2

3   *Title: Comparison of children's free-living physical activity derived from wrist and hip raw*

4   *accelerations during the segmented week.*

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Abstract

This study assessed children's physical activity (PA) levels derived from wrist-worn GENEActiv and hip-worn ActiGraph GT3X+ accelerometers and examined the comparability of PA levels between the two devices throughout the segmented week. One hundred twenty nine 9-10 year old children (79 girls) wore a GENEActiv (GAwrist) and ActiGraph GT3X+ (AGhip) accelerometer on the left wrist and right hip respectively for seven days. Mean minutes of light PA (LPA) and moderate-to-vigorous PA (MVPA) per weekday (whole-day, before-school, school and after-school) and weekend day (whole-day, morning and afternoon-evening) segments were calculated, and expressed as percentage of segment time. Repeated measures ANOVA examined differences in LPA and MVPA between GAwrist and AGhip for each time segment. Bland–Altman plots assessed between-device agreement for LPA and MVPA for whole weekday and whole weekend day segments. Correlations between GAwrist and AGhip were weak for LPA (r=0.18-0.28), but strong for MVPA (r=0.80-0.86). LPA and MVPA levels during all weekday and weekend day segments were significantly higher for GAwrist than AGhip (p<0.001). The largest inter-device percent difference of 26% was observed in LPA during the school day segment. Our data suggest that correction factors are needed to improve raw PA level comparability between GAwrist and AGhip.

Introduction

Accelerometers provide valid and reliable assessments of physical activity (PA) at varying intensities in children (Butte, Ekelund, & Westerterp, 2012; de Vries et al., 2009), and are the most widely used objective measure of child PA (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013). One of the advantages of using accelerometers is their ability to capture PA variability within and between days. Accelerometer device output is traditionally expressed as an arbitrary 'count' value which is then related to specific PA intensity thresholds. Due to differences in how raw data are processed, filtered, and scaled, count data cannot be directly compared across studies using different accelerometer devices (Welk, McClain, & Ainsworth, 2012). However, the latest versions of accelerometers, including

48 GENEActiv and ActiGraph GT3X+ can provide raw, unfiltered acceleration data. Compared to

49 traditional count-based approaches, raw acceleration data offers greater control over data reduction,

50 potentially allowing comparisons to be made more easily between studies using different accelerometer

51 brands (Fairclough et al., 2016; Hildebrand, Van Hees, Hansen, & Ekelund, 2014).

52 Aside from the challenge of comparing PA levels between device brands, another challenge is the

53 comparability of PA levels between devices placed at different body locations. Traditionally,

54 accelerometers are worn at the hip to capture whole-body movement, but compliance to device wear is

55 typically low (Fairclough et al., 2016). In an attempt to improve device wear there has been an increased

56 use of wrist-worn accelerometers, including the GENEActiv. Compared to hip-worn accelerometers,

57 wrist-worn accelerometers are more sensitive to upper body movement (e.g. climbing, throwing) but

58 less sensitive to sedentary activities (Ellis et al., 2014; Ellis, Kerr, Godbole, Staudenmayer, & Lanckriet,

59 2016; Kim, Lee, Peters, Gaesser, & Welk, 2014). This may limit the comparison of findings between

60 studies using wrist and hip-worn accelerometers. Given the increased use of the wrist-worn GENEActiv

61 (da Silva et al., 2014; Edwardson et al., 2015; Keane, Kearney, Perry, Browne, & Harrington, 2014;

62 Wake et al., 2014), and the wealth of existing international data obtained from hip-worn ActiGraph

63 accelerometers (Cooper et al., 2015; Corder et al., 2016; Sherar et al., 2011) it is important to understand

64 whether PA estimates derived from GAwrist and AGhip are comparable.

65 Fairclough et al. (2016) compared children's whole-day MPA and VPA derived from the GAwrist and

66 AGhip and found that mean PA levels for both intensities were significantly higher for the GAwrist

67 than the AGhip. However, the comparability of PA levels between the GAwrist and AGhip at the lower

68 end of the intensity spectrum is less well understood. Moreover, the agreement between the GAwrist

69 and AGhip may fluctuate in response to variability in PA levels both within and between days (Brooke,

70 Corder, Atkin, & van Sluijs, 2014; Fairclough, Beighle, Erwin, & Ridgers, 2012). However, studies

71 comparing GAwrist and AGhip data have been limited to reporting PA estimates (Fairclough et al.,

72 2016; Rowlands et al., 2014), and raw accelerations across the whole day (Rowlands et al., 2015).

73 Therefore, little is known about their comparability across specific time-segments. For that reason, the

74 aim of this study was to assess children's PA levels derived from GAwrist and AGhip raw acceleration

75 data, and examine the comparability of PA levels between the two devices throughout the segmented

76 week.

Methods

Participants and settings

79 The participants were 129 children (79 girls) aged 9-10 years (age: 10.1 ± 0.3 y (mean $\pm$ SD)) from six

80 schools in Liverpool, England. After ethical approval from the university research ethics committee

81 (13/SPS/048), all year 5 children (n = 326) in participating schools were invited to participate and

82 received parent and child information sheets, and consent and assent forms, to take home to parents and

83 return upon completion. Written informed consent and assent were received from parents and their

84 children, respectively, before children could participate in the study. Data collection took place between

85 January and May 2014.

Procedure and measurements

87 Each child wore a GENEActiv (GAwrist; Activinsights, Cambs, UK) and ActiGraph GT3X+ (AGhip;

88 ActiGraph, Pensacola, FL) accelerometer on their left wrist and right hip, respectively, for seven

89 consecutive days. The GAwrist was selected because it measures raw accelerations, is typically worn

90 on the wrist, and has demonstrated reliability and validity in child populations (Phillips, Parfitt, &

91 Rowlands, 2013). ActiGraph accelerometers are the most commonly used accelerometer in child PA

92 research (Cain et al., 2013). The GT3X+ model was selected because it is traditionally worn on the hip

93 (Rosenberger et al., 2013), has the capability to generate raw acceleration, and has been validated for

94 use with children (Hanggia, Phillips, & Rowlands, 2013; Robusto & Trost, 2012). Children were

95 instructed to wear both monitors concurrently during all waking hours except when engaged in water-

96 based activities. Verbal and written instructions for care and placement of the monitors were given to

97 children. Prior to testing, monitors were synchronised with Greenwich Mean Time (GMT) and

98   programmed to record data at 100 Hz. Data collection took place during the regular school term so

99   activities were representative of usual free-living activities.

100 *Data analysis*

101 GAwrist data were downloaded using GENEActiv v.2.2 software (Activinsights, Cambs, UK) and

102 saved in raw format as binary files. AGhip data were downloaded using ActiLife v. 6.11.4 (ActiGraph,

103 Pensacola, FL) and saved in raw format as GT3X files. These were subsequently converted to CSV

104 format to facilitate raw data processing. GAwrist and AGhip raw data files were then processed in R

105 (http://cran.r-project.org) using the GGIR package (version 1.1-4) which converted raw triaxial

106 acceleration values into one omnidirectional measure of acceleration, termed the signal vector

107 magnitude (SVM). SVM was calculated from raw accelerations from the three axes minus $1g$ which

108 represents the value of gravity (i.e., $SVM = \sqrt{(x^2 + y^2 + z^2)} - 1$), after which negative values were

109 rounded to zero. This metric is referred to as the Euclidean norm minus one (ENMO) (van Hees et al.,

110 2013). Raw data were further reduced by calculating the average SVM values per 1-s epoch expressed

111 in *mg* over each of the 7 monitored days. Wear time periods for raw data from GAwrist and AGhip

112 were estimated on the basis of the standard deviation and value range of each axis, calculated for 60

113 min moving windows with 15 min increments (van Hees et al., 2013). A time window was classified as

114 non-wear time if, for at least 2 out of the 3 axes, the standard deviation was less than 13.0 *mg* or if the

115 value range was less than 50 *mg* (van Hees et al., 2013). A valid day was classified as 10 hours or more

116 of device wear. At a minimum, children were required to have worn both devices on the same 3 days

117 including 1 weekend day to be included in the analyses. (Mattocks et al., 2008).

118 We used device specific prediction equations provided by Hildebrand et al. (2014) to identify ENMO

119 cut-points for classifying LPA and MVPA (Hildebrand et al., 2014). It has recently been reported that

120 in youth 2 METs and 4 METs had higher classification accuracy for differentiating sedentary time (from

121 LPA) and MVPA (from LPA), respectively, compared with 1.5 METs and 3 METs (Saint-Maurice,

122 Kim, Welk, & Gaesser, 2016). Therefore, the Hildebrand equations were solved for 2 METs and 4

123 METs resulting in LPA and MPVA cut-points of 23.5*mg* and 359.7*mg*, respectively, for GAwrist, and

124   35.2*mg* and 249.9*mg*, respectively, for AGhip. For example, the GAwrist LPA *mg* cut-point threshold

125   was calculated as follows: $mg = ((2METs \times 6 \text{ mL O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) - 11.16)/0.0357 = 23.5mg$.

126   Once converted to minutes of LPA and MVPA, data were sorted into hourly segments from 06:30 until

127   23:59 on weekdays and weekend days using Stata (STATA/SE Version 12; StataCorp LP, College

128   Station, TX) code developed by the third author. Sleep time was defined as midnight until 06:30. These

129   hourly values were then used to construct whole-day and segmented day minutes of LPA and MVPA.

130   During weekdays the following time segments were used: before-school (06.30 to 08:59), during school

131   (09:00 to 15:29), and after-school (15:30 to 23:59). For weekend days the segments were: morning

132   (06:30 to 11:59) and afternoon-evening (12:00 to 23:59). Variables were calculated by summing

133   minutes spent in each activity threshold during each discrete time segment. Mean minutes of GAwrist

134   and AGhip LPA and MVPA data for each segment were divided by total segment time, multiplied by

135   100, and expressed as percentage of total segment time.

136   The primary outcome variables were percentage segment time for LPA and MVPA. Repeated measures

137   ANOVAs examined between segment differences for each device (e.g., GAwrist LPA whole weekday

138   vs GAwrist LPA whole weekend day), and between device differences for each segment (e.g., GAwrist

139   LPA whole weekday vs AGhip LPA whole weekend day). Pearson correlation analyses examined

140   associations between the two devices for percentage of time spent in LPA and MVPA during whole-

141   day weekday and weekend day. Bland–Altman plots were constructed to assess between-device

142   agreement of LPA and MVPA for whole weekday and whole weekend day segments. All analyses were

143   conducted using IBM SPSS Statistics v.23 (IBM, Armonk, NY) and Microsoft Excel 2010 (Microsoft,

144   Redmond, WA). For all analyses, statistical significance was set at 0.05.

145   **Results**

146   AGhip and GAwrist data were available for 115 and 128 children, respectively. Participants not meeting

147   the wear time criteria for either monitor were excluded from analyses. This reduced the sample to 107

148   (67 girls) for the GAwrist and 83 (51 girls) for the AGhip. Children without 3 valid days for both

149 monitors were then excluded from the analysis, resulting in a final analytical sample of 77 (48 girls)

150 participants. There were no significant differences for any of the measured variables between children

151 included in analyses and those excluded. Means and 95% confidence intervals (CI) for PA outcomes

152 on weekdays and weekend days for GAwrist and AGhip are presented in Table 1. Whole weekday PA

153 outcomes were higher than mean whole weekend day PA outcomes ($p<0.05$). PA outcomes were higher

154 during the school segment compared to all other weekday segments ($p<0.001$). On weekend days

155 children were more active in the afternoon-evening compared to the morning ($p<0.01$).

156 GAwrist PA levels were significantly higher than AGhip PA levels during all weekday and weekend

157 day segments ($p<0.001$; Table 1) but varied between time segments and PA intensities. On weekdays

158 the largest inter-device differences in PA levels occurred during the school segment (LPA 26.7%;

159 MVPA 1.8%; $p<0.001$), and the smallest inter-device differences occurred in the before school segment

160 (LPA 10.3%; MVPA 0.5%; $p<0.001$). On weekend days the largest inter-device differences occurred

161 in the afternoon-evening (LPA 17.7%; MVPA 1.6%; $p<0.001$), and the smallest inter-device differences

162 occurred in the morning (LPA 10.3%, MVPA 0.8%; $p<0.001$). For all intensities the magnitude of inter-

163 device differences was largest at weekends compared to weekdays.

164 Significant correlations between whole weekday ($r=0.80$) and whole weekend day ($r=0.86$) MVPA

165 levels confirmed that MVPA was strongly associated between devices ($p<0.001$). Correlations between

166 the devices were weak for LPA during whole weekdays ($r=0.28$ $p<0.01$) and whole weekend days

167 ($r=0.18$; $p=0.11$). Bland–Altman plots (Figure 1) show the extent of differences in LPA and MVPA

168 between GAwrist and AGhip during whole weekdays and weekend days.

169 [TABLE 1 NEAR HERE]

170 [FIGURE 1 NEAR HERE]

171   **Discussion**

172 This is the first study to compare children's LPA and MVPA assessed with GAwrist and AGhip across

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173   distinct time windows in a week. Another novel aspect of this study is the use of raw data processing

174   techniques, which theoretically enables direct comparisons of activity outcomes obtained from different

175   accelerometer brands. Overall, we observed weak correlations between AGhip and GAwrist for LPA

176   (r=0.18-0.28), but strong correlations for MVPA (r=0.80-0.86). The strong correlations observed for

177   MVPA are similar to those reported by Fairclough et al. (2016). They are though slightly lower than

178   the reported correlation of r=0.93 between hip-worn GENEActiv and ActiGraph GT3X+ mean

179   accelerations (Rowlands et al., 2015). Despite these strong associations, we found that GAwrist derived

180   PA levels were consistently higher than those derived from the AGhip for all outcome variables and

181   across various time segments. These findings suggest that child PA surveillance is strongly influenced

182   by device brand and body placement.

183   LPA and MVPA levels during all weekday and weekend day segments were significantly higher for the

184   GAwrist than those for the AGhip (p<0.001). Previous research comparing whole-day accelerometer

185   output from wrist-worn GENEActiv and hip-worn ActiGraph in children reported similar findings

186   (Fairclough et al., 2016; Hildebrand et al., 2014). Fairclough et al. (2016) reported a 68% difference in

187   the number of children achieving at least 60 minutes of MVPA per day using the GENEActiv compared

188   to ActiGraph GT3X+. Similarly, Rowlands et al. (2015) found that average daily accelerations from the

189   wrist-worn GENEA were between 12%−13% higher than the ActiGraph GT3X+. Another recent study

190   found that the ActiGraph GT3X+ worn on the wrist produced higher average step counts per day

191   compared to the ActiGraph GT3X+ at the hip in free-living environments, but fewer steps during

192   laboratory treadmill testing (Tudor-Locke, Barreira, & Schuna, 2015). These contrasting differences in

193   step outputs between research settings are likely consequential of the restrictive nature of treadmill

194   walking which minimises free swinging of the arms relative to free-living.

195   A unique element of this study is the comparison of PA levels between GAwrist and AGhip across

196   different time segments. We found that differences in PA levels between the two devices varied in

197   magnitude between intensity levels. As the intensity level increased, the magnitude of the difference in

198   PA levels between the GAwrist and AGhip decreased. The largest differences in PA levels were seen

199   in LPA. . Mean GAwrist LPA was over 100% higher than that for the AGhip in all segments with the

200   exception of the before school segment.

201   During free-living children typically engage in a range of seated activities that involve a high level of

202   arm movement but limited movement at the hip (Kim et al., 2014). Unsurprisingly, during such

203   activities, disproportionate levels of acceleration will be observed at the wrist relative to the hip. This

204   is reflected by the high inter-device difference in LPA during the school day segment. LPA accounted

205   for 42.6% and 15.6% of school segment time for the GAwrist and AGhip, respectively, a difference of

206   over 26%. The profound difference in LPA observed during the school day likely reflects these

207   disjointed wrist and hip movement patterns when children characteristically spend a large proportion of

208   the day seated at a desk reading, writing, or using a computer which all involve some element of wrist

209   movement. Greater accelerations will also be observed at the wrist relative to the hip during mixed

210   static/dynamic movements (e.g., playing catch), and high intensity activities such as running and

211   jumping that naturally incur a medium to high level of shoulder and upper body rotation (Ellis et al.,

212   2014, 2016; Kim et al., 2014). However, the level of decoupling (i.e., greater acceleration capture at

213   one wear site relative to the other) during such activities is likely dependent on individual biomechanics

214   (i.e., level of arm swing), and thus will be population specific (Rowlands & Stiles, 2012; Tudor-Locke

215   et al., 2015).

216   The weaker correlations and larger inter-device differences observed for LPA compared to MVPA

217   suggests that in children of this age, pro-wrist "decoupling", is more dominant during LPA. In contrast,

218   earlier studies observed greater decoupling as the magnitude of acceleration increased. However, these

219   studies did not examine accelerations at intensities lower than 3 METs (Fairclough et al., 2016;

220   Hildebrand et al., 2014). Children's free-living accelerations were over 10% greater for the GENEActiv

221   compared to the ActiGraph in a recent study when both devices were worn at the hip (Rowlands et al.,

222   2015). This suggests that additional factors other than monitor placement may have also contributed to

223   the observed differences in GAwrist and AGhip PA levels. Similarly, John, Sasaki, and Staudenmayer

224   (2013) found that GENEActiv peak accelerations were up to 7.4% greater than ActiGraph peak

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225 accelerations during mechanical shaker testing. Irrespective of placement location, potential factors that

226 may cause inter-monitor differences in raw acceleration between the GAwrist and AGhip include

227 differences in microelectromechanical sensors, dynamic ranges and proprietary filtering processes used

228 to minimise signal distortion during initial analogue-to-digital conversion (John & Freedson, 2012; John

229 et al., 2013). Therefore, the current generation of accelerometry-based monitors may not be directly

230 compared with each other even at the raw acceleration level, due to the discrepancies in how the raw

231 data are collected and filtered. Further research and/or discussions are required to achieve the "true"

232 harmonization of raw data collected from different types of devices.

233 A common outcome in child PA research is time spent in MVPA which is used to identify the number

234 of children meeting the PA guidelines (i.e. at least 60 min of MVPA per day) (Chief Medical Officers,

235 2011). To complicate comparisons further between GAwrist and AGhip, accelerometer data are

236 commonly analysed using a broad range of intensity thresholds leading to widely varying estimates of

237 MVPA within and between studies (Guinhouya, Samouda, & de Beaufort, 2013; Routen, Upton,

238 Edwards, & Peters, 2012). For example, Schaefer, Nace, and Browning (2014) found that estimates of

239 wrist derived MVPA decreased by 27% (from 308 to 225 minutes) when the MVPA cut-point threshold

240 was increased from 3 METs to 4 METs. The difference in MVPA levels between GAwrist and AGhip

241 within this study and between other studies highlights the influence of device and wear location on

242 MVPA prevalence, and the challenge of comparing MVPA data between studies using different

243 intensity thresholds and devices worn at different body locations. Rowlands et al. (2015) found that

244 applying a population specific correction factor to the GAwrist data removed the significant difference

245 in accelerations between GAwrist and AGhip data. This method may therefore be an appropriate way

246 of improving the comparability of findings between studies using different device brands and placement

247 locations in the future.

248 This is the first study to examine the comparability of GAwrist and AGhip derived LPA and MVPA

249 throughout the segmented week. The study observed differential agreement between GAwrist and

250 AGhip. Agreement differed according to PA intensity and time of day, with the greatest difference

251 occurring in LPA during school hours. Future studies should therefore be cautious when comparing PA

252 data derived from GAwrist and AGhip, especially studies investigating children's school day PA and

253 segmented days. PA levels were derived from raw acceleration data and were processed and analysed

254 using the same open-source procedures, which adds transparency and consistency to the data. However,

255 the results of this study were performed in a relatively small sample of children living in a highly

256 deprived area of England, which limits the generalisability of findings to other locations and

257 populations. Device wear time was greater for the GAwrist compared to the AGhip which may have

258 contributed to the observed differences in PA levels. The inclusion criteria used in this study for whole-

259 day device wear is consistent with recommendations and common practices, but we did not apply wear

260 time criteria to specific time segments (e.g., before-school). This may have biased the PA outcomes for

261 individual segments depending on segment wear time.

262 **Conclusion**

263 In conclusion, PA levels from the GAwrist and AGhip are not comparable under free-living conditions.

264 PA levels derived using raw data processing procedures were significantly higher for GAwrist

265 compared with those for AGhip during all time segments. The magnitude of these differences was

266 greatest during school hours and in LPA. Comparisons of raw data assessed by different monitors worn

267 at the wrist and hip in children should therefore be undertaken with caution. We recommend the

268 development of PA level correction factors to aid comparison of findings between studies using the

269 GAwrist and AGhip.

270

271 **References**

272 Brooke, H. L., Corder, K., Atkin, A. J., & van Sluijs, E. M. F. (2014). A Systematic Literature Review

273 with Meta-Analyses of Within and Between-Day Differences in Objectively Measured Physical

274 Activity in School-Aged Children. *Sports Medicine*, *44*, 1427–1438.

275 Butte, N. F., Ekelund, U., & Westerterp, K. R. (2012). Assessing Physical Activity Using Wearable

276 Monitors: Measures of Physical Activity. *Medicine & Science in Sports & Exercise*, *44*(1 Suppl), S5–

277 S12.

278 Cain, K. L., Sallis, J. F., Conway, T. L., Van Dyck, D., & Calhoon, L. (2013). Using Accelerometers in

279 Youth Physical Activity Studies: A Review of Methods. *Journal of Physical Activity and Health*, *10*,

280 437-450.

281 Chief Medical Officers. (2011). *Start Active. Stay Active. A report on physical activity for health from*

282 *the four home countries.* London: Department of Health.

283 Corder, K., Sharp, S. J., Atkin, A. J., Andersen, L. B., Cardon, G., Page, A., … Sardinha, L. B., Ekelund,

284 U., & Van Sluijs EM, on behalf of the International Children's Accelerometry Database (ICAD)

285 Collaborators. (2016). Age-related patterns of vigorous-intensity physical activity in youth: the

286 International Children's Accelerometry Database. *Preventive Medicine Reports*, *4*, 17-22.

287 Cooper, A. R., Goodman, A., Page, A. S., Sherar, L. B., Esliger, D. W., van Sluijs, E. M., … Ekelund,

288 U. (2015). Objectively measured physical activity and sedentary time in youth: the International

289 children's accelerometry database (ICAD). *International Journal of Behavioral Nutrition and Physical*

290 *Activity*, *12*, 113.

291 da Silva, I. C. M., van Hees, V. T., Ramires, V. V., Knuth, A. G., Bielemann, R. M., Ekelund, U., …

292 Hallal, P. C. (2014). Physical activity levels in three Brazilian birth cohorts as assessed with raw triaxial

293 wrist accelerometry. *International Journal of Epidemiology*, *43*(6), 1959–1968.

294 de Vries, S. I., van Hirtum, W. J. E. M., Bekker, I., Hopman-Rock, M., Hirasing, R. A., & van

295 Mechellen, W. (2009). Validity and Reproducibility of Motion Sensors in Youth: A Systematic Update.

296 *Medicine & Science in Sports & Exercise*, *41*(4), pp. 818–827.

297 Edwardson, C. L., Harrington, D. M., Yates, T., Bodicoat, D. H., Khunti, K., Gorely, T., … Davies, M.

298 J. (2015). A cluster randomised controlled trial to investigate the effectiveness and cost effectiveness

299 of the 'Girls Active' intervention: a study protocol. *BMC Public Health*, 15, 526.

300 Ellis, K., Kerr, J., Godbole, S., Lanckriet, G., Wing, D., & Marshall, S. (2014). A random forest

301 classifier for the prediction of energy expenditure and type of physical activity from wrist and hip

302 accelerometers. *Physiological Measurement*, *35*, 2191–2203.

303 Ellis, K., Kerr, J., Godbole, S., Staudenmayer, J., & Lanckriet, G. (2016). Hip and Wrist Accelerometer

304 Algorithms for Free-Living Behavior Classification. *Medicine & Science in Sports & Exercise*, *48*(5),

305 933–940.

306 Fairclough, S. J., Beighle, A., Erwin, H., & Ridgers, N. D. (2012). School day segmented physical

307 activity patterns of high and low active children. *BMC Public Health*, *12*, 406.

308 Fairclough, S. J., Noonan, R. J., Rowlands, A. V., van Hees, V., Knowles, Z., & Boddy, L. M. (2016).

309 Wear compliance and activity in children wearing wrist and hip mounted accelerometers. *Medicine and*

310 *Science in Sports and Exercise*, *48*(2), 245–253.

311 Guinhouya, B. C., Samouda, H., & de Beaufort, C. (2013). Level of physical activity among children

312 and adolescents in Europe: a review of physical activity assessed objectively by accelerometry. *Public*

313 *Health*, *127*, 301-311.

314 Hanggia, J. M., Phillips, L. R. S., & Rowlands, A. V. (2013). Validation of the GT3X ActiGraph in

315 children and comparison with the GT1M ActiGraph. *Journal of Science and Medicine in Sport*, *16*(1),

316 40–44.

317 Hildebrand, M., Van Hees, V. T., Hansen, B. H., & Ekelund, U. (2014). Age-group comparibility of

318 raw accelerometer output from wrist- and hip worn monitors. *Medicine and Science in Sports and*

319 *Exercise*, *46*(9), 1816–24.

320 John, D., & Freedson, P. (2012). ActiGraph and Actical Physical Activity Monitors: A Peek under the

321 Hood. *Medicine & Science in Sports & Exercise*, *44*(1 Suppl), S86–S89.

322 John, D., Sasaki, J., Staudenmayer, J., Mavilia, M., & Freedson, P. (2013). Comparison of raw

323 acceleration from the GENEA and ActiGraph GT3X+ activity monitors. *Sensors*, *13*(11), 14754–63.

324 Keane, E., Kearney, P. M., Perry, I. J., Browne, G. M., & Harrington, J. M. (2014). Diet, physical

325 activity, lifestyle behaviours, and prevalence of childhood obesity in Irish children: the Cork Children's

326 Lifestyle Study Protocol. *JMIR Research Protocols*, *3*(3), e44.

327 Kim, Y., Lee, J-M., Peters, B. P., Gaesser, G. A., & Welk, G. J. (2014). Examination of Different

328 Accelerometer Cut-Points for Assessing Sedentary Behaviors in Children. *PLoS ONE*, *9*(4), e90630.

329 Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric Standardization Reference*

330 *Manual*. Champaign, IL: Human Kinetics.

331 Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S. N., Shield, J., … Riddoch, C. (2008). Use of

332 Accelerometers in a Large Field-Based Study of Children: Protocols, Design Issues, and Effects on

333 Precision. *Journal of Physical Activity & Health*, *5*(Suppl 1), S98-S111.

334 Phillips, L. R. S., Parfitt, G., & Rowlands, A. V. (2013). Calibration of the GENEA accelerometer for

335 assessment of physical activity intensity in children. *Journal of Science and Medicine in Sport*, *16*(2),

336 124–128.

337 Robusto, K. M., & Trost, S. G. (2012). Comparison of three generations of ActiGraph™ activity

338 monitors in children and adolescents, *Journal of Sports Sciences*, *30*(13), 1429-1435.

339 Rosenberger, M. E., Haskell, W. L., Albinali, F., Mota, S., Nawyn, J., and Intille, S. (2013). Estimating

340 activity and sedentary behavior from an accelerometer on the hip or wrist. *Medicine & Science in Sports*

341 *& Exercise*, *45*(5), 964–75.

342 Routen, A. C., Upton, D., Edwards, M. G., & Peters, D. (2012). Discrepancies in accelerometer-

343 measured physical activity in children due to cut-point non-equivalence and placement site, *Journal of*

344 *Sports Sciences*, *30*(12), 1303-1310.

345 Rowlands, A. V., Fraysse, F., Catt, M., Stiles, V. H., Stanley, R. M., Eston, R. G., & Olds, T. S. (2015).

346 Comparability of measured acceleration from accelerometry-based activity monitors. *Medicine &*

347 *Science in Sports & Exercise*, *47*(1), 201-210.

348 Rowlands, A. V., Rennie, K., Kozarski, R., Stanley, R. M., Eston, R. G., Parfitt, G. C., & Olds, T. S.

349 (2014). Children's physical activity assessed with wrist- and hip-worn accelerometers. *Medicine &*

350 *Science in Sports & Exercise*, *46*(12), 2308-2316.

351 Rowlands, A. V, & Stiles, V. H. (2012). Accelerometer counts and raw acceleration output in relation

352 to mechanical loading. *Journal of Biomechanics*, *45*, 448-454.

353 Saint-Maurice, P. F., Kim, Y., Welk, G. J., & Gaesser, G. A. (2016). Kids are not little adults: what

354 MET threshold captures sedentary behavior in children? *European Journal of Applied Physiology*,

355 *116*(1), 29-38.

356 Schaefer, C. A., Nace, H., & Browning R. (2014). Establishing Wrist-Based Cutpoints for the Actical

357 Accelerometer in Elementary School-Aged Children. *Journal of Physical Activity & Health*, *11*, 604-

358 613.

359 Sherar, L., Griew, P., Esliger, D., Cooper, A., Ekelund, U., Judge, K., & Riddoch C. (2011).

360 International children's accelerometry database (ICAD): Design and methods. *BMC Public Health*, *11*,

361 485.

362 Tudor-Locke, C., Barreira, T. V., & Schuna, Jr. J. M. (2015). Comparison of step outputs for waist and

363 wrist accelerometer attachment sites. *Medicine & Science in Sports & Exercise*, *47*(4), 839–842.

364 van Hees, V. T., Gorzelniak, L., Leon, E. C. D, Eder, M., Pias, M., Taherian, S., … Brage, S. (2013).

365 Separating movement and gravity components in an acceleration signal and implications for the

366 assessment of human daily physical activity. *PLoS One*, *8*(4), e61691.

367 Wake, M., Clifford, S., York, E., Mensah, F., Gold, L., Burgner, D., & Davies, S. (2014). Introducing

368   Growing Up in Australia's Child Health CheckPoint: A physical health and biomarkers module for the

369   Longitudinal Study of Australian Children. *Family Matters*, *95*, 15-23.

370   Welk, G. J., McClain, J., & Ainsworth, B. E. (2013). Protocols for evaluating equivalency of

371   accelerometry-based activity monitors. *Medicine & Science in Sports & Exercise*, *44*(Suppl 1), S39-49.

Table 1 Physical activity outcomes for GAwrist and AGhip for weekday and weekend day segments

	GAwrist				AGhip				GAwrist - AGhip segment difference
	Mean minutes	95% CI	% segment time	95% CI	Mean minutes	95% CI	% segment time	95% CI	%
LPA									
Whole week	306.8	291.3 - 322.3	29.2	27.9 - 30.9	128.8	118.3 - 139.5	12.3	11.3 - 13.4	16.9***
Whole weekday	329.9	316.6 - 343.3	31.5+++	30.3 - 33.0	134.7	124.4 - 145.1	12.9+	11.8 - 13.9	18.6***
Before school	34.8	31.6 - 38.0	23.3	21.1 - 25.6	18.3	16.0 - 20.5	12.3	10.8 - 13.8	11.0***
During school	165.5	160.1 - 173.0	42.6‡‡‡	40.6 - 44.5	61.7	56.4 - 67.4	15.9‡‡‡	14.6 - 17.3	26.7***
After school	129.6	121.7 - 137.5	25.5	23.7 - 27.2	54.7	49.3 - 60.1	10.8	9.8 - 11.9	14.7***
Whole weekend day	283.6	265.9 - 301.3	27.1	25.4 - 28.8	122.9	112.1 - 133.8	11.7	10.7 - 12.8	15.4***
Morning	58.3	48.4 - 68.1	17.7	14.7 - 20.7	24.5	20.5 - 28.6	7.4	6.2 - 8.7	10.3***
Afternoon-evening	225.4	213.0 - 37.8	31.4†††	29.6 - 33.1	98.3	88.5 - 108.2	13.7†††	12.3 - 15.1	17.7***
MVPA									
Whole week	30.0	27.3 - 32.8	2.9	2.6 - 3.2	16.5	14.5 - 18.5	1.6	1.4 - 1.8	1.3***
Whole weekday	31.9	29.7 - 34.2	3.0+	2.8 - 3.3	18.7	17.2 - 20.2	1.8+++	1.7 - 2.0	1.2***
Before school	2.4	2.0 - 2.8	1.6	1.4 - 1.9	1.7	1.4 - 2.0	1.1	0.9 - 1.3	0.5***
During school	16.7	15.3 - 18.0	4.3‡‡‡	3.9 - 4.7	9.8	8.8 - 10.7	2.5‡‡‡	2.2 - 2.7	1.8***
After school	12.7	11.4 - 14.1	2.5	2.2 - 2.8	7.2	6.2 - 8.3	1.4	1.2 - 1.6	1.1***
Whole weekend day	28.1	24.8 - 31.4	2.7	2.3 - 3.0	14.2	11.8 - 16.7	1.4	1.1 - 1.6	1.3***
Morning	5.9	4.1 - 7.6	1.8	1.3 - 2.3	3.3	2.2 - 4.5	1.0	0.7 - 1.4	0.8***
Afternoon-evening	22.2	19.1 - 25.2	3.1†††	2.7 - 3.5	10.9	8.8 - 12.9	1.5††	1.2 - 1.8	1.6***

Significantly different between GAwrist % segment and AGhip % segment at ***$p<0.001$. Significantly different between GAwrist % weekday and % weekend day at +$p<0.05$, +++$p<0.001$. Significantly different between AGhip % weekday and % weekend day at +$p<0.05$, +++$p<0.001$. Significantly different between GAwrist % before school – % during school – % after school at ‡‡‡$p<0.001$. Significantly different between AGhip % before school – % during school – % after school at ‡‡‡$p<0.001$. Significantly different between GAwrist % weekend morning and % afternoon-evening at †††$p<0.001$. Significantly different between AGhip % weekend morning and % afternoon-evening at †† $p<0.01$, †††$p<0.001$.

Figure caption

Figure 1 Bland–Altman plots displaying agreement between GAwrist and AGhip derived whole weekday and whole weekend day LPA and MVPA. Note that the observed positive bias indicates that GAwrist values were higher than AGhip values. Horizontal lines represent mean bias and 95% limits of agreement.