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1 **Title: Wrist acceleration cut-points for moderate-to-vigorous physical activity in youth**

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20 physical activity in youth. *Medicine and Science in Sports and Exercise*. 2018; 50(3):609-616.

21 **Abstract**

22 **Purpose:** To examine the validity of wrist acceleration cut-points for classifying moderate  
23 (MPA), vigorous (VPA) and moderate-to-vigorous (MVPA) physical activity.

24 **Methods:** Fifty-seven children (5-12y) completed 15 semi-structured activities. Three sets of  
25 wrist cut-points (>192mg, >250mg, >314mg), previously developed using Euclidian norm minus  
26 one (ENMO<sub>192+</sub>), GENEActiv software (GENEA<sub>250+</sub>) and Bandpass Filtered followed by  
27 Euclidian Norm (BFEN<sub>314+</sub>), were evaluated against indirect calorimetry. Analyses included  
28 classification accuracy, equivalence testing and Bland-Altman procedures.

29 **Results:** All cut-points classified MPA, VPA and MVPA with substantial accuracy (ENMO<sub>192+</sub>:  
30  $\kappa = 0.72$  [95% confidence interval: 0.72 – 0.73], MVPA: area under the receiver operating  
31 characteristic curve (ROC-AUC) = 0.85 [0.85 – 0.86]; GENEActiv:  $\kappa = 0.75$  [0.74 – 0.76],  
32 MVPA: ROC-AUC = 0.85 [0.85 – 0.86]; BFEN<sub>314+</sub>:  $\kappa = 0.73$  [0.72 – 0.74], MVPA: ROC-AUC  
33 = 0.86 [0.86 – 0.87]). BFEN<sub>314+</sub> misclassified 19.7% non-MVPA epochs as MPA, whereas  
34 ENMO<sub>192+</sub> and GENEActiv misclassified 32.6% and 26.5% of MPA epochs as non-MVPA,  
35 respectively. Group estimates of MPA time were equivalent ( $p < 0.01$ ) to indirect calorimetry for  
36 the BFEN<sub>314+</sub> MPA cut-point (mean bias: -1.5%, limits of agreement [LoA]: -57.5 - 60.6%),  
37 while estimates of MVPA time were equivalent ( $p < 0.01$ ) to indirect calorimetry for the  
38 ENMO<sub>192+</sub> (mean bias: -1.1% [LoA: -53.7% – 55.9%]) and GENEActiv (mean bias: 2.2% [LoA:  
39 -56.5% – 52.2%]) cut-points. Individual variability (LoAs) was large for MPA (min: BFEN<sub>314+</sub>, -  
40 60.6% – 57.5%; max: GENEActiv, -42.0% – 104.1%), VPA (min: BFEN<sub>314+</sub>, -238.9% – 54.6%;  
41 max: ENMO<sub>192+</sub>, -244.5% – 127.4%) and MVPA (min: ENMO<sub>192+</sub>, -53.7% – 55.0%; max:  
42 BFEN<sub>314+</sub>, -83.9% – 25.3%).

43 **Conclusion:** Wrist acceleration cut-points misclassified a considerable proportion of non-MVPA  
44 and MVPA. Group level estimates of MVPA were acceptable; however, error for individual  
45 level prediction was larger.

46

47 **Keywords:** activity monitor, children, validation, objective measurement, GENEActiv,  
48 ActiGraph

49

## 50 **Introduction**

51 Accurate measurement of physical activity (PA) in children is of critical importance to  
52 monitor prevalence and trends, establish associations with health outcomes, identify  
53 determinants, and to evaluate the effectiveness of interventions to promote PA (1). Hip-mounted  
54 accelerometers have commonly been used to objectively quantify habitual PA in children (2).  
55 However, low participant compliance with accelerometry protocols have resulted in considerable  
56 non-wear time and, subsequently, loss of data (3). National biobanks such as U.K. Biobank (4),  
57 and large population surveys (5) including the National Health and Nutrition Examination Study  
58 (NHANES) 2011-2014 (6) in the U.S. incorporated wrist-worn accelerometers. Recent evidence  
59 indicates that wrist-placement results in increased wear time due to greater compliance (6-8),  
60 which has consequently caused a shift from hip-placement to wrist-placement.

61 Traditionally, accelerometer-based PA monitoring devices have provided proprietary  
62 units referred to as “counts” from which cut-points have been developed to classify moderate  
63 (MPA), vigorous (VPA) and moderate-to-vigorous physical activity (MVPA) and estimate time  
64 spent in MVPA. However, more recently, commonly used accelerometer-based motion sensors  
65 such as the GENEActiv (ActivInsights Ltd., Cambridge, UK) and ActiGraph GT3X+ and GT9X  
66 (ActiGraph Corporation, Pensacola Beach, FL) provide access to high frequency tri-axial  
67 acceleration data, and therefore cut-points to define PA intensity have been developed for these  
68 data collected from wrist devices. The existence of multiple cut-points makes comparisons of PA  
69 outcomes from studies that have used different cut-points challenging, and inconsistencies  
70 between studies may affect conclusions about PA prevalence, health benefits, determinants and  
71 the effectiveness of interventions. Therefore, studies are needed that simultaneously compare the  
72 validity of multiple cut-points to provide evidence upon which consensus can be reached for

73 consistent data reduction approaches, which could increase the comparability of PA outcomes  
74 between studies.

75         Recent laboratory-based calibration studies (9-11) have developed three sets of PA  
76 intensity thresholds for raw acceleration output from wrist-worn devices in 6-14 year-old  
77 children using indirect calorimetry as the criterion measure. The cut-points were cross-validated  
78 and demonstrated acceptable classification accuracy. However, two studies (10, 11) applied the  
79 leave-one out cross-validation approach in the calibration sample and evaluated classification  
80 accuracy for the same MPA and VPA activities, which were predominantly ambulatory (e.g.,  
81 treadmill walking and running). As such, generalizability to free living scenarios may be limited.  
82 One set of cut-points (9) was cross-validated in an independent sample of 5-8 year-olds (12),  
83 however, the sample size was small (n=15), the protocol included a limited range of activities,  
84 and the cut-points were not cross-validated in children older than 8 years.

85         These independent calibration studies used different data processing methodologies and  
86 have resulted in different cut-points, ranging from 192mg (11) to 314mg (10) and 696mg (11) to  
87 998mg (10) for MPA and VPA, respectively; thus providing different PA estimates, which  
88 makes it difficult to compare outcomes between studies. Therefore, additional studies are needed  
89 to adequately cross-validate cut-points. A recent study (13) validated various data processing  
90 approaches for the wrist-worn ActiGraph in children and concluded that differences in PA  
91 estimates were caused by the use of different methods. However, because Kim et al. (13) did not  
92 include a valid criterion measure, the most accurate approach could not be determined. In  
93 agreement with best practice recommendations from Welk et al. (14), the authors suggested that  
94 the validity of different methods, along with their corresponding cut-points, should be evaluated  
95 simultaneously, relative to gold standard methods. Therefore, the aim of this study was to

96 simultaneously evaluate the performance of three sets of wrist acceleration cut-points for  
97 classifying MPA, VPA and MVPA and estimating time spent in PA intensities, under consistent  
98 conditions, using portable indirect calorimetry as the criterion measure in 5-12 year-old children.

99

## 100 **Methods**

### 101 *Participants*

102 Fifty-seven children aged 5-12y who were without physical or health conditions that  
103 would affect participation in PA were recruited as part of an activity monitor validation study.  
104 The study was approved by the University of Wollongong Health and Medical Human Research  
105 Ethics Committee. Descriptive characteristics of participants are presented in Table 1. Written  
106 parental consent and participant assent were obtained prior to participation.

### 107 *Procedures*

108 Participants were required to visit the laboratory on two occasions. Anthropometric  
109 measures were completed during the first visit using standardised procedures while children were  
110 wearing light clothing and with shoes removed. BMI ( $\text{kg}/\text{m}^2$ ) was calculated to categorize  
111 participants as normal weight or overweight/obese, according to the 2000 CDC Growth Charts  
112 for the United States (15). Children completed a protocol of 15 semi-structured activities (Table  
113 2) from sedentary (lying down, TV viewing, handheld e-game, writing/coloring, computer  
114 game), light-intensity PA (LPA: getting ready for school, standing class activity, slow walk,  
115 dancing), and MVPA (tidy up, brisk walk, soccer, basketball, running, locomotor course).

116 Activities were equally divided over 2 visits and completed in a structured order of increasing  
117 intensity for 5 min (except for lying down which was done for 10 min).

### 118 *Instrumentation*

119 At each visit, children were fitted with a portable respiratory gas analysis system (MetaMax<sup>®</sup> 3B,  
120 Cortex, Biophysics, Leipzig, Germany) to provide the criterion assessment of PA energy  
121 expenditure. Children were also fitted with a GENEActiv dorsally on the non-dominant wrist.

### 122 Indirect calorimetry

123 Oxygen consumption (O<sub>2</sub>) was assessed using the MetaMax<sup>®</sup> 3B portable breath-by-  
124 breath respiratory gas analysis system to provide the criterion assessment of energy expenditure.  
125 The participants wore a facemask (Hans Rudolph, Kansas City, MO) covering their nose and  
126 mouth, which was held in place by a head harness. Prior to every measurement, the analyser was  
127 calibrated according to the manufacturer's guidelines. Breath-by-breath data from indirect  
128 calorimetry were downloaded and exported using MetaSoft (version 4.3.2).

129

### 130 Activity monitor

131 The GENEActiv has a waterproof design and measures tri-axial accelerations ranging in  
132 magnitude  $\pm 8g$  at a sample frequency ranging from 10-100Hz. Acceleration values are digitized  
133 by a 12-bit analog-to-digital converter. Accelerometers were initialised with a sample frequency  
134 of 100Hz.

135

### 136 *Data reduction*



137 Energy expenditure

138           Volume of O<sub>2</sub> uptake and CO<sub>2</sub> production were averaged per 10s for every entire activity  
139 bout of 5min and converted into units of energy expenditure (kcal·min<sup>-1</sup>) using the Weir equation  
140 (16). For analytical purposes, and for consistency with the calibration studies of the cut-points  
141 (9-11), the activities were categorised in the primary analyses as non-MVPA (<3 METs), MPA  
142 (≥3 to <6 METs) or VPA (≥6 METs) based on average measured energy expenditure values.  
143 MPA and VPA were subsequently combined and classified as MVPA (≥3 METs). The  
144 participants' measured resting energy expenditure (REE) from the lying down trial was used to  
145 define 1 MET in order to calculate MET-values for all activities. Breath-by-breath samples from  
146 the data collected between minutes 7.0 and 9.0 during the lying down trial were averaged to  
147 calculate mean REE. Metabolic data (10s epochs) from the activities were scaled to the  
148 children's REE and converted into youth METs using customized software. Although 3 METs  
149 has widely been used as an intensity threshold to distinguish MPA from LPA, there is  
150 considerable evidence that 4 METs is more accurate for classifying MPA in children and  
151 adolescents (17) and that brisk walking, a key behavioral indicator of MPA, is associated with an  
152 energy cost of approximately 4 METs (18). It should be noted that researchers have based these  
153 estimates on either predicted REE or measured REE. As such, studies have demonstrated that  
154 MET levels for walking and other activities are somewhat contingent on the choice of the  
155 denominator (19, 20). In our sample, the larger value results in ~3 METs for brisk walking as the  
156 behavioural indicator, when based on measured REE (slow walking = 2.9 ± 0.5 METs; brisk  
157 walking = 3.4 ± 0.6 METs) (see Table, Supplemental Digital Content 1, metabolic data by  
158 activities for indirect calorimetry). However, when based on predicted REE, the value was closer  
159 to 4 METs (slow walking = 4.0 ± 0.6 METs; brisk walking = 4.7 ± 0.7 METs), which was

160 consistent with a previous study (comfortable walking =  $3.9 \pm 0.6$  METs; brisk walking =  $4.7 \pm$   
161  $0.6$  METs) (21). Therefore, supplementary analyses were conducted testing the consistency of  
162 the findings using a threshold of 4 METs, for which METs were calculated by dividing mean  
163 energy expenditure values by REE predicted from the participant's sex, age, body mass, and  
164 height using Schofield's (22) equation for children aged 3–10 or 10–18 yr.

165

### 166 Accelerometry

167 Data reduction approaches were performed according to the methods reported in calibration  
168 studies by Hildebrand et al. (11), Phillips et al. (9) and Schaefer et al. (10) for the development of  
169 the three cut-points evaluated. Raw wrist data were downloaded using the GENEActiv software  
170 version 2.2. Signal processing codes from Hildebrand et al. (11) were downloaded and applied to  
171 convert raw acceleration data into 1s epochs according to the Euclidian norm minus one  
172 (ENMO) approach. This method subtracted 1g from the Euclidian norm ( $EN = \sqrt{x^2 + y^2$   
173  $+z^2}$ ), after which negative values were rounded up to zero. According to the methods described  
174 by Phillips et al. (9), raw acceleration data was converted into 1s epochs using the GENEActiv  
175 post processing software, in order to create gravity-subtracted signal vector magnitude (SVMgs)  
176 data. Customized software was developed using the statistical computing language R (v.3.1.2) in  
177 order to apply a band-pass filter to the raw acceleration data (4th order Butterworth filter with  $\omega_0$   
178 = 0.2-15Hz) to remove the gravitational acceleration component as well as high-frequency  
179 sensor noise, as described by Schaefer et al. (10). EN was taken from the three resulting signals  
180 and averaged per 1s epoch. This method is referred to as Bandpass Filtered followed by  
181 Euclidian Norm (BFEN). The methods of the calibration studies resulted in sets of cut-points as  
182 described below in order of increasing acceleration magnitude, and hereafter referred to as:

- 183 • Hildebrand et al. (11), ENMO<sub>192+</sub>: non-dominant wrist; MPA, 192-695 mg; VPA, ≥696  
184 mg.
- 185 • Phillips et al. (9), GENE<sub>A250+</sub>: right wrist; MPA, >275 to ≤700 mg; VPA, >700 mg, left  
186 wrist; MPA, >250 to ≤750 mg; VPA, >750 mg. Calibration procedures for these cut-  
187 points were based on the cumulative sum of gravity-based accelerations measured with a  
188 sample frequency of 80Hz, making the original cut-points frequency dependent (11). For  
189 presentation purposes, the cut-point values were converted from a time dependent unit  
190 (g.seconds) to the time independent unit mg in order to compare with values of other cut-  
191 points.
- 192 • Schaefer et al. (10), BFEN<sub>314+</sub>: non-dominant wrist; MPA, 314-998 mg; VPA, ≥998 mg.

193 The 1s epochs for accelerometry data of all methods were averaged over 10s windows in  
194 order to align with indirect calorimetry data.

195

#### 196 Data synchronization

197 At the beginning of each laboratory visit, the activity monitors and indirect calorimetry  
198 were synchronized with an internal computer clock. After applying the cut-points, predicted  
199 intensity classification for the wrist acceleration data was aligned with the ground truth energy  
200 expenditure data in order to examine classification accuracy. All valid epochs from each activity  
201 trial were included in analyses to reflect how activity monitors are applied under free-living  
202 conditions. Estimated time spent in each PA intensity using indirect calorimetry or wrist  
203 accelerometry was established by summing the 10s epochs classified for each intensity.

204

205 *Statistical analyses*

206 Normality of the data was confirmed prior to analyses. Classification accuracy for each set of  
207 cut-points (MPA, VPA, non-MVPA) was examined by calculating weighted  $\kappa$  statistics. Kappa  
208 coefficients were interpreted using the ratings suggested by Landis and Koch (23): poor (0 –  
209 0.20), fair (0.21 – 0.40), moderate (0.41 – 0.60), substantial (0.61 – 0.80), and almost perfect  
210 (0.81 – 1.0). Contingency tables were applied to summarize classification accuracy and  
211 percentage of misclassified epochs for each intensity. Because of the public health focus on  
212 MVPA, the intensities of MPA and VPA were combined as one dichotomous variable MVPA  
213 and the classification accuracy was evaluated using sensitivity, specificity and area under the  
214 receiver operating characteristic curve (ROC-AUC). ROC-AUC values were defined as excellent  
215 ( $\geq 0.90$ ), good (0.80-0.89), fair (0.70-0.79), or poor ( $< 0.70$ ) (24). The equivalence of time  
216 estimates between the cut-points and indirect calorimetry for each intensity was examined at the  
217 group level using the 95% paired equivalence test. In order to reject the null-hypothesis of the  
218 equivalence test, the 90% confidence interval (CI) of time spent in the intensity predicted by the  
219 monitors should fall entirely within the predefined equivalence region of  $\pm 10\%$  (25).  
220 Measurement agreement and systematic bias for estimated time spent in intensities were  
221 evaluated at the individual level using Bland-Altman procedures (26). Analyses were performed  
222 using the statistical computing language R v.3.1.2 (The R Foundation for Statistical Computing)  
223 and SPSS v.21.0 (IBM Corporation, Armonk NY).

224

225 **Results**

226 All participants completed the protocol. For one of the visits, wrist acceleration data were  
227 unavailable for 3 children. Data from one child were entirely excluded from the analyses and

228 data from 3 participants for a total of 8 activities were excluded because of indirect calorimetry  
229 failure. A total of 25,452 PA intensity annotated 10s epochs (94.4% of the total data) from 57  
230 children were available for analyses.

231 Applying the contingency tables for classification accuracy (Table 3), ENMO<sub>192+</sub> ( $\kappa =$   
232 0.72 [95% confidence interval (CI): 0.72 to 0.73]), GENE<sub>A250+</sub> ( $\kappa = 0.75$  [95% CI: 0.74 to 0.76])  
233 and BFEN<sub>314+</sub> ( $\kappa = 0.73$  [95% CI: 0.72 to 0.74]) exhibited substantial agreement. The proportion  
234 of correctly classified epochs for the BFEN<sub>314+</sub> MPA and VPA cut-points (52.0% and 93.6%,  
235 respectively) was higher than for the ENMO<sub>192+</sub> cut-points (46.5% and 70.0%, respectively) and  
236 the GENE<sub>A250+</sub> cut-points (45.4% and 79.9%, respectively). However, ENMO<sub>192+</sub> and  
237 GENE<sub>A250+</sub> classified non-MVPA (90.5% and 89.2%, respectively) more accurately than BFEN  
238 (81.7%). BFEN misclassified 19.7% of non-MVPA as MPA and 39.4% of MPA as VPA. The  
239 highest proportions of misclassification for ENMO<sub>192+</sub> and GENE<sub>A250+</sub> on the other hand were  
240 found for MPA misclassified as non-MVPA (ENMO<sub>192+</sub>: 32.6% epochs; GENE<sub>A250+</sub>: 26.5%  
241 epochs) and VPA misclassified as MPA (ENMO<sub>192+</sub>: 20.8% epochs; GENE<sub>A250+</sub>: 28.1%  
242 epochs). ENMO<sub>192+</sub> and GENE<sub>A250+</sub> misclassified 25.0% and 19.4% of VPA as MPA.  
243 Classification accuracy for MVPA was good for all cut-points (ROC-AUC: ENMO<sub>192+</sub>, 0.85  
244 [95% CI: 0.85 to 0.86]; GENE<sub>A250+</sub>, 0.85 [95% CI: 0.85 to 0.86]; BFEN<sub>314+</sub>, 0.86 [95% CI: 0.86  
245 to 0.87]). Although the true-positive rate (sensitivity) for BFEN<sub>314+</sub> (0.94) was higher than for  
246 ENMO<sub>192+</sub> (0.80) and GENE<sub>A250+</sub> (0.81), specificity for BFEN<sub>314+</sub> was lower (0.78) compared to  
247 ENMO<sub>192+</sub> (0.90) and GENE<sub>A250+</sub> (0.89).

248 At the group level, estimated time spent in MPA was equivalent ( $p < 0.01$ ) to indirect  
249 calorimetry for BFEN<sub>314+</sub> and estimated time spent in MVPA was equivalent for ENMO<sub>192+</sub> and  
250 GENE<sub>A250+</sub> (Figure 1). Outcomes of the Bland-Altman analyses are presented in Table 4.

251 BFEN<sub>314+</sub> overestimated time spent in MPA by a small margin of 1.5% (limits of agreement  
252 [LoA]: -57.5% – 60.6%), whereas ENMO<sub>192+</sub> and GENE<sub>A250+</sub> overestimated time spent in MPA  
253 by 30.1% (LoA: -99.6% – 39.4%) and 31.0% (LoA: -104.1% – 42.0%), respectively.  
254 Overestimation of time spent in VPA was larger for BFEN<sub>314+</sub> (92.2% [LoA: -54.6% – 238.9%])  
255 compared to ENMO<sub>192+</sub> (58.5% [LoA: -127.4% – 244.5%]) and GENE<sub>A250+</sub> (75.2% [LoA: -  
256 91.8% – 242.2%]). Mean bias for time spent in MVPA was small for ENMO<sub>192+</sub> (-1.1% [LoA: -  
257 55.9% – 53.7%]) and GENE<sub>A250+</sub> (2.2% [LoA: -52.2% – 56.5%]), whereas time spent MVPA  
258 was overestimated by BFEN<sub>314+</sub> to a larger extent (29.3% [LoA: -25.3% – 83.9%]). At the  
259 individual level, LoAs were wide for all cut-points and for all intensities, especially for VPA  
260 estimates from all cut-points and for MPA estimates from the ENMO<sub>192+</sub> and GENE<sub>A250+</sub>.  
261 Systematic bias ( $p < 0.05$ ) was found for time spent in all intensities estimated by all cut-points,  
262 with the exceptions of time spent in MPA estimated by BFEN<sub>314+</sub> and GENE<sub>A250+</sub>, indicating  
263 that errors increased with increasing time spent in the intensities.

264       Supplementary analyses (see Tables and Figure, Supplemental Digital Content 2,  
265 supplementary analyses for the raw wrist acceleration cut-points using a  $\geq 4$ -MET MVPA  
266 definition) indicated that classification accuracy for MPA, VPA and non-MVPA remained  
267 similar when 1 MET was defined using predicted REE and a 4-MET threshold for MPA was  
268 applied to the data (ENMO<sub>192+</sub>,  $\kappa = 0.65$  [95% CI: 0.64 to 0.66], GENE<sub>A250+</sub>,  $\kappa = 0.71$  [95% CI:  
269 0.70 to 0.72], BFEN<sub>314+</sub>,  $\kappa = 0.75$  [95% CI: 0.74 to 0.76]). Although ROC-AUC values for  
270 MVPA (ENMO<sub>192+</sub>, 0.85 [95% CI: 0.85 to 0.86]; GENE<sub>A250+</sub>, 0.86 [95% CI: 0.85 to 0.86];  
271 BFEN<sub>314+</sub>, 0.87 [95% CI: 0.87 to 0.88]) were similar to the primary analyses, slightly more non-  
272 MVPA epochs were correctly classified (see Table, Supplemental Digital Content 2.1,  
273 contingency tables for classification accuracy of raw wrist acceleration cut-points using a  $\geq 4$ -

274 MET MVPA definition). Although time spent in MVPA estimated by ENMO<sub>192+</sub> and  
275 GENE<sub>A250+</sub> using the  $\geq 4$ -MET MVPA definition was not equivalent to indirect calorimetry as  
276 they were in the primary analyses, the means and/or 90% CIs for estimated time spent in MPA  
277 and MVPA for ENMO<sub>192+</sub> and GENE<sub>A250+</sub> overlapped the equivalence region and thus  
278 approached equivalence. BFEN<sub>314+</sub> overestimated time spent in MVPA for both the 3-MET (1  
279 MET = measured REE) approach (29.3% [LoA: -25.3% – 83.9%]) and the 4-MET (1 MET =  
280 predicted REE) approach (18.3% [LoA: -13.5% - 50.2%]) (see Table, Supplemental Digital  
281 Content 2.2, agreement analysis of raw wrist acceleration-based estimations of physical activity  
282 intensities compared to indirect calorimetry using a  $\geq 4$ -MET MVPA definition). Time spent in  
283 MPA estimated by BFEN<sub>314+</sub> was no longer equivalent to the criterion measure, whereas time  
284 spent in VPA was ( $p < 0.01$ ) (see Figure, Supplemental Digital Content 2.3, 95% equivalence test  
285 for raw wrist acceleration-based estimated time spent in physical activity intensities using a  $\geq 4$ -  
286 MET MVPA definition). In contrast, when defining MVPA as  $\geq 4$ -METs, fewer MPA epochs  
287 were misclassified by BFEN<sub>314+</sub> as VPA compared to the 3-MET approach, however more VPA  
288 epochs were misclassified as MPA. The overestimation of time spent in VPA from BFEN<sub>314+</sub>  
289 was small for the 4-MET approach (0.5% [LoA: -39.7% – 40.6%]), whereas overestimation of  
290 time spent in MPA for BFEN<sub>314+</sub> was larger (34.4% [LoA: -20.4% – 89.1%]). At the individual  
291 level, errors for all cut-points were decreased for time spent in VPA when using the 4-MET  
292 approach, but increased for time spent in MPA, compared to outcomes from the 3-MET  
293 approach.

294

## 295 **Discussion**

296 Current international PA guidelines specify that children should accumulate a minimum  
297 of 60 minutes per day of MVPA (27). Therefore, the accurate measurement of MVPA is central  
298 to understanding the prevalence and patterns of PA, the dose of PA required to achieve health  
299 benefits, the determinants of PA, and the effect of PA interventions for children, which typically  
300 target MVPA. This study simultaneously cross-validated three previously published wrist  
301 acceleration cut-points for the classification of MVPA in children. ENMO<sub>192+</sub>, GENE<sub>A250+</sub> and  
302 BFEN<sub>314+</sub> demonstrated good classification accuracy for MVPA. However, while time spent in  
303 MVPA estimated by ENMO<sub>192+</sub> and GENE<sub>A250+</sub> were equivalent to indirect calorimetry,  
304 misclassification of non-MVPA as MVPA resulted in an overestimation of time spent in MVPA  
305 for BFEN<sub>314+</sub>. Although ENMO<sub>192+</sub> and GENE<sub>A250+</sub> classified non-MVPA more accurately than  
306 BFEN<sub>314+</sub>, these cut-points still misclassified a significant proportion of MVPA epochs as non-  
307 MVPA (37.6% and 27.2%, respectively). Findings were relatively consistent in supplementary  
308 analyses, where predicted REE was used to define 1 MET and MVPA was defined as  $\geq 4$  METs.  
309 The classification accuracy of MPA, VPA and MVPA remained relatively similar for all cut-  
310 points compared to previous analyses and, although time spent in MVPA estimated by  
311 ENMO<sub>192+</sub> and GENE<sub>A250+</sub> were no longer equivalent to indirect calorimetry, estimates  
312 approached equivalence.

313 Findings from the current study were similar to findings in previous independent cross-  
314 validation studies, which demonstrated good classification accuracy for MVPA estimates from  
315 raw acceleration wrist cut-points (10, 12), and that classification for VPA is generally higher  
316 than for MPA (10-12). Even though classification of MPA, VPA and MVPA was most accurate  
317 for BFEN<sub>314+</sub>, ENMO<sub>192+</sub> and GENE<sub>A250+</sub> estimated time spent in MVPA more accurately than  
318 BFEN<sub>314+</sub>. Time spent in MVPA was overestimated by BFEN<sub>314+</sub> because a relatively large



319 proportion (19.7%) of non-MVPA was misclassified as MPA, which was in agreement with  
320 Schaefer et al.'s (10) application in free-living individuals. This misclassification could be  
321 explained by activities of light intensity that involve vigorous wrist movements. For example,  
322 BFEN<sub>314+</sub> misclassified 66.4% of non-MVPA as MPA during the non-MVPA activity "Getting  
323 ready for school" (see Table, Supplemental Digital Content 3, confusion matrices for the raw  
324 wrist acceleration cut-points using a  $\geq 3$ -MET MVPA definition), an activity of low intensity that  
325 involved relatively high wrist motion (e.g., while getting dressed, packing a schoolbag, brushing  
326 hair etc.) The opposite effect may occur when MVPA activities involve limited wrist movement.  
327 As such, the ENMO<sub>192+</sub> and GENE<sub>A250+</sub> misclassified 82.3% and 77.1%, respectively, of MPA  
328 as non-MVPA during "Tidy up", an activity of MPA intensity that may have involved limited  
329 upper body and wrist motions due to carrying objects while walking. Because of the public  
330 health focus on MVPA, misclassification by wrist cut-points of MPA as VPA and vice-versa  
331 may not represent a major measurement limitation. However, increased interest among  
332 researchers in the influence of sedentary behaviors, defined as any waking behaviors in a sitting  
333 or reclining position that require an energy expenditure of  $\leq 1.5$  METs (28), and light physical  
334 activity (1.5 to  $< 3.0$  METs), on health makes it critical to discriminate between these behaviors  
335 and MVPA. Previous studies indicate that accurate assessment of sedentary behaviors and the  
336 number of breaks in sedentary time based on a lack of wrist movement is challenging (11, 29,  
337 30). The findings from this study confirm that the use of the magnitude of acceleration only  
338 might not be effective in distinguishing MVPA from non-MVPA. This finding is relatively  
339 consistent with previous studies using cut-points based on proprietary activity "counts" (31-33).  
340 This is likely because the association between counts or raw acceleration and energy  
341 expenditure, whether on the hip or wrist, differs for different types of physical activities,

342 resulting in cut-points performing well for some activities and demonstrating considerable  
343 misclassification during other activities. It should be noted that the benefit of using raw  
344 acceleration-based cut-points over using count-based cut-points remains unclear, as in general  
345 cut-points result in misclassification, which was also demonstrated by the results in this study for  
346 all cut-points. Therefore, progress on alternative approaches, such as those utilizing machine  
347 learning (29, 33, 34), may be required. However, similar to the inconsistencies that occur  
348 because of the existence of multiple cut-points, the existence of different machine learning  
349 approaches and models, such as artificial neural networks (35), decision trees (36) and hidden  
350 Markov models (37), presents further challenges and evidence to reach consensus on the most  
351 accurate approach for categorizing physical activity intensities in children is required.

352         An additional limitation of the wrist cut-points validated in the current study is that  
353 calibration studies used different processing methodologies. While Schaefer et al. (10) used a  
354 filtering approach to remove static accelerations from the tri-axial data, Hildebrand et al. (11)  
355 and Phillips et al. (9) subtracted the value of gravity from the vector magnitude, in order to focus  
356 the outcome variable on dynamic rather than static accelerations. Hildebrand et al. (11) used the  
357 ENMO method, which rounds negative values, resulting from subtracting the vector magnitude  
358 by 1g, up to zero. Phillips et al. (9) on the other hand, replaced the negative values with their  
359 absolute values and summed the resulting values, which creates a dependency on sample  
360 frequency, and thus the cut-points should be converted when using different sample frequencies  
361 in order to compare results across studies. The ENMO<sub>192+</sub> and BFEN<sub>314+</sub> were developed using  
362 averaged acceleration magnitudes and can be used for different sample frequencies and epoch  
363 lengths. The different processing methods also resulted in different units for the outcomes;  
364 Hildebrand et al. (11) and Schaefer et al. (10) used gravity units in g and mg, respectively,

365 whereas Phillips et al. (9) used gravity-based acceleration seconds. Taking all of this into account  
366 makes it complicated to compare results from the different cut-points and, as the field progresses,  
367 it is important that procedures are standardized based on evidence. Furthermore, some data  
368 indicate that raw acceleration output from the GENEActiv and ActiGraph may differ in children  
369 during common activities (11). This is likely because manufacturer specific transformations (e.g.  
370 filtering) are applied to the raw acceleration data, resulting in different outputs from different  
371 devices that may not be a representation of the actual raw acceleration signals (38). As such, our  
372 findings may only apply to the GENEActiv monitor and further evaluation across different  
373 monitor brands is required.

374         A strength of this study was that three recently developed sets of raw wrist acceleration  
375 cut-points were evaluated simultaneously, against a criterion measure. The study included a  
376 broad age range and an equal distribution of age and sex across the sample. Additionally, a range  
377 of tasks, beyond treadmill-based ambulatory activities, that are likely to resemble children's free-  
378 living behaviors were included in the protocol. Although these activities reflect daily activities  
379 that children typically engage in, the findings of the present study should be confirmed under  
380 free-living conditions. A potential limitation of this study is that validation focused on MVPA  
381 and did not include light PA or sedentary behavior. Our previous cross-validation study (29) of  
382 sedentary cut-points demonstrated that, while hip-based cut-points typically misclassify light  
383 activities (e.g. standing still) as sedentary postures, wrist cut-points exhibit some  
384 misclassification of non-sedentary behaviors as sedentary and vice-versa. Therefore, it is  
385 essential to apply the most accurate intensity specific cut-points for accurate estimates of  
386 sedentary behaviors and light intensity PA. However, in order to investigate the accuracy of cut-  
387 points for distinguishing sedentary behaviors from light intensity PA, postures such as sitting and

388 standing should be evaluated. This is typically performed using alternative criterion measures,  
389 such as direct observation, as described in our previous work (39). Another potential limitation is  
390 that acceleration signals were not calibrated to local gravity before analysis in order to minimize  
391 sensor calibration errors, as described by van Hees et al. (40). Furthermore, body accelerations  
392 and metabolic rate during the exercise bouts may not have been aligned due to lags in oxygen  
393 consumption, and true classification accuracy may have been underestimated. However, this data  
394 reduction approach reflects how cut-points are used in free-living population studies and,  
395 because the approach was applied consistently across cut-points, one cut-point was not biased  
396 over the other.

397 In conclusion, although raw acceleration wrist cut-points exhibited good accuracy for  
398 classifying MVPA in children, all cut-points misclassified a significant proportion of MVPA  
399 epochs as non-MVPA. While the cut-points demonstrated acceptable estimates of time spent in  
400 MPA, VPA, and MVPA at the group level, their application was less accurate for individual  
401 measures. When combined with the practical advantages of wrist worn placement, surveillance  
402 application of the raw wrist acceleration cut-points would be acceptable for group level estimates  
403 of MVPA, although alternative data processing approaches such as machine learning methods  
404 may be needed to achieve a generally higher accuracy for the assessment of PA intensities  
405 among individual children.

406

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418

#### 419 **Conflict of Interest**

420 The authors have no conflict of interest to declare. The results of the present study do not  
421 constitute endorsement by the American College of Sports Medicine. The results are presented  
422 clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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531

532

**Table 1** Participant characteristics

| <b>Characteristics</b>  |              |
|-------------------------|--------------|
| <b>Age (y)</b>          | 9.2 ± 2.3    |
| <b>Sex</b>              |              |
| Boys ( <i>n</i> )       | 28 (49.1%)   |
| Girls ( <i>n</i> )      | 29 (50.9%)   |
| <b>Height (cm)</b>      | 135.9 ± 14.6 |
| <b>Body mass (kg)</b>   | 32.7 ± 10.9  |
| <b>BMI percentile</b>   | 53.2 ± 28.6  |
| Overweight ( <i>n</i> ) | 7 (12.3%)    |
| Obese ( <i>n</i> )      | 2 (3.5%)     |
| <b>Age distribution</b> |              |
| 5-7 ( <i>n</i> =19)     | 33.3%        |
| 8-10 ( <i>n</i> =24)    | 42.1%        |
| 11-12 ( <i>n</i> =14)   | 24.6%        |
| <b>Race</b>             |              |
| Caucasian ( <i>n</i> )  | 54 (94.7%)   |
| Asian ( <i>n</i> )      | 3 (5.3%)     |

533 Characteristics of the participants are presented as mean ± SD, distributions of the sample are  
534 presented in percentages. Weight status was classified according to the 2000 Centers for Disease  
535 Control and Prevention Growth Charts for the United States (11).

| <b>Activity Type</b> | <b>Activity Trial</b>    | <b>Intensity</b> | <b>Description of Activity Trial</b>  |
|----------------------|--------------------------|------------------|---|
| Resting              | Lying down               | Sedentary        | Lying down awake on a mattress in supine position - arms at sides - rest for 10 min.  |
| Sitting              | TV viewing               | Sedentary        | Watching a movie in a comfortable chair. Instructed to minimize body movements.   |
|                      | Handheld e-game          | Sedentary        | Sitting on a chair at a desk playing an e-game on a handheld device.  |
|                      | Writing/coloring         | Sedentary        | Sitting on a chair at a desk, 5-8 y: coloring on paper using pencils, 9-12 y: copying words on a pad of paper using a pencil.   |
|                      | Computer game            | Sedentary        | Sitting on a chair at a desk playing an educational computer game.  |
| Lifestyle            | Getting ready for school | Light            | Get dressed, set table, pour food, pack up, brush teeth, pack bag, leave for school.  |
|                      | Standing class activity  | Light            | Standing activities with minimal movement such as writing/drawing on a white board.   |
|                      | Dancing                  | Light            | Following a video with dance step instructions (Zumba® fitness).  |
|                      | Tidy up                  | Moderate         | Tidying up a 4x5 m area: pick up clothes, towels, toys and sport equipment and return them into boxes.  |
|                      | Basketball               | Moderate         | Shooting a basketball using a 2.29 m adjustable hoop, chase the ball within a 4.9x4.6 m area and bounce back to the start position at the boundary line apposite from the hoop.                     |
|                      | Soccer                   | Vigorous         | Kicking a foam soccer ball on a 5 m distance between a 1 m wide goal after dodging between a straight line of 5 cones (1 m apart). Instructed to jog back to start position after kicking the ball. |
|                      | Locomotor course         | Vigorous         | Continuously completing a course including 4x 2-foot jump, jogging and sliding between cones around a 4x9.5 m area.   |
| Ambulatory           | Slow walk                | Light            | Walking slowly at a self-selected comfortable speed around a 45 m indoor track. Examiner regulates constant speed by recording lap times.   |
|                      | Brisk walk               | Moderate         | Walking briskly at a self-selected brisk comfortable speed around a 45 m indoor track. Examiner regulates constant speed by recording lap times.  |
|                      | Running                  | Vigorous         | Run at a self-selected comfortable speed around a 45 m indoor track. Examiner regulates constant pace by speed lap times.   |

537 All activities are completed for 5 min, except from lying down (10 min)

538 **Table 3.** Contingency tables for classification accuracy of raw wrist acceleration cut-points

| Actual Intensity      | Cut-points classification of intensity |                    |                    |
|-----------------------|--|--------------------|--------------------|
|                       | 1                                      | 2                  | 3                  |
| ENMO <sub>192+</sub>  |  |                    |                    |
| 1. non-MVPA           | <b>14418 (90.5)</b>                    | 1312 (8.2)         | 193 (1.2)          |
| 2. MPA                | 2217 (32.6)                            | <b>3160 (46.5)</b> | 1416 (20.8)        |
| 3. VPA                | 138 (5.0)                              | 684 (25.0)         | <b>1914 (70.0)</b> |
| GENEA <sub>250+</sub> |  |                    |                    |
| 1. non-MVPA           | <b>14208 (89.2)</b>                    | 1493 (9.4)         | 222 (1.4)          |
| 2. MPA                | 1802 (26.5)                            | <b>3081 (45.4)</b> | 1910 (28.1)        |
| 3. VPA                | 20 (0.7)                               | 531 (19.4)         | <b>2185 (79.9)</b> |
| BFEN <sub>314+</sub>  |  |                    |                    |
| 1. non-MVPA           | <b>12448 (78.2)</b>                    | 3130 (19.7)        | 345 (2.2)          |
| 2. MPA                | 580 (8.5)                              | <b>3535 (52.0)</b> | 2678 (39.4)        |
| 3. VPA                | 8 (0.3)                                | 167 (6.1)          | <b>2561 (93.6)</b> |

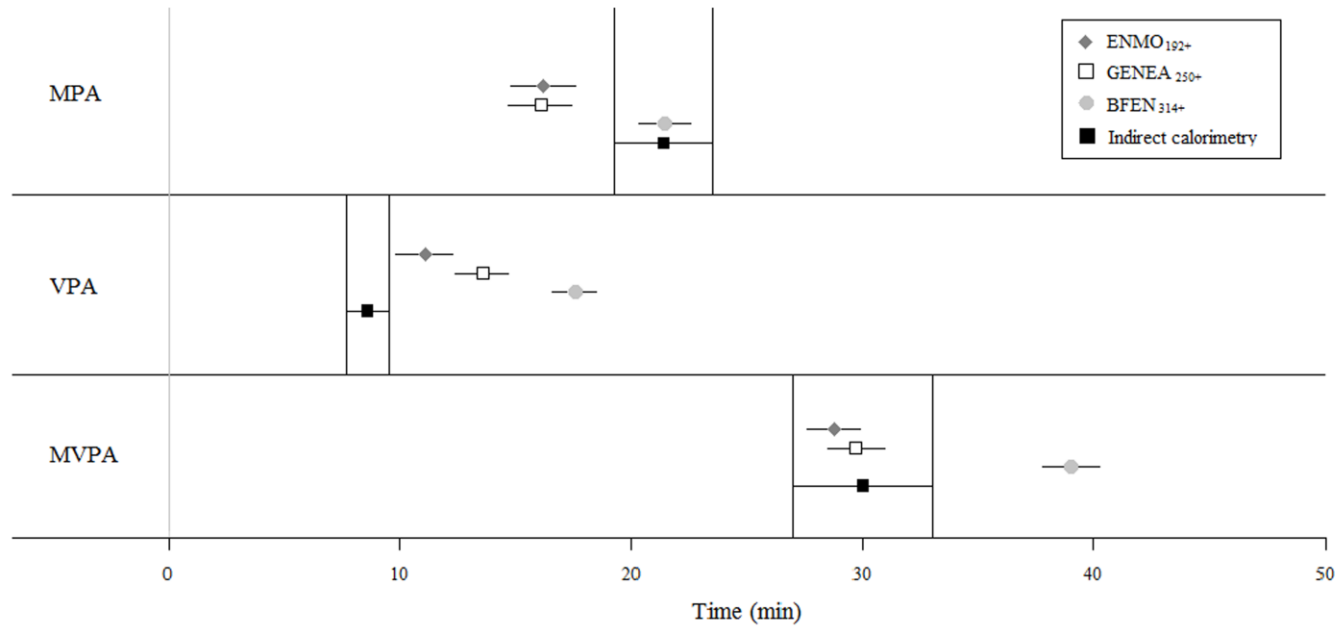
539 The presented values indicate the proportion of epochs classified for each intensity, with  
540 percentages presented between brackets. The values in boldface indicate the proportion of  
541 epochs correctly classified for the physical activity intensity. MPA: moderate physical activity;  
542 VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-  
543 points developed using Euclidian norm minus one; GENEActiv: cut-points developed using the  
544 GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered  
545 followed by Euclidian Norm.

546 **Table 4.** Agreement analysis of raw wrist acceleration-based estimations of physical activity  
 547 intensities compared to indirect calorimetry.

| <b>Intensity</b>            | <b>Mean bias (%)</b> | <b>Limits of agreement</b> | <b>p-value slope</b> |
|-----------------------------|----------------------|----------------------------|----------------------|
| <b>ENMO<sub>192+</sub></b>  |                      |                            |                      |
| <i>MPA</i>                  | 30.1                 | -39.4 – 99.6               | 0.04                 |
| <i>VPA</i>                  | -58.5                | -244.5 – 127.4             | 0.00                 |
| <i>MVPA</i>                 | 1.1*                 | -53.7 – 55.9               | 0.00                 |
| <b>GENEA<sub>250+</sub></b> |                      |                            |                      |
| <i>MPA</i>                  | 31.0                 | -42.0 – 104.1              | 0.05                 |
| <i>VPA</i>                  | -75.2                | -242.2 – 91.8              | 0.00                 |
| <i>MVPA</i>                 | -2.2*                | -56.5 – 52.2               | 0.00                 |
| <b>BFEN<sub>314+</sub></b>  |                      |                            |                      |
| <i>MPA</i>                  | -1.5*                | -60.6 – 57.5               | 0.28                 |
| <i>VPA</i>                  | -92.2                | -238.9 – 54.6              | 0.00                 |
| <i>MVPA</i>                 | -29.3                | -83.9 – 25.3               | 0.00                 |

548 ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed  
 549 using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass  
 550 Filtered followed by Euclidian Norm. Mean bias was calculated as: measured intensity time –  
 551 estimated intensity time; a positive value indicates underestimation; a negative value indicates  
 552 overestimation. \*Significantly equivalent to indirect calorimetry ( $p < 0.05$ ).

**Figure 1** The 95% equivalence test for raw wrist acceleration-based estimated time spent in physical activity intensities



Times estimated by wrist-worn cut-points are equivalent to indirect calorimetry if 90% confidence intervals lie entirely within the equivalence region of indirect calorimetry. ENMO: cut-points developed using Euclidian norm minus one; GENE A: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

**Supplemental Digital Content 1. Metabolic data by activities for indirect calorimetry**

| <b>Activity</b>          | <b>n</b> | <b>kcal/min</b> | <b>Min - Max</b> | <b>L/min</b> | <b>Min - Max</b> | <b>ml/kg/min</b> | <b>Min - Max</b> | <b>METs</b> | <b>Min - Max</b> |
|--------------------------|----------|-----------------|------------------|--------------|------------------|------------------|------------------|-------------|------------------|
| <i>REE</i>               |          |                 |                  |              |                  |                  |                  |             |                  |
| 5-12y                    | 56       | 1.19 ± 0.24     | 0.81 - 2.15      | 0.24 ± 0.05  | 0.17 - 0.42      | 7.89 ± 1.80      | 3.59 - 12.09     | -           | -                |
| 5-9y                     | 31       | 1.06 ± 0.13     | 0.81 - 1.31      | 0.22 ± 0.03  | 0.17 - 0.27      | 8.57 ± 1.71      | 5.78 - 12.09     | -           | -                |
| 10-12y                   | 25       | 1.35 ± 0.26     | 0.91 - 2.15      | 0.28 ± 0.05  | 0.19 - 0.42      | 7.05 ± 1.57      | 3.59 - 10.18     | -           | -                |
| <i>TV viewing</i>        |          |                 |                  |              |                  |                  |                  |             |                  |
| 5-12y                    | 56       | 1.24 ± 0.25     | 0.83 - 2.08      | 0.26 ± 0.05  | 0.17 - 0.43      | 8.29 ± 1.73      | 5.68 - 12.98     | 1.09 ± 0.16 | 0.84 - 1.81      |
| 5-9y                     | 31       | 1.12 ± 0.16     | 0.83 - 1.50      | 0.23 ± 0.03  | 0.17 - 0.31      | 9.10 ± 1.61      | 5.95 - 12.98     | 1.10 ± 0.14 | 0.84 - 1.56      |
| 10-12y                   | 25       | 1.39 ± 0.27     | 0.92 - 2.08      | 0.29 ± 0.06  | 0.19 - 0.43      | 7.28 ± 1.31      | 5.68 - 10.87     | 1.08 ± 0.18 | 0.90 - 1.81      |
| <i>Computer game</i>     |          |                 |                  |              |                  |                  |                  |             |                  |
| 5-12y                    | 56       | 1.28 ± 0.25     | 0.67 - 1.78      | 0.27 ± 0.05  | 0.14 - 0.38      | 8.55 ± 1.80      | 5.39 - 12.10     | 1.13 ± 0.18 | 0.75 - 1.83      |
| 5-9y                     | 31       | 1.17 ± 0.19     | 0.67 - 1.50      | 0.24 ± 0.04  | 0.14 - 0.31      | 9.50 ± 1.64      | 5.70 - 12.10     | 1.15 ± 0.17 | 0.75 - 1.54      |
| 10-12y                   | 25       | 1.41 ± 0.26     | 0.96 - 1.78      | 0.29 ± 0.06  | 0.19 - 0.38      | 7.38 ± 1.23      | 5.39 - 9.56      | 1.10 ± 0.20 | 0.75 - 1.83      |
| <i>Handheld e-game</i>   |          |                 |                  |              |                  |                  |                  |             |                  |
| 5-12y                    | 55       | 1.36 ± 0.25     | 0.85 - 2.24      | 0.28 ± 0.05  | 0.18 - 0.46      | 9.12 ± 2.18      | 5.93 - 14.17     | 1.19 ± 0.18 | 0.93 - 1.90      |
| 5-9y                     | 30       | 1.25 ± 0.17     | 0.85 - 1.70      | 0.26 ± 0.04  | 0.18 - 0.35      | 10.27 ± 2.10     | 5.99 - 14.17     | 1.22 ± 0.16 | 0.94 - 1.50      |
| 10-12y                   | 25       | 1.49 ± 0.28     | 0.94 - 2.24      | 0.31 ± 0.06  | 0.19 - 0.46      | 7.79 ± 1.37      | 5.93 - 11.07     | 1.16 ± 0.20 | 0.93 - 1.90      |
| <i>Writing/Coloring</i>  |          |                 |                  |              |                  |                  |                  |             |                  |
| 5-12y                    | 55       | 1.44 ± 0.28     | 0.91 - 2.18      | 0.30 ± 0.06  | 0.19 - 0.45      | 9.71 ± 2.25      | 5.41 - 15.99     | 1.27 ± 0.22 | 0.94 - 2.26      |
| 5-9y                     | 30       | 1.33 ± 0.20     | 0.91 - 1.82      | 0.28 ± 0.04  | 0.19 - 0.38      | 10.86 ± 2.11     | 7.12 - 15.99     | 1.30 ± 0.17 | 1.01 - 1.78      |
| 10-12y                   | 25       | 1.58 ± 0.30     | 1.08 - 2.18      | 0.33 ± 0.06  | 0.22 - 0.45      | 8.28 ± 1.47      | 5.41 - 12.07     | 1.24 ± 0.26 | 0.94 - 2.26      |
| <i>Standing activity</i> |          |                 |                  |              |                  |                  |                  |             |                  |
| 5-12y                    | 56       | 1.70 ± 0.34     | 1.15 - 2.77      | 0.35 ± 0.07  | 0.24 - 0.57      | 11.34 ± 2.25     | 7.66 - 16.45     | 1.50 ± 0.23 | 1.11 - 2.58      |
| 5-9y                     | 31       | 1.53 ± 0.24     | 1.15 - 2.06      | 0.32 ± 0.05  | 0.24 - 0.43      | 12.41 ± 2.07     | 8.85 - 16.45     | 1.50 ± 0.19 | 1.20 - 1.85      |
| 10-12y                   | 25       | 1.90 ± 0.34     | 1.32 - 2.77      | 0.40 ± 0.07  | 0.28 - 0.57      | 10.02 ± 1.71     | 7.66 - 13.03     | 1.49 ± 0.27 | 1.11 - 2.58      |



|                         |    |             |              |             |             |              |               |             |              |
|-------------------------|----|-------------|--------------|-------------|-------------|--------------|---------------|-------------|--------------|
| <i>Getting ready</i>    |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 56 | 2.81 ± 0.63 | 1.64 - 4.32  | 0.59 ± 0.13 | 0.33 - 0.92 | 18.64 ± 3.07 | 13.06 - 24.90 | 2.49 ± 0.45 | 1.67 - 4.01  |
| 5-9y                    | 31 | 2.52 ± 0.48 | 1.64 - 3.42  | 0.53 ± 0.10 | 0.33 - 0.71 | 20.17 ± 2.04 | 15.09 - 24.35 | 2.48 ± 0.44 | 1.67 - 3.23  |
| 10-12y                  | 25 | 3.18 ± 0.59 | 1.98 - 4.32  | 0.66 ± 0.13 | 0.42 - 0.92 | 16.75 ± 3.11 | 13.06 - 24.90 | 2.50 ± 0.48 | 1.73 - 4.01  |
| <i>Slow Walk</i>        |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 56 | 3.26 ± 0.66 | 2.28 - 4.93  | 0.68 ± 0.14 | 0.46 - 1.04 | 21.80 ± 3.86 | 15.05 - 33.44 | 2.90 ± 0.50 | 1.92 - 4.45  |
| 5-9y                    | 31 | 2.97 ± 0.47 | 2.28 - 4.61  | 0.62 ± 0.10 | 0.46 - 0.97 | 24.04 ± 3.24 | 16.40 - 33.44 | 2.92 ± 0.42 | 2.31 - 3.95  |
| 10-12y                  | 25 | 3.62 ± 0.70 | 2.43 - 4.93  | 0.76 ± 0.15 | 0.51 - 1.04 | 19.02 ± 2.55 | 15.05 - 25.17 | 2.87 ± 0.60 | 1.92 - 4.45  |
| <i>Dancing</i>          |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 55 | 3.53 ± 1.22 | 1.85 - 6.78  | 0.73 ± 0.25 | 0.39 - 1.39 | 22.77 ± 3.85 | 15.22 - 32.12 | 3.09 ± 0.85 | 1.70 - 5.26  |
| 5-9y                    | 31 | 2.98 ± 0.93 | 1.85 - 5.78  | 0.62 ± 0.19 | 0.39 - 1.22 | 23.45 ± 3.94 | 15.22 - 31.45 | 2.91 ± 0.82 | 1.70 - 5.15  |
| 10-12y                  | 24 | 4.24 ± 1.21 | 2.43 - 6.78  | 0.88 ± 0.25 | 0.50 - 1.39 | 21.90 ± 3.62 | 16.27 - 32.12 | 3.32 ± 0.86 | 2.12 - 5.26  |
| <i>Brisk Walk</i>       |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 56 | 3.88 ± 0.95 | 2.51 - 6.45  | 0.80 ± 0.19 | 0.51 - 1.30 | 25.34 ± 4.05 | 17.62 - 37.96 | 3.38 ± 0.63 | 2.26 - 5.83  |
| 5-9y                    | 31 | 3.41 ± 0.61 | 2.51 - 5.12  | 0.70 ± 0.12 | 0.51 - 1.05 | 27.13 ± 3.66 | 21.12 - 37.96 | 3.29 ± 0.44 | 2.63 - 4.42  |
| 10-12y                  | 25 | 4.47 ± 0.99 | 2.99 - 6.45  | 0.92 ± 0.20 | 0.63 - 1.30 | 23.12 ± 3.41 | 17.62 - 29.10 | 3.49 ± 0.81 | 2.26 - 5.83  |
| <i>Tidy up</i>          |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 55 | 4.07 ± 1.16 | 2.21 - 7.05  | 0.85 ± 0.24 | 0.45 - 1.49 | 26.31 ± 3.84 | 19.72 - 36.75 | 3.57 ± 0.84 | 2.14 - 7.42  |
| 5-9y                    | 30 | 3.52 ± 0.85 | 2.21 - 6.01  | 0.73 ± 0.18 | 0.45 - 1.26 | 27.72 ± 3.84 | 20.73 - 36.75 | 3.42 ± 0.65 | 2.14 - 4.71  |
| 10-12y                  | 25 | 4.74 ± 1.15 | 2.73 - 7.05  | 0.99 ± 0.24 | 0.58 - 1.49 | 24.63 ± 3.16 | 19.72 - 30.61 | 3.75 ± 1.02 | 2.79 - 7.42  |
| <i>Running</i>          |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 56 | 6.66 ± 2.12 | 2.76 - 11.61 | 1.36 ± 0.44 | 0.57 - 2.46 | 42.18 ± 6.99 | 21.05 - 59.34 | 5.68 ± 1.34 | 2.85 - 10.41 |
| 5-9y                    | 31 | 5.28 ± 1.21 | 2.76 - 7.18  | 1.08 ± 0.25 | 0.57 - 1.46 | 41.59 ± 8.07 | 21.05 - 59.34 | 5.05 ± 1.01 | 2.85 - 6.96  |
| 10-12y                  | 25 | 8.37 ± 1.73 | 5.18 - 11.61 | 1.72 ± 0.36 | 1.06 - 2.46 | 42.92 ± 5.43 | 33.05 - 52.75 | 6.47 ± 1.30 | 4.09 - 10.41 |
| <i>Locomotor course</i> |    |             |              |             |             |              |               |             |              |
| 5-12y                   | 54 | 7.14 ± 2.28 | 2.68 - 12.17 | 1.47 ± 0.47 | 0.56 - 2.54 | 45.16 ± 7.63 | 10.08 - 62.81 | 6.05 ± 1.20 | 2.81 - 8.22  |

|                   |    |             |              |             |             |              |               |             |              |
|-------------------|----|-------------|--------------|-------------|-------------|--------------|---------------|-------------|--------------|
| 5-9y              | 29 | 5.87 ± 1.34 | 3.88 - 9.62  | 1.20 ± 0.27 | 0.78 - 1.94 | 45.43 ± 5.68 | 37.06 - 60.59 | 5.58 ± 0.91 | 3.82 - 7.26  |
| 10-12y            | 25 | 8.62 ± 2.26 | 2.68 - 12.17 | 1.78 ± 0.47 | 0.56 - 2.54 | 44.85 ± 9.52 | 10.08 - 62.81 | 6.59 ± 1.28 | 2.81 - 8.22  |
| <i>Soccer</i>     |    |             |              |             |             |              |               |             |              |
| 5-12y             | 55 | 7.21 ± 2.08 | 3.53 - 12.76 | 1.47 ± 0.44 | 0.73 - 2.73 | 46.23 ± 7.06 | 35.19 - 70.82 | 6.22 ± 1.42 | 3.48 - 12.28 |
| 5-9y              | 31 | 6.05 ± 1.41 | 3.53 - 10.13 | 1.23 ± 0.29 | 0.73 - 2.04 | 47.03 ± 6.27 | 36.63 - 64.26 | 5.78 ± 1.18 | 3.48 - 7.67  |
| 10-12y            | 24 | 8.70 ± 1.87 | 5.99 - 12.76 | 1.79 ± 0.40 | 1.20 - 2.73 | 45.19 ± 7.99 | 35.19 - 70.82 | 6.77 ± 1.53 | 4.29 - 12.28 |
| <i>Basketball</i> |    |             |              |             |             |              |               |             |              |
| 5-12y             | 54 | 6.64 ± 2.15 | 3.27 - 11.65 | 1.36 ± 0.44 | 0.66 - 2.33 | 41.44 ± 5.99 | 28.83 - 54.42 | 5.65 ± 1.41 | 2.97 - 11.44 |
| 5-9y              | 29 | 5.29 ± 1.36 | 3.27 - 7.90  | 1.08 ± 0.27 | 0.66 - 1.59 | 40.89 ± 6.10 | 28.83 - 54.42 | 5.06 ± 1.15 | 2.97 - 7.04  |
| 10-12y            | 25 | 8.19 ± 1.81 | 5.24 - 11.65 | 1.69 ± 0.37 | 1.10 - 2.33 | 42.07 ± 5.93 | 30.68 - 52.00 | 6.33 ± 1.39 | 4.27 - 11.44 |

Notes: Mean volume of oxygen consumption and carbon dioxide production were converted into units of energy expenditure (kcal/min) using the Weir equation (16). METs, metabolic equivalents; REE, resting energy expenditure.

**Supplemental Digital Content 2.** Supplementary analyses for the raw wrist acceleration cut-points using a  $\geq 4$ -MET MVPA definition.

Supplemental Digital Content 2.1: Contingency tables for classification accuracy of raw wrist acceleration cut-points using a  $\geq 4$ -MET MVPA definition

| Actual Intensity      | Cut-points classification of intensity |                    |                    |
|-----------------------|--|--------------------|--------------------|
|                       | 1                                      | 2                  | 3                  |
| ENMO <sub>192+</sub>  |  |                    |                    |
| 1. non-MVPA           | <b>14032 (93.1)</b>                    | 904 (6.0)          | 137 (0.9)          |
| 2. MPA                | 2181 (46.0)                            | <b>2213 (46.6)</b> | 352 (7.4)          |
| 3. VPA                | 560 (9.9)                              | 2039 (36.2)        | <b>3034 (53.9)</b> |
| GENEA <sub>250+</sub> |  |                    |                    |
| 1. non-MVPA           | <b>13887 (92.1)</b>                    | 1035 (6.9)         | 161 (1.1)          |
| 2. MPA                | 1936 (40.8)                            | <b>2363 (49.8)</b> | 447 (9.4)          |
| 3. VPA                | 217 (3.9)                              | 1707 (30.3)        | <b>3709 (65.8)</b> |
| BFEN <sub>314+</sub>  |  |                    |                    |
| 1. non-MVPA           | <b>12322 (81.7)</b>                    | 2493 (16.5)        | 258 (1.7)          |
| 2. MPA                | 672 (14.2)                             | <b>3421 (72.1)</b> | 653 (13.8)         |
| 3. VPA                | 42 (0.7)                               | 918 (16.3)         | <b>4673 (83.0)</b> |

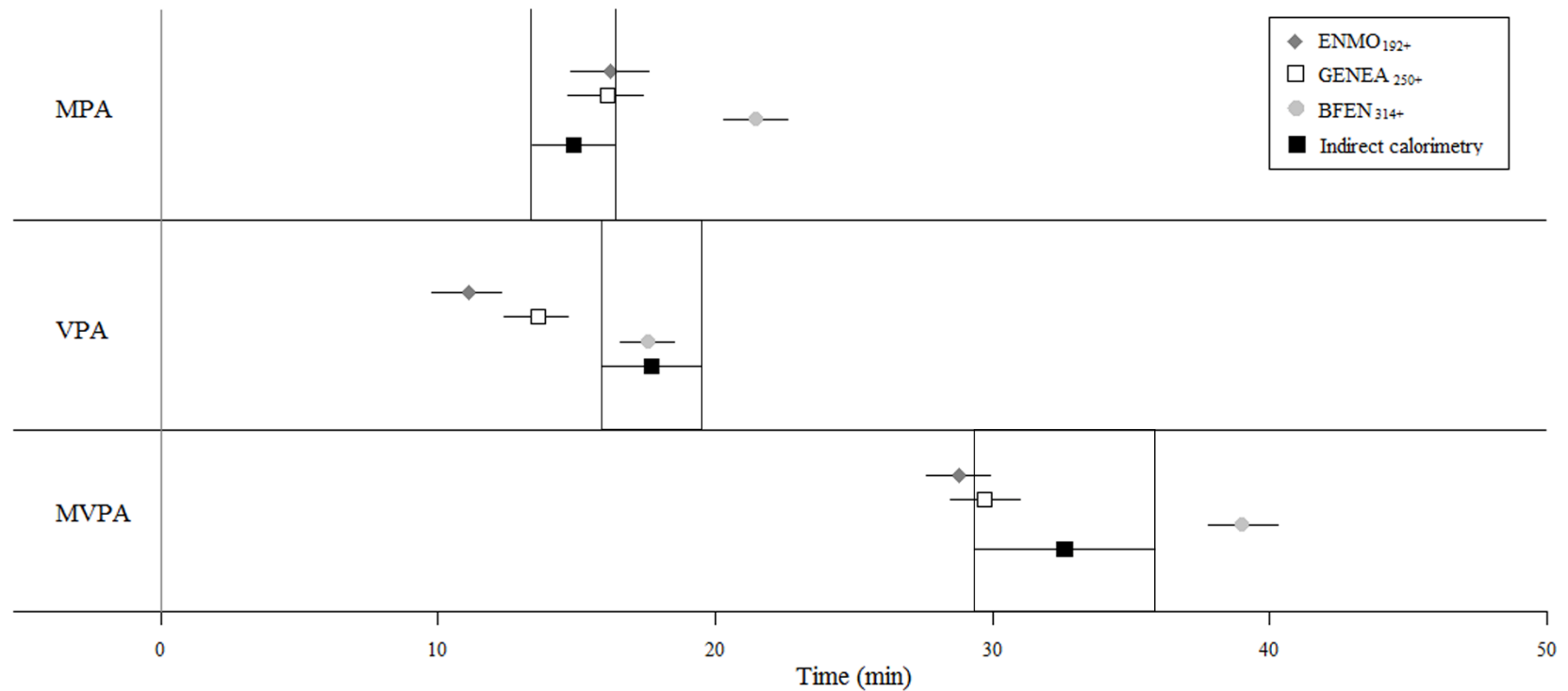
The presented values indicate the proportion of epochs classified for each intensity, with percentages presented between brackets. The values in boldface indicate the proportion of epochs correctly classified for the physical activity intensity. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENEActiv: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

Supplemental Digital Content 2.2: Agreement analysis of raw wrist acceleration-based estimations of physical activity intensities compared to indirect calorimetry using a  $\geq 4$ -MET MVPA definition.

| <b>Intensity</b>            | <b>Mean bias (%)</b> | <b>Limits of agreement</b> | <b>p-value slope</b> |
|-----------------------------|----------------------|----------------------------|----------------------|
| <b>ENMO<sub>192+</sub></b>  |                      |                            |                      |
| <i>MPA</i>                  | -2.6                 | -78.7 - 73.6               | 0.00                 |
| <i>VPA</i>                  | 53.7                 | -44.6 - 152.1              | 0.00                 |
| <i>MVPA</i>                 | 12.6                 | -18.3 - 43.5               | 0.85                 |
| <b>GENEA<sub>250+</sub></b> |                      |                            |                      |
| <i>MPA</i>                  | -1.5                 | -80.0 - 76.9%              | 0.01                 |
| <i>VPA</i>                  | 28.6                 | -39.4 - 96.6               | 0.00                 |
| <i>MVPA</i>                 | 9.3                  | -23.0 - 41.6               | 0.03                 |
| <b>BFEN<sub>314+</sub></b>  |                      |                            |                      |
| <i>MPA</i>                  | -34.4                | -89.1 - 20.4               | 0.01                 |
| <i>VPA</i>                  | -0.5*                | -40.6 - 39.7               | 0.04                 |
| <i>MVPA</i>                 | -18.3                | -50.2 - 13.5               | 0.11                 |

*MPA*: moderate physical activity; *VPA*: vigorous physical activity; *MVPA*: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENEActiv: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm. Mean bias was calculated as: measured intensity time – estimated intensity time; a positive value indicates underestimation; a negative value indicates overestimation. \*Significantly equivalent to indirect calorimetry ( $p < 0.05$ ).

Supplemental Digital Content 2.3: 95% equivalence test for raw wrist acceleration-based estimated time spent in physical activity intensities using a  $\geq 4$ -MET MVPA definition.



Times estimated by wrist-worn cut-points are equivalent to indirect calorimetry if 90% confidence intervals lie entirely within the equivalence region of indirect calorimetry. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

Supplemental Digital Content 2.4: Confusion matrices for the raw wrist acceleration cut-points using a  $\geq 4$ -MET MVPA definition.

Table 1. Confusion matrix for sedentary and light physical activity intensity activities.

| Actual Intensity | Lying Down                  |            |   | TV viewing   |     |   | Computer Game |     |   | Handheld e-game |            |   | Writing/ Colouring |     |   | Standing activity |             |   | Getting ready |             |     | Slow walk   |             |             |
|------------------|-----------------------------|------------|---|--------------|-----|---|---------------|-----|---|-----------------|------------|---|--------------------|-----|---|-------------------|-------------|---|---------------|-------------|-----|-------------|-------------|-------------|
|                  | 1                           | 2          | 3 | 1            | 2   | 3 | 1             | 2   | 3 | 1               | 2          | 3 | 1                  | 2   | 3 | 1                 | 2           | 3 | 1             | 2           | 3   | 1           | 2           | 3           |
|                  | <b>ENMO<sub>192+</sub></b>  |            |   |              |     |   |               |     |   |                 |            |   |                    |     |   |                   |             |   |               |             |     |             |             |             |
| 1. non-MVPA      | <b>100.0</b>                | 0.0        | - | <b>100.0</b> | 0.0 | - | <b>99.9</b>   | 0.1 | - | <b>100.0</b>    | 0.0        | - | <b>99.9</b>        | 0.1 | - | <b>99.1</b>       | 0.9         | - | <b>97.3</b>   | 2.0         | 0.8 | <b>80.9</b> | 18.5        | 0.6         |
| 2. MPA           | 100.0                       | <b>0.0</b> | - | -            | -   | - | -             | -   | - | 100.0           | <b>0.0</b> | - | -                  | -   | - | 100.0             | <b>0.0</b>  | - | 92.3          | <b>7.4</b>  | 0.3 | 55.5        | <b>44.5</b> | 0.0         |
| 3. VPA           | -                           | -          | - | -            | -   | - | -             | -   | - | -               | -          | - | -                  | -   | - | -                 | -           | - | -             | -           | -   | 25.0        | 75.0        | <b>0.0</b>  |
| 4. MVPA          |                             | <b>0.0</b> |   |              | -   |   |               | -   |   |                 | <b>0.0</b> |   |                    | -   |   |                   | <b>0.0</b>  |   |               | <b>7.7</b>  |     |             | <b>44.7</b> |             |
|                  | <b>GENEA<sub>250+</sub></b> |            |   |              |     |   |               |     |   |                 |            |   |                    |     |   |                   |             |   |               |             |     |             |             |             |
| 1. non-MVPA      | <b>100.0</b>                | 0.0        | - | <b>100.0</b> | -   | - | <b>100.0</b>  | 0.0 | - | <b>100.0</b>    | 0.0        | - | <b>99.4</b>        | 0.6 | - | <b>98.8</b>       | 1.2         | - | <b>96.8</b>   | 2.4         | 0.8 | <b>69.8</b> | 29.5        | 0.7         |
| 2. MPA           | 100.0                       | <b>0.0</b> | - | -            | -   | - | -             | -   | - | 100.0           | <b>0.0</b> | - | -                  | -   | - | 100.0             | <b>0.0</b>  | - | 91.4          | <b>8.3</b>  | 0.3 | 47.0        | <b>53.0</b> | 0.0         |
| 3. VPA           | -                           | -          | - | -            | -   | - | -             | -   | - | -               | -          | - | -                  | -   | - | -                 | -           | - | -             | -           | -   | 25.0        | 75.0        | <b>0.0</b>  |
| 4. MVPA          |                             | <b>0.0</b> |   |              | -   |   |               | -   |   |                 | <b>0.0</b> |   |                    | -   |   |                   | <b>16.7</b> |   |               | <b>12.3</b> |     |             | <b>48.5</b> |             |
|                  | <b>BFEN<sub>314+</sub></b>  |            |   |              |     |   |               |     |   |                 |            |   |                    |     |   |                   |             |   |               |             |     |             |             |             |
| 1. non-MVPA      | <b>99.8</b>                 | 0.2        | - | <b>100.0</b> | 0.1 | - | <b>98.7</b>   | 1.3 | - | <b>99.9</b>     | 0.1        | - | <b>98.4</b>        | 1.6 | - | <b>87.3</b>       | 12.7        | - | <b>33.3</b>   | 66.0        | 0.8 | <b>63.7</b> | 35.3        | 1.1         |
| 2. MPA           | 100.0                       | <b>0.0</b> | - | -            | -   | - | -             | -   | - | 100.0           | <b>0.0</b> | - | -                  | -   | - | 100.0             | <b>0.0</b>  | - | 18.5          | <b>80.9</b> | 0.6 | 38.5        | <b>61.4</b> | 0.1         |
| 3. VPA           | -                           | -          | - | -            | -   | - | -             | -   | - | -               | -          | - | -                  | -   | - | -                 | -           | - | -             | -           | -   | 25.0        | 25.0        | <b>50.0</b> |
| 4. MVPA          |                             | <b>0.0</b> |   |              | -   |   |               | -   |   |                 | <b>0.0</b> |   |                    | -   |   |                   | <b>0.0</b>  |   |               | <b>81.5</b> |     |             | <b>61.6</b> |             |

Values in boldface indicate the percentage of epochs correctly classified. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

Table 2. Confusion matrix for moderate physical activity intensity activities.

| Actual Intensity | Dancing                     |             |             | Brisk walk  |             |            | Tidy up     |             |            |
|------------------|-----------------------------|-------------|-------------|-------------|-------------|------------|-------------|-------------|------------|
|                  | 1                           | 2           | 3           | 1           | 2           | 3          | 1           | 2           | 3          |
|                  | <b>ENMO<sub>192+</sub></b>  |             |             |             |             |            |             |             |            |
| 1. non-MVPA      | <b>40.6</b>                 | 54.2        | 5.2         | <b>48.4</b> | 51.6        | 0.0        | <b>91.6</b> | 8.4         | 0.0        |
| 2. MPA           | 19.2                        | <b>61.8</b> | 19.1        | 23.2        | <b>76.4</b> | 0.4        | 85.8        | <b>14.2</b> | 0.0        |
| 3. VPA           | 12.0                        | 56.4        | <b>31.6</b> | 3.4         | 96.6        | <b>0.0</b> | 64.2        | 35.8        | <b>0.0</b> |
| 4. MVPA          |                             | <b>87.5</b> |             |             | <b>79.6</b> |            |             | <b>17.7</b> |            |
|                  | <b>GENEA<sub>250+</sub></b> |             |             |             |             |            |             |             |            |
| 1. non-MVPA      | <b>38.2</b>                 | 55.0        | 6.8         | <b>43.2</b> | 56.8        | <b>0.0</b> | <b>86.1</b> | 13.9        | 0.0        |
| 2. MPA           | 12.1                        | <b>61.2</b> | 26.7        | 20.3        | <b>78.9</b> | 0.8        | 79.6        | <b>20.4</b> | 0.0        |
| 3. VPA           | 3.4                         | 46.2        | <b>50.4</b> | 8.6         | 90.5        | <b>0.9</b> | 59.7        | 40.3        | <b>0.0</b> |
| 4. MVPA          |                             | <b>89.9</b> |             |             | <b>78.2</b> |            |             | <b>28.4</b> |            |
|                  | <b>BFEN<sub>314+</sub></b>  |             |             |             |             |            |             |             |            |
| 1. non-MVPA      | <b>14.3</b>                 | 70.8        | 14.9        | <b>34.4</b> | 65.6        | 0.0        | <b>28.6</b> | 71.4        | 0.0        |
| 2. MPA           | 0.7                         | <b>59.0</b> | 40.3        | 14.2        | <b>84.8</b> | 1.0        | 6.6         | <b>93.4</b> | 0.0        |
| 3. VPA           | 0.0                         | 35.9        | <b>64.1</b> | 0.9         | 90.5        | <b>8.6</b> | 6.5         | 93.5        | <b>0.0</b> |
| 4. MVPA          |                             | <b>99.4</b> |             |             | <b>86.9</b> |            |             | <b>93.4</b> |            |

Values in boldface indicate the percentage of epochs correctly classified. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

Table 3: Confusion matrix for vigorous physical activity intensity activities.

| Actual Intensity | Basketball                  |             |             | Running     |             |             | Locomotor course |             |             | Soccer      |             |             |
|------------------|-----------------------------|-------------|-------------|-------------|-------------|-------------|------------------|-------------|-------------|-------------|-------------|-------------|
|                  | 1                           | 2           | 3           | 1           | 2           | 3           | 1                | 2           | 3           | 1           | 2           | 3           |
|                  | <b>ENMO<sub>192+</sub></b>  |             |             |             |             |             |                  |             |             |             |             |             |
| 1. non-MVPA      | <b>30.0</b>                 | 68.3        | 1.7         | <b>21.5</b> | 23.4        | 55.1        | <b>20.7</b>      | 39.1        | 40.2        | <b>45.6</b> | 38.2        | 16.2        |
| 2. MPA           | 17.0                        | <b>78.1</b> | 4.9         | 6.1         | <b>22.1</b> | 71.8        | 13.8             | <b>39.4</b> | 46.8        | 15.7        | <b>35.2</b> | 49.1        |
| 3. VPA           | 7.5                         | 71.6        | <b>21.0</b> | 9.4         | 19.2        | <b>71.4</b> | 7.7              | 28.5        | <b>63.8</b> | 7.2         | 19.2        | <b>73.6</b> |
| 4. MVPA          |                             | <b>96.4</b> |             |             | <b>98.5</b> |             |                  | <b>98.2</b> |             |             | <b>98.8</b> |             |
|                  | <b>GENEA<sub>250+</sub></b> |             |             |             |             |             |                  |             |             |             |             |             |
| 1. non-MVPA      | <b>38.3</b>                 | 58.3        | 3.3         | <b>21.5</b> | 22.4        | 56.1        | <b>29.3</b>      | 34.5        | 36.2        | <b>48.5</b> | 32.4        | 19.1        |
| 2. MPA           | 15.2                        | <b>77.7</b> | 7.1         | 4.6         | <b>20.6</b> | 74.8        | 6.5              | <b>29.0</b> | 64.5        | 9.3         | <b>36.1</b> | 54.6        |
| 3. VPA           | 3.0                         | 63.8        | <b>33.2</b> | 1.1         | 15.0        | <b>83.9</b> | 1.7              | 17.6        | <b>80.7</b> | 0.6         | 17.2        | <b>82.2</b> |
| 4. MVPA          |                             | <b>95.8</b> |             |             | <b>98.5</b> |             |                  | <b>98.1</b> |             |             | <b>98.6</b> |             |
|                  | <b>BFEN<sub>314+</sub></b>  |             |             |             |             |             |                  |             |             |             |             |             |
| 1. non-MVPA      | <b>13.3</b>                 | 75.0        | 11.7        | <b>13.1</b> | 19.6        | 67.3        | <b>11.5</b>      | 21.8        | 66.7        | <b>39.7</b> | 26.5        | 33.8        |
| 2. MPA           | 3.1                         | <b>71.9</b> | 25.0        | 3.8         | <b>3.1</b>  | 93.1        | 5.3              | <b>13.8</b> | 80.9        | 8.3         | <b>19.4</b> | 72.2        |
| 3. VPA           | 0.2                         | 31.7        | <b>68.1</b> | 0.9         | 2.4         | <b>96.7</b> | 0.7              | 5.6         | <b>93.8</b> | 0.3         | 5.7         | <b>94.1</b> |
| 4. MVPA          |                             | <b>99.3</b> |             |             | <b>98.8</b> |             |                  | <b>99.0</b> |             |             | <b>99.1</b> |             |

Values in boldface indicate the percentage of epochs correctly classified. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.



**Supplemental Digital Content 3.** Confusion matrices for the raw wrist acceleration cut-points using a  $\geq 3$ -MET MVPA definition.

Table 1. Confusion matrix for sedentary and light physical activity intensity activities.

| Actual Intensity | Lying Down                  |     |   | TV viewing   |     |   | Computer Game |     |   | Handheld e-game |            |   | Writing/ Colouring |     |   | Standing activity |            |   | Getting ready |             |     | Slow walk   |             |     |
|------------------|-----------------------------|-----|---|--------------|-----|---|---------------|-----|---|-----------------|------------|---|--------------------|-----|---|-------------------|------------|---|---------------|-------------|-----|-------------|-------------|-----|
|                  | 1                           | 2   | 3 | 1            | 2   | 3 | 1             | 2   | 3 | 1               | 2          | 3 | 1                  | 2   | 3 | 1                 | 2          | 3 | 1             | 2           | 3   | 1           | 2           | 3   |
|                  | <b>ENMO<sub>192+</sub></b>  |     |   |              |     |   |               |     |   |                 |            |   |                    |     |   |                   |            |   |               |             |     |             |             |     |
| 1. non-MVPA      | <b>100.0</b>                | 0.0 | - | <b>100.0</b> | 0.0 | - | <b>99.9</b>   | 0.1 | - | <b>100.0</b>    | 0.0        | - | <b>99.9</b>        | 0.1 | - | <b>99.1</b>       | 0.9        | - | <b>97.6</b>   | 2.0         | 0.4 | <b>75.1</b> | 24.7        | 0.2 |
| 2. MPA           | -                           | -   | - | -            | -   | - | -             | -   | - | 100.0           | <b>0.0</b> | - | -                  | -   | - | 100.0             | <b>0.0</b> | - | 89.5          | <b>8.6</b>  | 1.9 | 57.7        | <b>41.8</b> | 0.5 |
| 3. VPA           | -                           | -   | - | -            | -   | - | -             | -   | - | -               | -          | - | -                  | -   | - | -                 | -          | - | -             | -           | -   | -           | -           | -   |
| 4. MVPA          |                             | -   |   |              | -   |   |               | -   |   |                 | <b>0.0</b> |   |                    | -   |   |                   | <b>0.0</b> |   |               | <b>10.5</b> |     |             | <b>42.5</b> |     |
|                  | <b>GENEA<sub>250+</sub></b> |     |   |              |     |   |               |     |   |                 |            |   |                    |     |   |                   |            |   |               |             |     |             |             |     |
| 1. non-MVPA      | <b>100.0</b>                | 0.0 | - | <b>100.0</b> | 0.0 | - | <b>100.0</b>  | 0.0 | - | <b>100.0</b>    | 0.0        | - | <b>99.4</b>        | 0.6 | - | <b>98.8</b>       | 1.2        | - | <b>96.9</b>   | 2.6         | 0.4 | <b>66.4</b> | 33.4        | 0.2 |
| 2. MPA           | -                           | -   | - | -            | -   | - | -             | -   | - | 100.0           | <b>0.0</b> | - | -                  | -   | - | 100.0             | <b>0.0</b> | - | 89.5          | <b>8.6</b>  | 1.9 | 46.2        | <b>53.1</b> | 0.6 |
| 3. VPA           | -                           | -   | - | -            | -   | - | -             | -   | - | -               | -          | - | -                  | -   | - | -                 | -          | - | -             | -           | -   | -           | -           | -   |
| 4. MVPA          |                             | -   |   |              | -   |   |               | -   |   |                 | <b>0.0</b> |   |                    | -   |   |                   | <b>0.0</b> |   |               | <b>12.7</b> |     |             | <b>51.7</b> |     |
|                  | <b>BFEN<sub>314+</sub></b>  |     |   |              |     |   |               |     |   |                 |            |   |                    |     |   |                   |            |   |               |             |     |             |             |     |
| 1. non-MVPA      | <b>99.8</b>                 | 0.2 | - | <b>99.9</b>  | 0.1 | - | <b>98.7</b>   | 1.3 | - | <b>99.9</b>     | 0.1        | - | <b>98.4</b>        | 1.6 | - | <b>87.9</b>       | 12.1       | - | <b>33.1</b>   | 66.4        | 0.4 | <b>59.3</b> | 40.3        | 0.4 |
| 2. MPA           | -                           | -   | - | -            | -   | - | -             | -   | - | 100.0           | <b>0.0</b> | - | -                  | -   | - | 100.0             | <b>0.0</b> | - | 16.1          | <b>81.6</b> | 2.2 | 38.7        | <b>60.1</b> | 1.3 |
| 3. VPA           | -                           | -   | - | -            | -   | - | -             | -   | - | -               | -          | - | -                  | -   | - | -                 | -          | - | -             | -           | -   | -           | -           | -   |
| 4. MVPA          |                             | -   |   |              | -   |   |               | -   |   |                 | <b>0.0</b> |   |                    | -   |   |                   | <b>0.0</b> |   |               | <b>83.9</b> |     |             | <b>61.3</b> |     |

Values in boldface indicate the percentage of epochs correctly classified. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

Table 2. Confusion matrix for moderate physical activity intensity activities.

| Actual Intensity | Dancing                     |             |              | Brisk walk  |             |            | Tidy up     |             |            |
|------------------|-----------------------------|-------------|--------------|-------------|-------------|------------|-------------|-------------|------------|
|                  | 1                           | 2           | 3            | 1           | 2           | 3          | 1           | 2           | 3          |
|                  | <b>ENMO<sub>192+</sub></b>  |             |              |             |             |            |             |             |            |
| 1. non-MVPA      | <b>38.1</b>                 | 55.1        | 6.8          | <b>38.9</b> | 61.1        | 0.0        | <b>89.5</b> | 10.5        | 0.0        |
| 2. MPA           | 17.0                        | <b>61.3</b> | 21.7         | 20.4        | <b>79.2</b> | 0.5        | 82.3        | <b>17.7</b> | 0.0        |
| 3. VPA           | 0.0                         | 50.0        | <b>50.0</b>  | 0.0         | 100.0       | <b>0.0</b> | 64.2        | 35.8        | <b>0.0</b> |
| 4. MVPA          |                             | <b>89.7</b> |              |             | <b>80.7</b> |            |             | <b>17.9</b> |            |
|                  | <b>GENEA<sub>250+</sub></b> |             |              |             |             |            |             |             |            |
| 1. non-MVPA      | <b>35.3</b>                 | 55.8        | 8.9          | <b>30.0</b> | 69.7        | <b>0.0</b> | <b>82.4</b> | 17.6        | 0.0        |
| 2. MPA           | 9.2                         | <b>59.2</b> | 31.6         | 20.3        | <b>78.5</b> | 1.0        | 77.1        | <b>22.9</b> | 0.0        |
| 3. VPA           | 0.0                         | 50.0        | <b>50.0</b>  | 0.0         | 100.0       | <b>0.0</b> | 33.3        | 66.7        | <b>0.0</b> |
| 4. MVPA          |                             | <b>90.7</b> |              |             | <b>77.2</b> |            |             | <b>28.7</b> |            |
|                  | <b>BFEN<sub>314+</sub></b>  |             |              |             |             |            |             |             |            |
| 1. non-MVPA      | <b>12.4</b>                 | 70.1        | 17.5         | <b>21.7</b> | 78.0        | 0.4        | <b>21.6</b> | 78.4        | 0.0        |
| 2. MPA           | 0.3                         | <b>54.0</b> | 45.7         | 14.8        | <b>83.4</b> | 1.8        | 7.2         | <b>92.8</b> | 0.0        |
| 3. VPA           | 0.0                         | 0.0         | <b>100.0</b> | 0.0         | 100.0       | <b>0.0</b> | 0.0         | 100.0       | <b>0.0</b> |
| 4. MVPA          |                             | <b>99.7</b> |              |             | <b>85.2</b> |            |             | <b>92.8</b> |            |

Values in boldface indicate the percentage of epochs correctly classified. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.

Table 3: Confusion matrix for vigorous physical activity intensity activities.

| Actual Intensity | Basketball                  |             |             | Running     |             |             | Locomotor course |             |             | Soccer      |             |             |
|------------------|-----------------------------|-------------|-------------|-------------|-------------|-------------|------------------|-------------|-------------|-------------|-------------|-------------|
|                  | 1                           | 2           | 3           | 1           | 2           | 3           | 1                | 2           | 3           | 1           | 2           | 3           |
|                  | <b>ENMO<sub>192+</sub></b>  |             |             |             |             |             |                  |             |             |             |             |             |
| 1. non-MVPA      | <b>28.3</b>                 | 69.7        | 2.0         | <b>16.7</b> | 18.9        | 64.4        | <b>23.5</b>      | 48.5        | 27.9        | <b>41.6</b> | 36.0        | 22.5        |
| 2. MPA           | 9.2                         | <b>78.6</b> | 12.2        | 13.2        | <b>28.8</b> | 58.0        | 10.9             | <b>39.8</b> | 49.3        | 13.0        | <b>29.2</b> | 57.8        |
| 3. VPA           | 7.4                         | 63.6        | <b>29.1</b> | 3.6         | 6.7         | <b>89.6</b> | 5.6              | 20.5        | <b>73.9</b> | 3.5         | 13.7        | <b>82.8</b> |
| 4. MVPA          |                             | <b>97.0</b> |             |             | <b>98.4</b> |             |                  | <b>98.2</b> |             |             | <b>99.2</b> |             |
|                  | <b>GENEA<sub>250+</sub></b> |             |             |             |             |             |                  |             |             |             |             |             |
| 1. non-MVPA      | <b>32.3</b>                 | 65.7        | 2.0         | <b>16.7</b> | 18.9        | 64.4        | <b>23.5</b>      | 35.3        | 41.2        | <b>43.8</b> | 31.5        | 24.7        |
| 2. MPA           | 7.1                         | <b>72.2</b> | 20.7        | 1.9         | <b>24.3</b> | 73.8        | 3.2              | <b>27.6</b> | 69.2        | 1.5         | <b>26.9</b> | 71.6        |
| 3. VPA           | 0.2                         | 55.9        | <b>43.9</b> | 1.1         | 3.1         | <b>95.8</b> | 1.0              | 10.3        | <b>88.7</b> | 0.4         | 12.3        | <b>87.3</b> |
| 4. MVPA          |                             | <b>96.6</b> |             |             | <b>98.4</b> |             |                  | <b>98.0</b> |             |             | <b>99.0</b> |             |
|                  | <b>BFEN<sub>314+</sub></b>  |             |             |             |             |             |                  |             |             |             |             |             |
| 1. non-MVPA      | <b>8.1</b>                  | 80.8        | 11.1        | <b>9.8</b>  | 15.9        | 74.2        | <b>13.2</b>      | 30.9        | 55.9        | <b>37.1</b> | 23.6        | 39.3        |
| 2. MPA           | 1.2                         | <b>48.9</b> | 49.9        | 1.6         | <b>3.6</b>  | 94.8        | 1.7              | <b>10.0</b> | 88.3        | 1.2         | <b>10.2</b> | 88.6        |
| 3. VPA           | 0.0                         | 17.6        | <b>82.4</b> | 0.9         | 0.7         | <b>98.4</b> | 0.5              | 2.6         | <b>96.9</b> | 0.0         | 3.9         | <b>96.1</b> |
| 4. MVPA          |                             | <b>99.3</b> |             |             | <b>98.7</b> |             |                  | <b>98.4</b> |             |             | <b>99.5</b> |             |

Values in boldface indicate the percentage of epochs correctly classified. MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; ENMO: cut-points developed using Euclidian norm minus one; GENE: cut-points developed using the GENEActiv post processing software; BFEN: cut-points developed using Bandpass Filtered followed by Euclidian Norm.