markers such as glucose and triglycerides. In our study, although the estimates of the intensity of PA differed according to thresholds used, relationships detected with the clustered cardiometabolic risk score were consistent. However, the IC cut points had the strongest associations with VO_2peak, an important independent predictor of cardiometabolic risk (Andersen et al., 2011). This may be due to the methods utilised to create the IC cutpoints and the treadmill-based VO_2peak protocol. Whether the approach of individually calibrating PA thresholds according to limb length is as effective at predicting energy expenditure across a range of different activities warrants further investigation. Furthermore, the empirical cutpoints used in this study were created using field-based protocols that included a range of typical daily activities. The differences described between these methods and the IC approach may relate to the protocols used to generate the cutpoints, rather than the accuracy of the cutpoints per se.

When compared to the use of a portable metabolic unit (Ev) or PA observation (Mack), it appears that the treadmill-based calibration protocol used in this study was more effective in accounting for individual differences in biomechanical efficiency of movement (e.g limb length, stride length/frequency) by matching the accelerometer counts to changes in speed and resulting PA intensity. Whereas in previous research, the observed relationships between CRF and PA in children have been weaker than expected, for example weak-moderate standardized regression coefficeints (0.14-0.33) between aerobic fitness and PA have been reported(Kristensen et al., 2010), the present findings suggest that IC cut points highlight stronger associations between children's PA and CRF than are often reported. Moreover, there is a growing body of evidence that links CRF to cardiometabolic disease risk in children (Anderssen et al., 2007) (Boddy et al., 2014). Therefore, our findings have important implications for researchers investigating the associations between activity status, CRF and health, and practitioners referring inactive individuals for lifestyle intervention.

Strengths and Limitations: This is the first study to examine differences in reported PA, and PA-health relationships between Fr IC and empirically derived cut points. The generic cutpoint method is less time consuming than completing laboratory calibration studies involving multiple activities and portable calorimetry or observation. Despite this, the individual calibration approach used within this study does not take into account movement patterns other than walking and running, and although the majority of children's activity is ambulatory the method may not accurately classify other types of movements completed by children. The method also did not merge the VO_2 data from the fitness assessment that would have provided energy expenditure data. This was purposeful to allow the examination of the thresholds based on the Fr number alone, rather than a more complex hybrid threshold approach. An evolution of this method could be proposed that utilises VO_2 data to examine whether the precision of the thresholds is improved, however this was beyond the scope and aims of the current study. In addition, the Fr number could result in non-ecological walking patterns which are not representative of 'usual' walking speeds. It is important to note that maturational factors may influence metabolic efficiency and therefore energy expenditure within this population. The influence of maturation on energy expenditure was not explored within this study, mainly because of the repeated measures nature of the analysis when comparing thresholds, however warrants consideration when working with populations within this age range. This study used a range of established and emerging risk factors to provide a robust estimate of cardiometabolic risk. However, the participants involved in this study were healthy children, which may account for the lack of associations observed between the PA data and cardiometabolic risk scores. Stronger PA-health associations may be apparent in a population exhibiting greater cardiometabolic risk. The treadmill measure of VO_2peak is considered the reference standard, though standardised protocols were used, data were taken using different gas analysis systems in Liverpool and Ulster (Oxycon Pro and COSMED) which may influence comparability between the VO_2peak estimates.

Conclusion

This study has demonstrated that the application of different intensity thresholds has an impact when determining the proportion of children meeting current daily PA guidelines. To make accurate evidence based recommendations, a consensus on appropriate accelerometer thresholds for quantifying PA intensity is needed. IC cut points provide evidence of a stronger association between children's PA and CRF than is often reported. This finding has important implications for researchers and practitioners investigating the associations between activity status, CRF and health and referring inactive individuals for lifestyle intervention. Additional research is needed with larger cohorts to fully examine the potential of using IC cut points to classify children's PA.

References

Alexander, R. M. (1989). Optimization and gaits in the locomotion of vertebrates. *Physiol Rev, 69*(4), 1199-1227

Andersen, L. B., Hasselstrom, H., Gronfeldt, V., Hansen, S. E., & Karsten, F. (2004). The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study. *Int J Behav Nutr Phys Act, 1*(1), 6

Andersen, L. B., Riddoch, C., Kriemler, S., & Hills, A. P. (2011). Physical activity and cardiovascular risk factors in children. *Br J Sports Med, 45*(11), 871-876. doi: 10.1136/bjsports-2011-090333

Anderssen, S. A., Cooper, A. R., Riddoch, C., Sardinha, L. B., Harro, M., Brage, S., & Andersen, L. B. (2007). Low cardiorespiratory fitness is a strong predictor for clustering of cardiovascular disease risk factors in children independent of country, age and sex. *Eur J Cardiovasc Prev Rehabil, 14*(4), 526-531. doi: 10.1097/HJR.0b013e328011efc1

Bailey, D. P., Boddy, L. M., Savory, L. A., Denton, S. J., & Kerr, C. J. (2013). Choice of activity-intensity classification thresholds impacts upon accelerometer-assessed physical activity-health relationships in children. *PLoS One, 8*(2), e57101. doi: 10.1371/journal.pone.0057101

Baquet, G., Stratton, G., Van Praagh, E., & Berthoin, S. (2007). Improving physical activity assessment in prepubertal children with high-frequency accelerometry monitoring: a methodological issue. *Prev Med, 44*(2), 143-147. doi: 10.1016/j.ypmed.2006.10.004

Biddle, S. J., & Asare, M. (2011). Physical activity and mental health in children and adolescents: a review of reviews. *Br J Sports Med, 45*(11), 886-895. doi: 10.1136/bjsports-2011-090185

Boddy, L. M., Murphy, M. H., Cunningham, C., Breslin, G., Foweather, L., Gobbi, R., . . . Stratton, G. (2014). Physical activity, cardiorespiratory fitness, and clustered cardiometabolic risk in 10- to 12-year-old school children: The REACH Y6 study. *Am J Hum Biol, 26*(4), 446-451. doi: 10.1002/ajhb.22537

Boreham, C. A., & McKay, H. A. (2011). Physical activity in childhood and bone health. *Br J Sports Med, 45*(11), 877-879. doi: 10.1136/bjsports-2011-090188

Buchan, D. S., Young, J. D., Boddy, L. M., & Baker, J. S. (2014). Independent associations between cardiorespiratory fitness, waist circumference, BMI, and clustered cardiometabolic risk in adolescents. *Am J Hum Biol, 26*(1), 29-35. doi: 10.1002/ajhb.22466

Cain, K., Sallis, J. F., Conway, T. L., Van Dyck, D., & Calhoon, L. (2013). Using accelerometers in youth physical activity studies: a review of methods. *Journal of Physical Activity & Health, 10*, 437-450

Catellier, D. J., Hannan, P. J., Murray, D. M., Addy, C. L., Conway, T. L., Yang, S., & Rice, J. C. (2005). Inputation of missing data when measuring activity by accelerometry. *Med Sci Sports Exerc, 37*(Suppl 11), S555-S562

Chu, E. Y., McManus, A. M., & Yu, C. C. (2007). Calibration of the RT3 accelerometer for ambulation and nonambulation in children. *Med Sci Sports Exerc, 39*(11), 2085-2091. doi: 10.1249/mss.0b013e318148436c

Cole, T. J., Freeman, J. V., & Preece, M. A. (1995). Body mass index reference curves for the UK, 1990. *Arch Dis Child, 73*(1), 25-29

Ekelund, U., Tomkinson, G., & Armstrong, N. (2011). What proportion of youth are physically active? Measurement issues, levels and recent time trends. *Br J Sports Med, 45*(11), 859-865. doi: 10.1136/bjsports-2011-090190

Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of two objective measures of physical activity for children. *J Sports Sci, 26*(14), 1557-1565. doi: 10.1080/02640410802334196

Fischer, C., Yildirim, M., Salmon, J., & Chinapaw, M. J. M. (2012). Comparing different accelerometer cut-points for sedentary time in children. *Pediatric Exercise Science, 24*(2), 220-228

Freedson, P., Pober, D., & Janz, K. F. (2005). Calibration of accelerometer output for children. *Med Sci Sports Exerc, 37*(11 Suppl), S523-530

Harrell, J. S., McMurray, R. G., Baggett, C. D., Pennell, M. L., Pearce, P. F., & Bangdiwala, S. I. (2005). Energy costs of physical activities in children and adolescents. *Med Sci Sports Exerc, 37*(2), 329-336

Hislop, J., Bulley, C., Mercer, T., & Reilly, J. (2012). Comparison of accelerometry cut points for physical activity and sedentary behavior in preschool children: a validation study. *Pediatric Exercise Science, 24*(4), 563-576

Kram, R., Domingo, A., & Ferris, D. P. (1997). Effect of reduced gravity on the preferred walk-run transition speed. *J Exp Biol, 200*(Pt 4), 821-826

Kristensen, P. L., Moeller, N. C., Korsholm, L., Kolle, E., Wedderkopp, N., Froberg, K., & Andersen, L. B. (2010). The association between aerobic fitness and physical activity in children and adolescents: the European youth heart study. *Eur J Appl Physiol, 110*(2), 267-275. doi: 10.1007/s00421-010-1491-x

Lohman, T., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference manual*. Champaign, Illinois: Human Kinetics.

Mackintosh, K. A., Fairclough, S. J., Stratton, G., & Ridgers, N. D. (2012). A calibration protocol for population-specific accelerometer cut-points in children. *PLoS One, 7*(5), e36919. doi: 10.1371/journal.pone.0036919

Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S., Shield, J., . . . Riddoch, C. (2008). Use of accelerometers in a large field-based study of children: Protocols, design issues, and effects on precision. *Journal of Physical Activity & Health, 5*(S1), S98-S111

McMurray, R. G., & Ondrak, K. S. (2013). Cardiometabolic risk factors in children: The importance of physical activity. *American Journal of Lifestyle Medicine, 7*(5), 292-303

Minetti, A. E. (2001). Walking on other planets. *Nature, 409*(6819), 467-469

Mirwald, R., Baxter-Jones, A., Bailey, D., & Beunen, G. (2002). An assessment of maturity from anthropometric measurements. *Medicine & Science in Sports & Exercise, 34*(4), 689-694

Reilly, J. J., Penpraze, V., Hislop, J., Davies, G., Grant, S., & Paton, J. (2008). Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child, 93*(7), 614-619

Ridley, K., & Olds, T. S. (2008). Assigning energy costs to activities in children: a review and synthesis. *Med Sci Sports Exerc, 40*(8), 1439-1446. doi: 10.1249/MSS.0b013e31817279ef

Rowlands, A. V. (2007). Accelerometer assessment of physical activity in children: an update. *Pediatr Exerc Sci, 19*(3), 252-266

Rowlands, A. V., Thomas, P. W., Eston, R. G., & Topping, R. (2004). Validation of the RT3 triaxial accelerometer for the assessment of physical activity. *Med Sci Sports Exerc, 36*(3), 518-524

Trost, S. G., Loprinzi, P. D., Moore, R., & Pfeiffer, K. A. (2011). Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc, 43*(7), 1360-1368. doi: 10.1249/MSS.0b013e318206476e

Vanhelst, J., Beghin, L., Rasoamanana, P., Theunynck, D., Meskini, T., Iliescu, C., . . . Gottrand, F. (2010). Calibration of the RT3 accelerometer for various patterns of

physical activity in children and adolescents. *J Sports Sci, 28*(4), 381-387. doi: 10.1080/02640410903508821
WHO. (2010). *Global Recommendations on Physical Activity for Health*. Geneva, Switzerland.

494 Table 1. Raw mean [SE] participant characteristics by sex

Variable	Boys (n = 32)	Girls (n = 43)
Age (years)	10.47 [0.57]	10.5 [0.75]
Maturation offset (years)	-2.64 [0.71]	-0.95 [0.68]
BMI Z-score	0.65 [0.86]	0.53 [1.24]
Waist circumference (cm)	64.4 [6.4]	65.7 [9.57]
VO_2peak (ml/kg/min)	45.55 [9.71]	40.81 [8.7]
Diastolic BP (mmHg)	63 [6.2]	62.1 [6.7]
Systolic BP (mmHg)	103.6 [11.9]	102.3 [12.1]
FMD %	8.39 [3.24]	8.54 [4.26]
C-Reactive Protein (mg/L)	0.38 [0.29]	0.94 [1.32]
Triglycerides (mmol/L)	0.64 [0.2]	0.78 [0.28]
Cholesterol (mmol/L)	4.17 [0.67]	4.21 [0.54]
HDL-C (mmol/L)	1.59 [0.31]	1.49 [0.38]
Glucose (mmol/L)	4.71 [0.34]	4.63 [0.3]
Adiponectin (µg/mL)	10.58 [5.4]	11.14 [6.78]
Clustered CM risk	0.18 [4.01]	-0.38 [3.71]
Sedentary Time (mins/day)	440.4 [41]	458.8 [41.2]

IC LPA (mins/day)	220 [46]	200.7 [33]
IC MPA (mins/day)	52.4 [36.3]	38.3 [24.7]
IC VPA (mins/day)	14.2 [9.7]	12.2 [17.7]
IC MVPA (mins/day)	66.6 [37.5]	50.4 [31.9]
Accelerometer wear time (mins/day)	716.8 [49.2]	716.6 [116.9]

Table 2. Mean values [SE] for boys and girls adjusted for wear time (MANCOVA output, n = 61).

Variable	Boys	Girls	P value
Age (years)	10.45 [.13]	10.49 [.12]	.833
Maturation offset (years)	**-2.63 [.14]**	**-0.89 [.13]**	**< 0.001**
BMI Z-score	0.62 [.21]	0.70 [.18]	.776
Waist circumference (cm)	64.0 [1.6]	67.0 [1.5]	.173
VO_2peak (ml/kg/min)	**46.39 [1.61]**	**39.28 [1.44]**	**.002**
Clustered CM risk	-0.047 [.75]	-0.282 [.67]	.816
Sedentary Time (mins/day)	438.6 [7.7]	457.8 [6.9]	.069
IC LPA (mins/day)	**221.5 [7.4]**	**196.3 [6.6]**	**.014**
IC MPA (mins/day)	**53.5 [5.9]**	**37.4 [5.3]**	**.047**
IC VPA (mins/day)	14.0 [3.1]	12.6 [2.8]	.741
IC MVPA (mins/day)	67.5 [7.0]	50.1 [6.2]	.066

Table 3. Adjusted mean [SE] physical activity across the three cutpoint sets

Activity Component	Individually Calibrated (IC) Minutes/day		Mackintosh et al. 2012 (Mack) Minutes/day		Evenson et al., 2008 (Ev) Minutes/day	
	Mean	SE	Mean	SE	Mean	SE
VPA	13.0[*¬]	1.7	17.8[†]	1.7	25.9	2.0
MPA	44.3[^^]	3.6	51.6[^]	2.4	38.4	1.8
LPA	209.0[‡]	4.1	195.0[†]	3.7	200.3	3.8

[*]Ev > IC ($p < 0.001$),[¬]Mack > IC ($p < 0.001$), [†]Ev > Mack ($p < 0.001$), [^^]Mack > IC ($p = 0.005$) [^]Mack > Ev ($p < 0.001$), [‡]IC > Mack ($p < 0.01$) and IC > Ev ($p = 0.006$).