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Fairclough, SJ, Noonan, RJ, Rowlands, AV, van Hees, V, Knowles, ZR and Boddy, LM

**Wear Compliance and Activity in Children Wearing Wrist and Hip-Mounted Accelerometers.**

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### Article

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1 Title: *Wear compliance and activity in children wearing wrist and hip mounted*  
2 *accelerometers*

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26

## ABSTRACT

27

28 *Purpose.* This study aimed to (i) explore children's compliance to wearing wrist and hip-  
29 mounted accelerometers, (ii) compare children's physical activity (PA) derived from wrist and  
30 hip raw accelerations, and (iii) examine differences in raw and counts PA measured by hip-  
31 worn accelerometry.

32 *Methods.* One hundred and twenty nine 9-10 y old children wore a wrist-mounted GENEActiv  
33 accelerometer (GAwrist) and a hip-mounted ActiGraph GT3X+ accelerometer (AGhip) for 7  
34 d. Both devices measured raw accelerations and the AGhip also provided counts-based data.

35 *Results.* More children wore the GAwrist than the AGhip regardless of wear time criteria  
36 applied ( $p < .001 - .035$ ). Raw data signal vector magnitude (SVM;  $r = .68$ ), moderate PA (MPA;  
37  $r = .81$ ), vigorous PA (VPA;  $r = .85$ ), and moderate-to-vigorous PA (MVPA;  $r = .83$ ) were  
38 strongly associated between devices ( $p < .001$ ). GAwrist SVM ( $p = .001$ ), MPA ( $p = .037$ ), VPA  
39 ( $p = .002$ ), and MVPA ( $p = .016$ ) were significantly greater than AGhip. According to GAwrist  
40 raw data, 86.9% of children engaged in at least 60 min MVPA $\cdot$ d<sup>-1</sup>, compared to 19% for AGhip.  
41 ActiGraph MPA (raw) was  $41.93 \pm 1.66$  min $\cdot$ d<sup>-1</sup> compared to  $35.26 \pm 1.01$  min $\cdot$ d<sup>-1</sup> (counts)  
42 ( $p = .02$ ). Actigraph VPA was  $7.63 \pm 0.47$  min $\cdot$ d<sup>-1</sup> (raw) and  $37.45 \pm 1.87$  min $\cdot$ d<sup>-1</sup> (counts;  
43  $p = .52$ ).

44 *Conclusion.* In children accelerometer wrist placement promotes superior compliance than the  
45 hip. Raw accelerations were significantly higher for GAwrist compared to AGhip, possibly due  
46 to placement location and technical differences between devices. AGhip PA calculated from  
47 raw accelerations and counts differed substantially, demonstrating that PA outcomes derived  
48 from cutpoints for raw output and counts cannot be directly compared. Raw acceleration data  
49 processing potentially allows for greater transparency and comparability between studies, but  
50 presently, comparisons with counts-based data are limited.

51 Keywords: raw accelerations, wear time, physical activity, GENEActiv, ActiGraph GT3X+

52

53

## INTRODUCTION

54 Accelerometry is the most widely used objective method of assessing children's free-living  
55 physical activity (PA) (2). Accelerometers allow accelerations to be quantified, and in the  
56 context of PA research the accelerometer outcome is related to a measure of energy expenditure  
57 (13) or PA behaviour (19). Traditionally, accelerometers have been worn on the hip as this  
58 location is thought to provide the most accurate estimations of energy expenditure and activity  
59 intensity (28). Recently there has been an increased use of wrist-worn devices, which it has  
60 been argued, promote better compliance to device wear. In the NHANES 2011-12 data  
61 collection cycle using wrist-worn accelerometers, median wear time duration was 21-22 hours  
62 per day, which was up to 100% longer than in previous cycles using hip-worn devices (30).  
63 Compared to hip-worn accelerometers, those worn on the wrist may be perceived as less  
64 burdensome to research participants, thus promoting wear-time compliance (23, 39). Variable  
65 compliance to accelerometer monitoring protocols influences the application of minimum wear  
66 time criteria (i.e., number of minutes wear that constitutes a 'valid' day of measurement and  
67 the minimum number of days required for a reliable estimate of PA levels), which are subject  
68 to variation in researcher decisions about how 'non-wear' time is defined (35). Better  
69 compliance gives greater confidence that PA data are representative of actual daily PA due to  
70 the association between duration of monitoring and reliability of PA data (17). Presently  
71 though, there is limited evidence of the extent of improved compliance in children wearing  
72 accelerometers on the wrist.

73 The growing popularity of the wrist as the accelerometer placement site warrants comparisons  
74 with PA data derived from devices worn on the hip, which has traditionally been the most  
75 commonly used site. Recently, PA intensity cutpoints derived from raw acceleration output

76 have been developed in the same study for the GENEActiv (Activinsights, Cambs, UK) and  
77 ActiGraph GT3X+ (ActiGraph, Pensacola, FL) accelerometers, which are designed for wear  
78 both on the wrist and hip (13). Using these protocol-specific cutpoints together may help  
79 improve our understanding of how concurrent estimates of PA intensity from the wrist and hip  
80 sites compare. This move towards raw acceleration signal processing is a recent advance in  
81 accelerometer-based PA monitoring, which has traditionally used accelerometer output  
82 reduced to 'counts'. Direct comparison of PA outcomes derived from different devices has not  
83 previously been possible due to differences in proprietary algorithms used to collect, process,  
84 filter, and scale raw signal data to produce the device-specific counts (4, 40). This lack of  
85 equivalency between devices and therefore comparability between studies using different  
86 devices, has led to the emergence of accelerometers such as the GENEActiv and ActiGraph  
87 GT3X+ and GT9X, that are capable of collecting and recording raw, unfiltered accelerations  
88 which can then be subject to researcher-driven data processing procedures (40). Basing PA  
89 data on raw accelerations provides an opportunity to improve comparability between studies  
90 using different devices, and promote transparency and consistency of post-data collection  
91 analytical processes (13). Presently though, limited published research is available describing  
92 children's free-living PA derived from raw accelerometer data. One study involving 47, 1<sup>st</sup> to  
93 5<sup>th</sup> grade children wearing GENEActiv accelerometers on the wrist reported mean daily MVPA  
94 and VPA of 308.2 min and 32.7 min, respectively (33). In a sample of 58 Australian 10-12 year  
95 olds, MVPA from GENEActiv raw data was 67.8 min·d<sup>-1</sup> (hip) and 98.2 min·d<sup>-1</sup> (wrist) with  
96 VPA recorded as 11.1 min·d<sup>-1</sup> (hip) and 16.7 min·d<sup>-1</sup> (wrist) (30). These studies however,  
97 calculated the signal vector magnitude values differently (i.e., averaging vs. summing raw  
98 accelerations per epoch), and used different PA intensity cutpoints (25, 33), which makes direct  
99 comparison of findings challenging. Another important issue is that historical accelerometer  
100 data used counts and extensive validation work has been conducted on counts-based

101 accelerometer data (10, 19, 26, 37). Although the ‘cutpoint conundrum’ exists, there has been  
102 some consensus in recent years for using the cutpoints of Evenson et al. (10), which have  
103 convincing evidence of validity in children (36). These cutpoints therefore provide a basis for  
104 free-living comparison with more contemporary cutpoints based on raw accelerations (13, 25,  
105 33).

106 As the field moves more towards utilisation of raw data processing and the availability of wrist-  
107 worn devices increases, studies reporting the comparability of PA outcomes based on raw  
108 accelerations and counts from both wrist and hip are warranted. Therefore, the aims of this  
109 study were (i) to explore children’s compliance to wearing wrist and hip-mounted  
110 accelerometers during free-living, (ii) to compare children’s PA derived from raw acceleration  
111 signals of wrist and hip worn accelerometers, and (iii) to examine differences in PA estimated  
112 from raw data with that from counts data measured by a hip worn accelerometer.

## 113 METHODS

114 *Participants.* The participants were 129 Year 5 (9-10 y) children (79 girls) from six primary  
115 schools in Liverpool, England. Following ethical approval from the University Research Ethics  
116 Committee, all Year 5 children (n = 326) in participating schools were invited to participate.  
117 They received a pack which contained parent and child information sheets, consent and assent  
118 forms, and a medical screening form. Written informed consent and assent was received from  
119 parents and their children, respectively before children could participate in the study.

120 *Anthropometrics.* Stature and sitting stature were assessed to the nearest 0.1 cm using a portable  
121 stadiometer (Leicester Height Measure, Seca, Birmingham, UK). Body mass was assessed to  
122 the nearest 0.1kg (Seca, Birmingham, UK). Body mass index (BMI) was calculated for each  
123 participant with BMI z-scores also assigned (5). Age and sex specific BMI cut points were used  
124 to classify children as normal weight or overweight/obese (6). Gender-specific regression

125 equations (22) were used to predict children's age from peak height velocity (APHV), which  
126 is a proxy measure of biological maturation. All measurements were taken by the second author  
127 and a research assistant using standard procedures (18).

128 *Socio-economic status.* Neighbourhood-level socio-economic status (SES) was calculated  
129 using the 2010 Indices of Multiple Deprivation (IMD) (8). The IMD is a UK Government  
130 produced measure comprising seven areas of deprivation (income, employment, health,  
131 education, housing, environment, and crime). Deprivation scores were generated using the  
132 National Statistics Postcode Directory database from parent reported home postcodes. Higher  
133 SES was represented by lower IMD scores.

134 *Physical Activity.* Free-living PA was assessed using the GENEActiv triaxial accelerometer  
135 (Activinsights, Cambs, UK) worn on the non-dominant wrist (GAwrist) and the ActiGraph  
136 GT3X+ triaxial accelerometer (ActiGraph, Pensacola, FL) worn on the right hip (AGhip). The  
137 GENEActiv can be worn on the wrist, upper arm, hip, chest, ankle, and thigh, has a dynamic  
138 range of  $\pm 8$  g, and is a valid measure of PA in children (13, 25, 33). The GENEActiv was  
139 selected because it measures raw accelerations and is typically worn on the wrist (1). ActiGraph  
140 accelerometers have been used in PA research for around 20 years and have been validated on  
141 several occasions with children (10, 21, 26, 37). The GT3X+ model has a dynamic range of  $\pm$   
142 6 g, and can be worn on the hip, ankle, wrist, and thigh. The ActiGraph was selected as it is the  
143 most commonly used accelerometer in children's PA research, and though it is being worn on  
144 the wrist in the most recent NHANES data collection phases (30), traditionally it has been worn  
145 on the hip (28). The GT3X+ has the capability to generate raw acceleration and count data to  
146 enable straightforward backwards interpretation of data in either format. Both devices were  
147 initialised to record raw accelerations at a frequency of 100 Hz, and participants were asked to  
148 wear the monitors at all times for 7 consecutive days except when sleeping and engaging in  
149 water based activities (e.g., bathing, swimming). Data collection took place during the regular

150 school term from January to May 2014 so activities were representative of usual free-living  
151 activities. After 7 days GAwrst data were downloaded using GENEActiv v.2.2 software  
152 (Activinsights, Cambs, UK) and saved in raw format as binary files. AGHip data were  
153 downloaded using ActiLife v. 6.11.4 (ActiGraph, Pensacola, FL) and saved in raw format as  
154 GT3X files. These were subsequently converted to CSV format to facilitate raw data  
155 processing, and to AGD format for analysis of counts data. GAwrst and AGhip raw data files  
156 were then processed in R (<http://cran.r-project.org>) using the GGIR package (version 1.1-4)  
157 which converted raw triaxial acceleration values into one omnidirectional measure of  
158 acceleration, termed the signal vector magnitude (SVM). SVM was calculated from raw  
159 accelerations from the three axes minus 1 g which represents the value of gravity (i.e.,  $SVM =$   
160  $\sqrt{(x^2 + y^2 + z^2) - 1}$ ), after which negative values were rounded to zero. This metric has  
161 previously been referred to as the Euclidean norm minus one (ENMO) (38). Raw data were  
162 further reduced by calculating the average SVM values per 1-s epoch expressed in  $mg \cdot s^{-1}$  over  
163 each of the 7 monitored days.

164

165 AGhip and GAwrst raw data wear times were estimated on the basis of the standard deviation  
166 and value range of each axis, calculated for 60 min moving windows with 15 min increments  
167 (38). A time window was classified as nonwear time if, for at least 2 out of the 3 axes, the  
168 standard deviation was less than 13.0 mg or if the value range was less than 50 mg (32). This  
169 approach has been applied previously in studies using both devices worn at the wrist and hip  
170 (29, 30, 38). For ActiGraph counts data, non-wear is conventionally determined from  
171 accumulated pre-determined time periods of consecutive zero counts. To address study aim 3,  
172 and in keeping with previous work (11, 27), the 1-s epoch AGhip counts data non-wear time  
173 was defined as at least 20 min periods of consecutive zero counts (3).

174



175 Raw acceleration outcome variables for AGhip and GAwrist were average gravity-based SVM  
176 (mg), and min of MPA, VPA, and MVPA which were calculated using device and location-  
177 specific cutpoints based on the ENMO metric (13). These were 142.6 mg (MPA) and 464.6 mg  
178 (VPA) for AGhip, and 191.6 mg (MPA) and 695.8 mg (VPA) for GAwrist (13). Comparing  
179 PA values based on ENMO-derived SVM was important as this metric was applied to  
180 ActiGraph GT3X+ and GENEActiv data in the same calibration study (13). For analysis of  
181 raw acceleration and counts-based PA levels, inclusion criteria were at least 10 h·day<sup>-1</sup> wear  
182 time for at least three days, including a minimum of one weekend day. This resulted in  
183 analytical samples of 84 participants for the GAwrist vs. AGhip raw data analyses, and 65  
184 participants for the AGhip raw vs. counts data analyses. Outcome variables for AGhip counts  
185 data were min of MPA, VPA, and MVPA which were classified according to empirical  
186 cutpoints (10) that have demonstrated acceptable classification accuracy across a range of  
187 intensities in children (36). Presently, no published sedentary time cutpoints exist for GAwrist  
188 and AGhip raw accelerations calculated using the ENMO approach. For this reason we did not  
189 investigate differences in sedentary time and light intensity PA.

190

191 *Analysis.* Kolmogorov-Smirnov tests confirmed that raw PA outcome data for the overall week  
192 and week days were normally distributed but that weekend GAwrist SVM and VPA, weekend  
193 AGhip SVM, MVPA, and VPA, and AGhip counts data had skewed distributions ( $p < .05$ ).  
194 Following log (SVM, MVPA), square root (VPA), and reciprocal (AGhip counts MPA, VPA,  
195 MVPA) transformations, data were normalized and included for analyses. All transformed data  
196 were back-transformed for presentation purposes. To analyse compliance (study aim 1), mean  
197 daily valid wear time and number of valid days were calculated for GAwrist and AGhip raw  
198 data. Paired samples McNemar's tests and t-tests assessed compliance and wear time  
199 differences against differing wear time criteria. To address study aim 2, partial Pearson

200 correlation analyses assessed raw data relationships between devices for SVM, MPA, VPA,  
201 and MVPA, while controlling for the effects of wear time. Bland-Altman plots were  
202 constructed to assess agreement between device raw data outputs, and repeated measures  
203 ANCOVAs compared raw data PA outcomes between AGhip and GAwrist for the whole week,  
204 week days, and weekend days. For aim 3, repeated measures ANCOVAs examined differences  
205 in whole week reciprocal transformed MPA, VPA, and MVPA between AGhip raw and counts  
206 data. In each ANCOVA adjustment was made for device wear time and sex. Statistical  
207 significance was set to  $p < .05$ . All analyses were conducted using IBM SPSS Statistics version  
208 22 (IBM, Armonk, NY).

## 209 RESULTS

210 Descriptive characteristics of the participants are displayed in Table 1. Around three-quarters  
211 of the children were of healthy weight which is typical for Liverpool but somewhat lower than  
212 the English national average. Boys and girls were similarly aged but girls were more advanced  
213 than boys in regards to somatic maturation. IMD scores indicated that participants resided in  
214 some of the lowest SES neighbourhoods in England.

215 TABLE 1 HERE

### 216 *Raw data device compliance*

217 AGhip and GAwrist data were available for 115 and 128 children, respectively. Instances of  
218 device malfunction or software errors, and accelerometer non-wear accounted for the modest  
219 data attrition. The percentage of children that wore each device for between 6 and 12 h·d<sup>-1</sup> on  
220 1 to 7 d is presented in the Supplemental Digital Content (see Table, Supplemental Digital  
221 Content 1). Over 95% of children wore the AGhip and GAwrist for at least 12 h on a single  
222 day. Irrespective of the number of monitoring days, the percentage of children wearing both  
223 devices decreased with hours of wear, and this drop-off was more prominent for the AGhip.

224 For example, the difference in the proportion of children wearing the AGhip for 6 h over 3 days  
225 and those wearing it for 12 h over 3 d was -18.3%, compared to -5.8% for the GAwrist. Ten h  
226 wear time over at least 2 d has been demonstrated to provide reliable estimates of PA in  
227 population studies of older primary school aged children (27). Taking 10 h wear time as the  
228 criterion for a valid day, the decrease in children wearing the AGhip for between 1 and 7 d was  
229 80.5%, in comparison to 62.0% for the GAwrist. A similar trend was observed when the  
230 inclusion of at least one weekend day was considered. With inclusion criteria of a minimum of  
231 10 h wear on at least 3 weekdays plus a minimum of one weekend day, GAwrist non-  
232 compliance (16.4%) was lower than for the AGhip (25.2%).

233

234 When the number of children classified as 'included' as defined by commonly used wear time  
235 criteria (27) were analysed, significantly more children achieved wear time criteria when  
236 wearing the GAwrist than the AGhip for at least  $9 \text{ h}\cdot\text{d}^{-1}$  ( $p=.002$ ) and  $10 \text{ h}\cdot\text{d}^{-1}$  ( $p=.035$ ) on any  
237 4 d of the week (Table 2). When a weekend day was included in the criteria this level of  
238 compliance was achieved by significantly more children wearing the GAwrist than the AGhip  
239 for either  $9 \text{ h}\cdot\text{d}^{-1}$  or  $10 \text{ h}\cdot\text{d}^{-1}$  over 2, 3, and 4 week days ( $p=.001-.002$ ). Average daily wear time  
240 across the different wear time criteria ranged from 15.57 to 15.82  $\text{h}\cdot\text{d}^{-1}$  for the GAwrist, and  
241 14.18 to 14.21  $\text{h}\cdot\text{d}^{-1}$  for the AGhip. GAwrist daily wear time was significantly higher than for  
242 the AGhip, regardless of wear time criteria applied ( $p<.001$ ). Children wore the GAwrist for  
243 significantly more days than the AGhip. When a valid day was defined as at least 9 h wear, the  
244 GAwrist was worn for 5.8 d out of 7 d compared to 5.1 d for the AGhip ( $p<.001$ ), and for 5.6  
245 d versus 4.9 d when 10 h wear was the criterion ( $p<.001$ ). During weekdays the GAwrist was  
246 worn for 4.2 d (9 h) and 4.1 (10 h) in comparison to 3.8 d ( $p<.001$ ) and 3.7 d ( $p<.001$ )  
247 respectively, for the AGhip. The GAwrist was also worn most at weekends when valid day

248 minimum wear was set to 9 and 10 h (GAwrist: 1.6 d and 1.5 d, respectively; AGhip: 1.3 d and  
249 1.2 d, respectively;  $p < .001$ ).

250 TABLE 2 HERE

251 *Raw data physical activity levels*

252 Significant partial correlations between raw data PA outcomes confirmed that after adjustment  
253 for wear time, SVM ( $r = .68$ ), MPA ( $r = .81$ ), VPA ( $r = .85$ ), and MVPA ( $r = .83$ ) were  
254 moderately to strongly associated between devices ( $p < .001$ ). Bland-Altman plots are presented  
255 in Figure 1A-D and show that the extent of differences in SVM, MPA, VPA, and MVPA  
256 between GAwrist and AGhip increased linearly with children's levels of PA engagement.  
257 Correlation coefficients between mean and bias were  $r = .75$  (SVM),  $r = .64$  (MPA),  $r = .75$   
258 (VPA), and  $r = .69$  (MVPA).

259 FIGURE 1A-D HERE

260

261 Comparisons of PA levels between devices are presented in Table 3. Wear time and sex-  
262 adjusted SVM values during the whole week, weekdays, and weekend days were significantly  
263 higher for the GAwrist than the AGhip ( $p = .001$ ). MPA recorded by the GAwrist on weekdays,  
264 weekend days, and over the whole week was 45.2% ( $p = .07$ ), 41.1% ( $p = 0.1$ ), and 44.2% ( $p = .04$ )  
265 greater respectively, than values derived from the AGhip. GAwrist VPA was also significantly  
266 higher than AGhip at the different times of the week ( $p = .02 - .001$ ), with the greatest difference  
267 of 54.7% occurring at weekends. MVPA was 43.3-45.7% greater for the GAwrist than the  
268 AGhip across the whole week, week days, and weekend days. According to the GAwrist raw  
269 data, 86.9% of children engaged in at least 60 min MVPA $\cdot$ d<sup>-1</sup>, compared to 19% according to  
270 AGhip-derived MVPA.

271 TABLE 3 HERE

272 *Physical activity levels from AGhip raw and counts data*

273 Analyses of raw and counts data for AGhip revealed that children's adjusted whole week MPA  
274 (raw) was  $42.00 \pm 1.61 \text{ min}\cdot\text{d}^{-1}$  compared to  $35.05 \pm 0.99 \text{ min}\cdot\text{d}^{-1}$  (counts) ( $p=.02$ ), a difference  
275 of 16.5% (Figure 2). Adjusted VPA differed by 79.5% between counts ( $37.06 \pm 1.85 \text{ min}\cdot\text{d}^{-1}$ )  
276 and raw data ( $7.59 \pm 0.46 \text{ min}\cdot\text{d}^{-1}$ ;  $p=.19$ ). These combined MPA and VPA differences were  
277 reflected in overall MVPA ( $72.11 \pm 2.60 \text{ min}\cdot\text{d}^{-1}$  [counts] vs.  $49.59 \pm 2.01 \text{ min}\cdot\text{d}^{-1}$  [raw];  
278  $p=.57$ ). The recommended  $60 \text{ min}\cdot\text{d}^{-1}$  of MVPA was achieved by 20.2% and 67.7% of children  
279 with valid raw and counts data, respectively.

280 FIGURE 2 HERE

281 DISCUSSION

282 In 2009 experts in PA measurement recommended that researchers' estimations of PA should  
283 in future be based on raw acceleration data rather than proprietary movement counts (12). Since  
284 then more raw accelerometer data have been reported, but still much less frequently than counts  
285 data. This study adds to the raw accelerometer data evidence base, as it is the first to examine  
286 children's compliance to wrist and hip-worn devices, between-device differences in PA  
287 intensities derived from raw accelerations, and differences in hip-mounted ActiGraph GT3X+  
288 raw acceleration versus counts-based estimates of free-living PA.

289 *Accelerometer compliance*

290 More children wore the GAwrist than AGhip irrespective of the wear time inclusion criteria  
291 applied or time of week observed. Using the wrist as the accelerometer placement site may  
292 promote better device compliance, as illustrated by the improved wear time reported in the  
293 2011-12 NHANES data collection cycle (30). There is though a paucity of research  
294 investigating children's compliance to wrist and hip-worn accelerometers worn in parallel.  
295 While it has been suggested that children (34) and adults (39) prefer the wrist as the device

296 placement site, such preferences may be partly dependent upon specific device features (e.g.,  
297 feedback on activity (34)) and monitor-specific wear instructions (e.g., removal of hip-worn  
298 devices during sleep and water-based activities (39)). This latter point is exemplified by a  
299 recent examination of hip-worn ActiGraph data from 9-11 y olds across 12 countries, which  
300 reported how a 24 h accelerometer wear protocol resulted in an average wear time of 22.6 h  
301 **REF TUDOR-LOCKE**. Thus, asking children to only remove devices for water-based activities  
302 elicits much greater total wear times than are typically observed in waking time protocols.  
303 Waking wear time though was 14.7 h·d<sup>-1</sup> **REF TUDOR-LOCKE** which was similar to the  
304 AGhip values and less than the GAwrist values observed in our study. These findings confirm  
305 the combined influences of wear location and protocol on accelerometer wear compliance. To  
306 our knowledge no previous studies have examined children's compliance to wearing wrist and  
307 hip-mounted accelerometers concurrently. Our findings confirm that children's perceived  
308 acceptability of and preference for wrist-worn devices (34), reflect actual wear when children  
309 were asked to use two devices under the same conditions. Where feasible, future youth PA  
310 studies should employ wrist-worn accelerometry to increase the likelihood of longer wear time  
311 which would result in more representative and reliable estimates of PA (17). Wrist-worn  
312 devices may not only result in superior compliance, but according to recent evidence, may also  
313 provide better estimates of children's energy expenditure compared to hip mounted  
314 accelerometers (7). For wrist-worn accelerometry to become widely adopted however, more  
315 needs to be known about the comparability of children's PA levels derived from raw  
316 accelerations, with historical counts-based data.

### 317 *PA derived from raw acceleration signals of wrist and hip worn accelerometers*

318 Correlations between wrist-worn GENEActiv and hip-worn ActiGraph free-living raw  
319 accelerations have not previously been reported in children. We observed moderate to strong  
320 partial correlations between AGhip and GAwrist ( $r = .68-.85$ ) which were lower than the

321 recently reported correlation of  $r = .93$  between hip worn GENEActiv and ActiGraph GT3X+  
322 average accelerations (29). Our findings indicate that both devices measured children's free-  
323 living accelerations which explained almost 70% of the shared variance in MVPA.  
324 Notwithstanding these strong associations, there were considerable differences between  
325 devices in average SVM and time spent in MPA, VPA, and MVPA. GAwrist values were  
326 consistently higher than those from the AGhip, particularly at higher intensities. These  
327 differences were most extreme for SVM values (~60%) which were calculated for both devices  
328 using identical data processing methods. In the only previous study to compare children's raw  
329 GAwrist and AGhip data using the ENMO data processing approach, GAwrist SVM was  
330 significantly higher for a range of moderate-to-vigorous activities performed during a  
331 controlled device calibration protocol (i.e., fast walking, stepping, running, and circuit training)  
332 (13). Moreover, in agreement with our MPA and VPA results, greater relative differences  
333 between AGhip and GAwrist SVM values were observed as activity intensity increased (13).  
334 Similar differences between devices worn at the same site have previously been reported in  
335 adults as well as children regardless of analytical approaches used to generate raw accelerations  
336 (16, 29, 30). During vigorous ambulatory activities such as fast running, higher accelerations  
337 at the wrist relative to the hip may be observed due to greater shoulder muscle activity,  
338 compared to during walking and slow running, when arm swing and resultant wrist  
339 accelerations are more passive (31). Moreover, wrist accelerations will be disproportionately  
340 greater than those of the hip for certain types of movements that may occur regularly during  
341 children's free-living activity (e.g., some sports, computer gaming, homework), and for  
342 example among children who gesticulate vigorously (30). This 'decoupling' of wrist and hip  
343 accelerations may also occur in reverse (e.g., walking with hands in pockets) and is likely  
344 population-specific (30). We did not record the children's activity modes but it may be feasible

345 that their daily activities involved a disproportionate volume of ‘pro-wrist’ decoupling of wrist  
346 and hip accelerations, which contributed to higher GA<sub>wrist</sub> values.

347

348 Although device location is arguably the most obvious reason why PA outcomes differed to  
349 the extent that they did, the strong inter-device associations between outcomes suggest that  
350 placement was not the only reason. Raw acceleration data from each device were used to  
351 generate the PA outcomes, but data cannot be considered equivalent (40), as raw accelerations  
352 for the GENEActiv have been observed to be greater than those for the ActiGraph GT3X+  
353 when worn at the same site in controlled and free-living conditions (16, 29, 31). For example,  
354 during mechanical shaker testing GENEActiv peak accelerations were up to 7.4% greater than  
355 ActiGraph GT3X+ with differences increasing in line with shaker acceleration magnitude (16).  
356 Similarly, average GENEActiv high-pass filtered accelerations were recently observed to be  
357 over 10% greater than ActiGraph GT3X+ accelerations when both devices were worn at the  
358 hip during children’s free-living activities (29). Technical differences between devices, such  
359 as the micro-electro-mechanical sensors used and their dynamic ranges, reference voltage,  
360 analogue-to-digital conversion rate, and ActiGraph’s proprietary data filtering processes (15,  
361 16, 29), are the likely explanations of the differences in each device’s acceleration outputs.

362

### 363 *Comparison of raw and counts PA data measured by a hip-mounted accelerometer*

364 Systematic differences in AG<sub>hip</sub> PA outcomes from raw and counts data were not observed.  
365 Raw data MPA values were 15.9% higher than counts data, but raw data VPA values were  
366 79.6% lower than counts data. To our knowledge, no previous study has compared hip-  
367 mounted ActiGraph GT3X+ raw and counts data output in children. The closest comparison is  
368 provided by Rowlands and colleagues who compared ActiGraph GT3X+ counts data using the  
369 cutpoints of Evenson et al. (10) with GENEActiv raw data, with both devices worn at the hip



370 (30). The comparison is based on the very strong associations between devices for MVPA  
371 measured at the hip ( $r=.93$ ) (30). Rowlands et al.'s findings mirrored ours whereby raw data  
372 MPA was greater than counts data (56.7 vs. 32.3  $\text{min}\cdot\text{d}^{-1}$ ), but was lower for VPA (11.1 vs.  
373 30.0  $\text{min}\cdot\text{d}^{-1}$ ) (30). The magnitude of the differences though differed somewhat, which may  
374 relate to the different raw data processing procedures and raw acceleration cutpoints (25)  
375 applied between our study and that of Rowlands and colleagues (30). It is likely that  
376 comparable raw acceleration values reported by Rowlands et al. would have been higher than  
377 those observed in our study, due to differences in raw acceleration data processing (i.e.,  
378 converting acceleration negative values to their absolute, summing acceleration values per 1-s  
379 epoch) (9, 13, 25). Moreover, the PA intensity cutpoints used in both studies were derived from  
380 different calibration protocols (13, 25), which may be a more influential factor on PA outcomes  
381 than placement site or device type (30). While some inferences about output differences can be  
382 made on the basis of raw acceleration data processing, the proprietary nature of the ActiGraph  
383 GT3X+ algorithm to convert raw acceleration into counts makes similar suppositions difficult.  
384 These findings demonstrate that raw acceleration and counts data cannot be directly compared  
385 because insufficient information is available about how counts are generated. This reinforces  
386 the calls of others (14, 20, 24) for transparent raw accelerometer data processing to become the  
387 norm so as to progress the field towards equivalency of data output and better scope for  
388 comparability of findings between studies using different devices.

389

390 A strength of this study is that it is the first to assess children's free-living PA derived from  
391 raw wrist and hip accelerations using the GENEActiv and ActiGraph GT3X+ accelerometers,  
392 respectively. Further, for the first time, children's compliance to wearing these devices  
393 concurrently over a 7-d monitoring protocol has been reported. Wearing the accelerometers in  
394 parallel standardizes possible confounding variables such as the type of PA performed during

395 the monitoring period (39). Raw acceleration data were processed and analysed using the same  
396 open source procedures which adds transparency and consistency to the data. The study sample  
397 was though limited to 9-10 y olds in a low socioeconomic area of England and our findings  
398 should be interpreted and applied with this in mind as free-living PA routines may be different  
399 for other age groups and for children from other areas. A further limitation is that data were  
400 collected during school term times and so may not be representative of PA during extended  
401 non-school time such as school holidays and vacations. We also did not report time spent being  
402 sedentary or in light intensity PA. Children's sedentary time and light PA are associated with  
403 various health outcomes but presently, raw acceleration thresholds for GENEActiv and  
404 ActiGraph GT3X+ based on the ENMO metric do not exist, and so we were limited to reporting  
405 MPA, VPA, and MVPA.

406

407 During free-living activity children had significantly better compliance to wearing the GAwrst  
408 than AGhip. The recognised association between duration of monitoring and reliability of PA  
409 data means that better compliance gives researchers and research users greater confidence in  
410 the PA data reported. The superior compliance of the GAwrst confirms that the wrist is a  
411 feasible accelerometer placement location in children. Raw acceleration values derived using  
412 the same data processing procedures were significantly higher for GAwrst compared to  
413 AGhip. It is unclear why these disparities occurred but it was likely a combination of the effects  
414 of placement location and technical differences between the GENEActiv and ActiGraph  
415 GT3X+. To address this, it has been recently suggested that differences in acceleration  
416 magnitude between GENEActiv and ActiGraph GT3X could be addressed by the application  
417 of an appropriate conversion factor to make values interchangeable between devices (29). For  
418 this approach to be effective standardized data processing procedures would need to be applied  
419 to the raw acceleration data collected. AGhip PA levels calculated from raw accelerations and

420 counts differed substantially, particularly in respect of VPA. These findings demonstrate that  
421 regardless of device placement location raw output and counts cannot be directly compared  
422 because of the lack of information about the ActiGraph proprietary filtering algorithm applied  
423 to generate counts. Raw acceleration data processing potentially enables greater transparency,  
424 and comparability between studies using the same data processing methods, though  
425 comparisons to counts-based data are limited . From a health promotion perspective, current  
426 PA guidelines are mainly based on self-report questionnaires and to a lesser extent, data from  
427 hip mounted accelerometer counts. As the use of raw acceleration data increases, examination  
428 of activity-health relationships using raw data from wrist mounted devices is warranted. We  
429 used the ENMO metric to calculate SVM but presently no SVM thresholds for children’s light  
430 PA and sedentary time exist using this method. Future work should include development of  
431 these thresholds which may help enhance our understanding of the influence of device type  
432 and placement location on children’s free-living raw accelerations and associated health  
433 outcomes.

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#### 437 CONFLICTS OF INTEREST

438 The authors declare no conflicts of interest. The results of the present study do not constitute  
439 endorsement by ACSM.

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## FIGURE CAPTIONS

540 Figure 1A-D. Bland-Altman plots displaying agreement between AGhip and GAwrist derived  
541 (A) SVM, (B) MPA, (C) VPA, and (D) MVPA. Note. The observed positive bias indicates that

542 GA<sub>wrist</sub> values were higher than AG<sub>hip</sub>. Horizontal lines represent mean bias and 95% limits  
543 of agreement.

544 Figure 2. Whole week MPA and VPA according to AG<sub>hip</sub> counts and raw data (n = 65)

545 \* AG<sub>hip</sub> raw MPA > AG<sub>hip</sub> counts MPA, p=.02

546

547 LIST OF SUPPLEMENTAL DIGITAL CONTENT

548 Supplemental Digital Content 1. Table showing percentage of children available for analyses  
549 according to daily wear time and number of wear days.pdf