



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

Boddy, L. M., Cunningham, C., Fairclough, S. J., Murphy, M. H., Breslin, G., Foweather, L., Dagger, R. M., Graves, L. E. F., Hopkins, N. D., & Stratton, G. (2018). Individual calibration of accelerometers in children and their health-related implications. *Journal of Sports Sciences*, 36(12), 1340-1345. Advance online publication. <https://doi.org/10.1080/02640414.2017.1377842>

[Link to publication record in Ulster University Research Portal](#)

### Published in:

Journal of Sports Sciences

### Publication Status:

Published (in print/issue): 30/06/2018

### DOI:

[10.1080/02640414.2017.1377842](https://doi.org/10.1080/02640414.2017.1377842)

### Document Version

Author Accepted version

### General rights

Copyright for the publications made accessible via Ulster University's Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

### Take down policy

The Research Portal is Ulster University's institutional repository that provides access to Ulster's research outputs. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact [pure-support@ulster.ac.uk](mailto:pure-support@ulster.ac.uk).

1 **Title Page**

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

4 **Running Title:** Individual PA calibration and health implications

5 **Keywords:** physical activity, accelerometry, threshold, children

6 **Authors:** Lynne M. Boddy<sup>1</sup>, [L.M.Boddy@ljmu.ac.uk](mailto:L.M.Boddy@ljmu.ac.uk) \*\*  
7 Conor Cunningham<sup>2</sup>, [Cunningham-C15@email.ulster.ac.uk](mailto:Cunningham-C15@email.ulster.ac.uk)  
8 Stuart J. Fairclough<sup>3,4</sup>, [Stuart.Fairclough@edgehill.ac.uk](mailto:Stuart.Fairclough@edgehill.ac.uk)  
9 Marie H. Murphy<sup>2</sup>, [mh.murphy@ulster.ac.uk](mailto:mh.murphy@ulster.ac.uk)  
10 Gavin Breslin<sup>2</sup>, [g.breslin1@ulster.ac.uk](mailto:g.breslin1@ulster.ac.uk)  
11 Lawrence Foweather<sup>3</sup>, [L.Foweather@ljmu.ac.uk](mailto:L.Foweather@ljmu.ac.uk)  
12 Rebecca M. Dagger<sup>5</sup>, [Daggerb@hope.ac.uk](mailto:Daggerb@hope.ac.uk)  
13 Lee E.F. Graves<sup>1</sup>, [L.E.Graves@ljmu.ac.uk](mailto:L.E.Graves@ljmu.ac.uk)  
14 Nicola D. Hopkins<sup>1</sup>, [N.D.Hopkins@ljmu.ac.uk](mailto:N.D.Hopkins@ljmu.ac.uk)  
15 Gareth Stratton<sup>6,7</sup>, [G.Stratton@swansea.ac.uk](mailto:G.Stratton@swansea.ac.uk)  
16

17 1. The Physical Activity Exchange, Research Institute for Sport and Exercise Sciences,  
18 Liverpool John Moores University, 62 Great Crosshall Street, Liverpool, L3 2AT.  
19 2. Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of  
20 Ulster, Jordanstown Campus, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, UK.  
21 3 Department of Sport and Physical Activity, Edge Hill University, St Helens Road, Ormskirk,  
22 L39 4QP  
23 4. Department of Physical Education and Sport Sciences, University of Limerick, Limerick,  
24 Ireland  
25 Limerick  
26 5. Department of Health Sciences, Liverpool Hope University, Hope Park, Liverpool, L16  
27 9JD, UK.  
28 6. Applied Sports Technology, Exercise and Medicine Research Centre, College of  
29 Engineering, Swansea University, Bay Campus Fabian Way Swansea SA1 8EN  
30 7. School of Sports Science, Exercise and Health, the University of Western Australia, Perth,  
31 Australia.  
32

33 \*\* Corresponding Author: Dr. Lynne M. Boddy,  
34 The Physical Activity Exchange,  
35 Research Institute for Sport and Exercise Sciences,  
36 Liverpool John Moores University,  
37 62 Great Crosshall Street,  
38 Liverpool,  
39 L3 2AT  
40 Email: [L.M.Boddy@ljmu.ac.uk](mailto:L.M.Boddy@ljmu.ac.uk)  
41 Tel: 0151 231 4275  
42

43 **Abbreviated Title:** Children's Activity-health associations using different intensity cutpoints  
44

45 **Article Type:** Original research article  
46

47 **Author Contributions:** Contributors: LMB; analysed the data. LMB, CC, GS and SJF; wrote  
48 this manuscript. LMB and GS; designed and conceived the REACH Y6 study. LMB, LF, RG,  
49 LEFG and NDH: acquisition and analysis of REACH Y6 data in Liverpool, MHM, CC, GB;

50 acquisition and analysis of data in Ulster. GS, MHM, SJF, CC; substantial contribution to  
51 writing and critical review of the article. All authors approved the article prior to submission.

52

53 **Funding:** This study was funded by Liverpool John Moores University and by the University  
54 of Ulster.

55

56

57 **Disclosure:** There are no conflicts of interest for this study.

58

59 **Author declaration:** This study has not been published elsewhere and is not being considered  
60 for publication elsewhere.

61

62

### 63 *Acknowledgments*

64 We would like to thank the participants, parents, schools and researchers involved in the

65 REACH Y6 study. We would also like to thank Nicola Lyons, Dr Paul Newland, Dr Jeff Jones

66 and Dr Marcus Auth for Alder Hey Children's NHS Foundation Trust for their key input in

67 arranging phlebotomy and biochemical analysis and Dr Giles Aldworth from the Ulster

68 Hospital for his involvement in this study. We would also like to acknowledge the contribution

69 of Professor Non Thomas who passed away in 2012 for her expert advice and support when

70 setting up this project. This study was funded by Liverpool John Moores University and Ulster

71 University.

72 **Abstract**

73 This study compared children's physical activity (PA) levels, the prevalence of children  
74 meeting current guidelines of  $\geq 60$  minutes of daily moderate to vigorous PA (MVPA), and  
75 PA-health associations using individually calibrated (IC) and empirical accelerometer  
76 cutpoints. Data from 75 (n = 32 boys) 10-12 year old children were included in this study.  
77 Clustered cardiometabolic (CM) risk, directly measured cardiorespiratory fitness (CRF),  
78 anthropometric and 7 day accelerometer data were included within analysis. PA data were  
79 classified using Froude anchored IC, Evenson et al., 2008 (Ev) and Mackintosh et al., 2012  
80 (Mack) cutpoints. The proportion of the cohort meeting  $\geq 60$ mins MVPA/day ranged from  
81 37%-56% depending on the cutpoints used. Reported PA differed significantly across the  
82 cutpoint sets. IC LPA and MPA were predictors of CRF (LPA: standardised  $\beta = 0.32$ ,  $p =$   
83  $0.002$ , MPA: standardised  $\beta = 0.27$   $p = 0.013$ ). IC MPA also predicted BMI Z-score  
84 (standardised  $\beta = -0.35$ ,  $p = 0.004$ ). Ev VPA was a predictor of BMI Z-score (standardised  $\beta$   
85  $= -0.33$ ,  $p = 0.012$ ). Cutpoint choice has a substantial impact on reported PA levels though no  
86 significant associations with CM risk were observed. Froude IC cut points represent a  
87 promising approach towards classifying children's PA data.

88 **Introduction**

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

103

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

114

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

137

## 138 **Methods**

### 139 *Participants and Settings*

140 The data for this analysis were taken from the REACH Year 6 study (Boddy et al., 2014).  
141 Seventy-five children (n = 32 boys) 10-12 years of age agreed to take part in the study which  
142 had ethical clearance from the respective institutional ethics committees. The study was

143 conducted in Liverpool, England (2010, n = 39) and Belfast, Northern Ireland (2011, n = 35).  
144 Each participant attended one school-based blood sampling session and one laboratory testing  
145 session. Participants also wore an accelerometer to quantify PA over seven days.

146

147

#### 148 *Procedure and Measurements*

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

159

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

171 set to record using 5 second epochs throughout the treadmill protocol. The highest 15-second  
172 average oxygen uptake was used to represent  $\text{VO}_2\text{peak}$  (ml/kg/min) for each participant.

173

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

187

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

196 PA data were classified into light (LPA), moderate (MPA), vigorous (VPA) and moderate to  
197 vigorous PA (MVPA) intensities using three sets of intensity cutpoints: two sets of empirical  
198 cutpoints: Evenson et al., 2008 (Ev) and Mackintosh et al., 2012 (Mack). The Mack



199 thresholds were generated from data derived from a field-based observational protocol with  
200 children of the same age and from a similar geographical location as those included within  
201 this study and were included to provide an additional comparison. PA was also classified using  
202 individually calibrated (IC) cut points. Sedentary time was defined as  $\leq 100$  counts per minute  
203 for all cut point sets (Fischer, Yildirim, Salmon, & Chinapaw, 2012). Individually calibrated  
204 cut points were generated using the data from the  $VO_2$ peak treadmill protocol. Froude 0.25  
205 and 0.50 represent the thresholds for optimum walking speed and the transition between  
206 walking and running. The average counts for the middle 90 seconds (18 epochs) of the two  
207 Fr stages (Fr 0.25 and Fr 0.50) were used to represent MPA and VPA thresholds for each  
208 individual. The middle 90 seconds were selected to avoid the transitional periods between the  
209 Fr.25 (walking) and Fr.5 (running). To examine the energy cost associated with each Fr  
210 threshold metabolic equivalents were calculated for Fr.25 and Fr.5 stages using the gas  
211 analysis data (1 MET = 4.59  $VO_2$  ml/kg/min; (Ridley & Olds, 2008) and compared to the  
212 energy costs outlined by Harrell et al. (2005). This gas analysis data was simply used to assess  
213 the MET values associated with the Fr stages for each individual.

214

#### 215 *Data analysis*

216 Differences in anthropometrics, clustered risk,  $VO_2$ peak, sedentary time and PA components  
217 (MPA, VPA, MVPA) were examined by sex using MANCOVA, controlling for accelerometer  
218 wear time. The prevalence of those reaching  $\geq 60$ mins MVPA per day was calculated for each  
219 cutpoint set. Differences in PA intensities were examined using repeated measures ANOVAs  
220 by cutpoint. To investigate the association between PA components and health markers  
221 ( $VO_2$ peak, BMI Z-score, waist circumference, clustered cardiometabolic risk) multiple  
222 regression was employed controlling for sex, maturation, BMI and wear time. For each  
223 dependent variable three multiple regression models, one for each cutpoint, were created.  
224 Where BMI was used as a dependent variable it was excluded as a covariate. All analyses  
225 were completed using SPSS V21.0 (SPSS Inc, IBM). Alpha was set at  $P \leq 0.05$ .

226 **Results**

227 Unadjusted mean participant characteristics and adjusted mean anthropometric, VO<sub>2</sub>peak,  
228 sedentary time and PA values for boys and girls are illustrated in tables 1 and 2 respectively.  
229 Boys were significantly less mature, had higher VO<sub>2</sub>peak and accrued more LPA and MPA  
230 than girls.

231

232 TABLE 1 ABOUT HERE

233 TABLE 2 ABOUT HERE

234

235 The IC cut points ranged from 1234-4476 counts per minute for MPA and 3192-9357 counts  
236 per minute for VPA The mean oxygen consumption (VO<sub>2</sub> ml·kg<sup>-1</sup>·min<sup>-1</sup>) and MET values (1  
237 MET = 4.59 VO<sub>2</sub> ml·kg<sup>-1</sup>·min<sup>-1</sup>) achieved during the treadmill stages Fr0.25 and Fr.5 were  
238 20.1ml·kg<sup>-1</sup>·min<sup>-1</sup> (SD = 4.2 ml·kg<sup>-1</sup>·min<sup>-1</sup>), 4.4 METs and 31.2 ml·kg<sup>-1</sup>·min<sup>-1</sup> (SD = 7.4 ml·kg<sup>-1</sup>·min<sup>-1</sup>)  
239 6.8 METs respectively. These values are proximal to those commonly used to  
240 represent MPA (≥4 METS+) and VPA (≥6 METS) in the PA literature. Data from Harrell et  
241 al (2005) calculated for children aged 8-12 years confirm that participants were working at an  
242 intensity approximately equivalent to moderate intensity during Fr 0.25 (Harrell et al. (2005)  
243 values: VO<sub>2</sub> = 18.3 ml·kg<sup>-1</sup>·min<sup>-1</sup>) and approaching high intensity activity during Fr 0.50  
244 (Harrell et al. (2005) values: VO<sub>2</sub> = 38.5 ml·kg<sup>-1</sup>·min<sup>-1</sup>).

245

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

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

253 (13.0 mins/day). Significantly less LPA was observed using the Mack (195 mins/day)  
254 cutpoints in comparison to IC (209 mins/day) and Ev (200.3 mins/day), the difference between  
255 IC and Ev LPA was also statistically significant.

256

257 TABLE 3 ABOUT HERE

258

259 Results of multiple regression found that IC LPA and MPA were significant predictors of  
260  $VO_2$ peak ( $R^2$  for the model = 0.55, LPA: standardised beta = 0.32,  $t = 3.24$ ,  $p = 0.002$ , MPA:  
261 standardized beta = 0.27,  $t = 2.57$ ,  $p = 0.013$ ) IC MPA was also a significant predictor for BMI  
262 Z-score ( $R^2$  for the model = 0.31, standardised beta = -0.35,  $t = -2.96$ ,  $p = 0.004$ ). Ev VPA was  
263 a significant predictor for BMI Z-score ( $R^2$  for the model = 0.32, standardized beta = -0.33,  $t$   
264 = -2.59,  $p = 0.012$ ), Mack data were not significant predictors for any health variables,  
265 however Mack VPA approached statistical significance as a predictor for BMI Z-score ( $R^2$  for  
266 the model = 0.29, VPA standardized beta = -0.23,  $t = -1.98$ ,  $p = 0.052$ ). No significant PA-  
267 clustered risk score associations were observed irrespective of cut point set used.

268

## 269 **Discussion**

270 The aims of this study were to compare children's physical activity (PA) levels, the prevalence  
271 of children meeting current guidelines of 60 minutes of daily moderate to vigorous PA  
272 (MVPA), and PA-health associations using individually calibrated Fr (IC) and empirical  
273 accelerometer cutpoints. In this study the proportion of the cohort meeting current guidelines  
274 for daily MVPA ranged from 37% - 56% depending upon the cut point used. A number of  
275 studies have shown differences in PA prevalence depending on the choice of cut points used  
276 to analyse data (Hislop et al., 2012; Reilly et al., 2008). For example, a review by Ekelund et  
277 al. (2011) highlighted that the reported prevalence of children and young people meeting  
278 current PA guidelines ranged across six studies from 1% and 100%, with authors suggesting  
279 that the variability could be largely attributed to the different intensity cutpoints used between  
280 studies. At a 4 MET intensity (approximate to MPA) recommended counts per minute have

281 ranged widely from 1400 to 3600 (Cain et al., 2013). In this study, IC cut points derived from  
282 the treadmill-based protocol ranged from 1234-4476 for MPA, with a mean MET value of 4.4  
283 (range 2.49-7.04 METs) and 3192-9357 for VPA (mean MET value of 6.8, range 3.83-12.33  
284 METs). This demonstrates the substantial variation that exists in the biomechanical efficiency  
285 of movement (e.g. stride length, stride pattern) between children of a similar age completing  
286 the same activity, and provides support for the use of IC cut points that take account of  
287 individual differences.

288

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

304

305 Despite calls for raw data processing techniques to remove the reliance on proprietary counts  
306 based data, this approach still requires the use of cutpoints or acceleration thresholds to  
307 classify raw acceleration signals, therefore the findings of this study apply in the raw data  
308 analysis context. To remove the requirement of cutpoints, pattern recognition or machine

309 learning approaches to classify accelerometer data have been proposed Despite the potential  
310 utility of this approach the majority of PA research conducted to date using accelerometers  
311 still utilises proprietary counts data and apply group level thresholds to the data, therefore the  
312 IC approach proposed within this paper is recommended. The range in prevalence and  
313 classification of PA resulting from the application of different cut points underscores the need  
314 for a consensus on accelerometer thresholds to quantify PA intensity. The array of thresholds  
315 used by researchers makes comparison between studies problematic, leading to conflicting  
316 conclusions (Hislop et al., 2012). The inconsistent use of these thresholds is also a major issue  
317 when attempting to quantify the prevalence of inactivity (Ekelund et al., 2011), has impacted  
318 upon PA policy making for children (Bailey et al., 2013) and the relationships between PA  
319 and health outcomes (Bailey et al., 2013). For example, in their comparison of three published  
320 thresholds (Chu, McManus, & Yu, 2007; Rowlands, Thomas, Eston, & Topping, 2004;  
321 Vanhelst et al., 2010) Bailey et al. (2013) reported a range of different associations between  
322 PA and health outcomes such as blood pressure, waist circumference, cardiorespiratory fitness  
323 and metabolic markers such as glucose and triglycerides. In our study, although the estimates  
324 of the intensity of PA differed according to thresholds used, relationships detected with the  
325 clustered cardiometabolic risk score were consistent. However, the IC cut points had the  
326 strongest associations with  $VO_2$ peak, an important independent predictor of cardiometabolic  
327 risk (Andersen et al., 2011). This may be due to the methods utilised to create the IC cutpoints  
328 and the treadmill-based  $VO_2$ peak protocol. Whether the approach of individually calibrating  
329 PA thresholds according to limb length is as effective at predicting energy expenditure across  
330 a range of different activities warrants further investigation. Furthermore, the empirical  
331 cutpoints used in this study were created using field-based protocols that included a range of  
332 typical daily activities. The differences described between these methods and the IC approach  
333 may relate to the protocols used to generate the cutpoints, rather than the accuracy of the  
334 cutpoints per se.

335

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

349

350 Strengths and Limitations: This is the first study to examine differences in reported PA, and  
351 PA-health relationships between Fr IC and empirically derived cut points. The generic  
352 cutpoint method is less time consuming than completing laboratory calibration studies  
353 involving multiple activities and portable calorimetry or observation. Despite this, the  
354 individual calibration approach used within this study does not take into account movement  
355 patterns other than walking and running, and although the majority of children's activity is  
356 ambulatory the method may not accurately classify other types of movements completed by  
357 children. The method also did not merge the  $VO_2$  data from the fitness assessment that would  
358 have provided energy expenditure data. This was purposeful to allow the examination of the  
359 thresholds based on the Fr number alone, rather than a more complex hybrid threshold  
360 approach. An evolution of this method could be proposed that utilises  $VO_2$  data to examine  
361 whether the precision of the thresholds is improved, however this was beyond the scope and  
362 aims of the current study. In addition, the Fr number could result in non-ecological walking  
363 patterns which are not representative of 'usual' walking speeds. It is important to note that

364 maturational factors may influence metabolic efficiency and therefore energy expenditure  
365 within this population. The influence of maturation on energy expenditure was not explored  
366 within this study, mainly because of the repeated measures nature of the analysis when  
367 comparing thresholds, however warrants consideration when working with populations within  
368 this age range. This study used a range of established and emerging risk factors to provide a  
369 robust estimate of cardiometabolic risk. However, the participants involved in this study were  
370 healthy children, which may account for the lack of associations observed between the PA  
371 data and cardiometabolic risk scores. Stronger PA-health associations may be apparent in a  
372 population exhibiting greater cardiometabolic risk. The treadmill measure of  $VO_2$ peak is  
373 considered the reference standard, though standardised protocols were used, data were taken  
374 using different gas analysis systems in Liverpool and Ulster (Oxycon Pro and COSMED)  
375 which may influence comparability between the  $VO_2$ peak estimates.

376

### 377 *Conclusion*

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

387

388 **References**

- 389 Alexander, R. M. (1989). Optimization and gaits in the locomotion of vertebrates. *Physiol*  
390 *Rev*, 69(4), 1199-1227
- 391 Andersen, L. B., Hasselstrom, H., Gronfeldt, V., Hansen, S. E., & Karsten, F. (2004). The  
392 relationship between physical fitness and clustered risk, and tracking of clustered  
393 risk from adolescence to young adulthood: eight years follow-up in the Danish  
394 Youth and Sport Study. *Int J Behav Nutr Phys Act*, 1(1), 6
- 395 Andersen, L. B., Riddoch, C., Kriemler, S., & Hills, A. P. (2011). Physical activity and  
396 cardiovascular risk factors in children. *Br J Sports Med*, 45(11), 871-876. doi:  
397 10.1136/bjsports-2011-090333
- 398 Anderssen, S. A., Cooper, A. R., Riddoch, C., Sardinha, L. B., Harro, M., Brage, S., &  
399 Andersen, L. B. (2007). Low cardiorespiratory fitness is a strong predictor for  
400 clustering of cardiovascular disease risk factors in children independent of country,  
401 age and sex. *Eur J Cardiovasc Prev Rehabil*, 14(4), 526-531. doi:  
402 10.1097/HJR.0b013e328011efc1
- 403 Bailey, D. P., Boddy, L. M., Savory, L. A., Denton, S. J., & Kerr, C. J. (2013). Choice of activity-  
404 intensity classification thresholds impacts upon accelerometer-assessed physical  
405 activity-health relationships in children. *PLoS One*, 8(2), e57101. doi:  
406 10.1371/journal.pone.0057101
- 407 Baquet, G., Stratton, G., Van Praagh, E., & Berthoin, S. (2007). Improving physical activity  
408 assessment in prepubertal children with high-frequency accelerometry monitoring:  
409 a methodological issue. *Prev Med*, 44(2), 143-147. doi:  
410 10.1016/j.ypmed.2006.10.004
- 411 Biddle, S. J., & Asare, M. (2011). Physical activity and mental health in children and  
412 adolescents: a review of reviews. *Br J Sports Med*, 45(11), 886-895. doi:  
413 10.1136/bjsports-2011-090185
- 414 Boddy, L. M., Murphy, M. H., Cunningham, C., Breslin, G., Foweather, L., Gobbi, R., . . .  
415 Stratton, G. (2014). Physical activity, cardiorespiratory fitness, and clustered  
416 cardiometabolic risk in 10- to 12-year-old school children: The REACH Y6 study. *Am*  
417 *J Hum Biol*, 26(4), 446-451. doi: 10.1002/ajhb.22537
- 418 Boreham, C. A., & McKay, H. A. (2011). Physical activity in childhood and bone health. *Br J*  
419 *Sports Med*, 45(11), 877-879. doi: 10.1136/bjsports-2011-090188
- 420 Buchan, D. S., Young, J. D., Boddy, L. M., & Baker, J. S. (2014). Independent associations  
421 between cardiorespiratory fitness, waist circumference, BMI, and clustered  
422 cardiometabolic risk in adolescents. *Am J Hum Biol*, 26(1), 29-35. doi:  
423 10.1002/ajhb.22466
- 424 Cain, K., Sallis, J. F., Conway, T. L., Van Dyck, D., & Calhoun, L. (2013). Using accelerometers  
425 in youth physical activity studies: a review of methods. *Journal of Physical Activity*  
426 *& Health*, 10, 437-450
- 427 Catellier, D. J., Hannan, P. J., Murray, D. M., Addy, C. L., Conway, T. L., Yang, S., & Rice, J. C.  
428 (2005). Imputation of missing data when measuring activity by accelerometry. *Med*  
429 *Sci Sports Exerc*, 37(Suppl 11), S555-S562
- 430 Chu, E. Y., McManus, A. M., & Yu, C. C. (2007). Calibration of the RT3 accelerometer for  
431 ambulation and nonambulation in children. *Med Sci Sports Exerc*, 39(11), 2085-  
432 2091. doi: 10.1249/mss.0b013e318148436c
- 433 Cole, T. J., Freeman, J. V., & Preece, M. A. (1995). Body mass index reference curves for the  
434 UK, 1990. *Arch Dis Child*, 73(1), 25-29
- 435 Ekelund, U., Tomkinson, G., & Armstrong, N. (2011). What proportion of youth are  
436 physically active? Measurement issues, levels and recent time trends. *Br J Sports*  
437 *Med*, 45(11), 859-865. doi: 10.1136/bjsports-2011-090190



438 Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of  
439 two objective measures of physical activity for children. *J Sports Sci*, 26(14), 1557-  
440 1565. doi: 10.1080/02640410802334196

441 Fischer, C., Yildirim, M., Salmon, J., & Chinapaw, M. J. M. (2012). Comparing different  
442 accelerometer cut-points for sedentary time in children. *Pediatric Exercise Science*,  
443 24(2), 220-228

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

446 Harrell, J. S., McMurray, R. G., Baggett, C. D., Pennell, M. L., Pearce, P. F., & Bangdiwala, S. I.  
447 (2005). Energy costs of physical activities in children and adolescents. *Med Sci*  
448 *Sports Exerc*, 37(2), 329-336

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

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

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

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

460 Mackintosh, K. A., Fairclough, S. J., Stratton, G., & Ridgers, N. D. (2012). A calibration  
461 protocol for population-specific accelerometer cut-points in children. *PLoS One*,  
462 7(5), e36919. doi: 10.1371/journal.pone.0036919

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

466 McMurray, R. G., & Ondrak, K. S. (2013). Cardiometabolic risk factors in children: The  
467 importance of physical activity. *American Journal of Lifestyle Medicine*, 7(5), 292-  
468 303

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

470 Mirwald, R., Baxter-Jones, A., Bailey, D., & Beunen, G. (2002). An assessment of maturity  
471 from anthropometric measurements. *Medicine & Science in Sports & Exercise*,  
472 34(4), 689-694

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

476 Ridley, K., & Olds, T. S. (2008). Assigning energy costs to activities in children: a review and  
477 synthesis. *Med Sci Sports Exerc*, 40(8), 1439-1446. doi:  
478 10.1249/MSS.0b013e31817279ef

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

481 Rowlands, A. V., Thomas, P. W., Eston, R. G., & Topping, R. (2004). Validation of the RT3  
482 triaxial accelerometer for the assessment of physical activity. *Med Sci Sports Exerc*,  
483 36(3), 518-524

484 Trost, S. G., Loprinzi, P. D., Moore, R., & Pfeiffer, K. A. (2011). Comparison of accelerometer  
485 cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*, 43(7),  
486 1360-1368. doi: 10.1249/MSS.0b013e318206476e

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

489 physical activity in children and adolescents. *J Sports Sci*, 28(4), 381-387. doi:  
490 10.1080/02640410903508821  
491 WHO. (2010). *Global Recommendations on Physical Activity for Health*. Geneva,  
492 Switzerland.  
493

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 <sub>2</sub> peak (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]

---

495

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

<b>Variable</b>	<b>Boys</b>	<b>Girls</b>	<b>P value</b>
Age (years)	10.45 [.13]	10.49 [.12]	.833
<b>Maturation offset (years)</b>	<b>-2.63 [.14]</b>	<b>-0.89 [.13]</b>	<b>&lt; 0.001</b>
BMI Z-score	0.62 [.21]	0.70 [.18]	.776
Waist circumference (cm)	64.0 [1.6]	67.0 [1.5]	.173
<b>VO<sub>2</sub>peak (ml/kg/min)</b>	<b>46.39 [1.61]</b>	<b>39.28 [1.44]</b>	<b>.002</b>
Clustered CM risk	-0.047 [.75]	-0.282 [.67]	.816
Sedentary Time (mins/day)	438.6 [7.7]	457.8 [6.9]	.069
<b>IC LPA (mins/day)</b>	<b>221.5 [7.4]</b>	<b>196.3 [6.6]</b>	<b>.014</b>
<b>IC MPA (mins/day)</b>	<b>53.5 [5.9]</b>	<b>37.4 [5.3]</b>	<b>.047</b>
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

498

499

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

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

501

502 <sup>\*</sup>Ev > IC ( $p < 0.001$ ), <sup>†</sup>Mack > IC ( $p < 0.001$ ), <sup>†</sup>Ev > Mack ( $p < 0.001$ ), <sup>^^</sup>Mack > IC

503 ( $p = 0.005$ ) <sup>^</sup>Mack > Ev ( $p < 0.001$ ), <sup>‡</sup>IC > Mack ( $p < 0.01$ ) and IC > Ev ( $p = 0.006$ ).

504